Ministry for the
Environment
Manatū Mō Te Taiao

MODULES

Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand

June 1999

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

INTRODUCTION

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1 Preface

1.1 Sites in New Zealand contaminated with petroleum hydrocarbons

Attention to contaminated sites has increased over recent years, both internationally and in New Zealand. This is due to increased awareness among regulators, industry and the public of past practices which may have resulted in soil and water contamination.

Petroleum hydrocarbon facilities are potential sources of site contamination. These facilities range from refineries through to retail service stations.

Sites contaminated with petroleum hydrocarbons vary widely in complexity, physical and chemical characteristics, and the potential risk they may pose to human health and the environment.

These guidelines have been developed to provide both industry and regulatory authorities with advice on uniform and suitable methods for site investigation, contamination and risk assessment, modelling and site management. Such comprehensive guidance has not been readily available in New Zealand in the past, and this has lead to varied approaches to contaminated and potentially contaminated sites management.

This document aims to address this shortfall and to establish consistency in approach by all parties as to the levels of site investigation and the way in which acceptance criteria are applied.

1.2 Guideline development

With the introduction of the Resource Management Act in 1991, the oil industry was faced with new regulators - the regional councils. With the prospect of widely variable requirements, the industry searched for a way to introduce a national solution.

The oil industry met with the Local Government Commission in 1993 to discuss what the priority issues were and what was the best mechanism for progressing the work. The outcome of this meeting was that five regional councils, Auckland, Waikato, Taranaki, Wellington and Canterbury; the Ministry for the Environment; and representatives from the four oil companies, Mobil, Shell, BP and Caltex, would work together to develop guidelines for:

- above-ground storage tank-farm containment systems
- analytical methods (for measuring levels of contamination)
- water quality
- existing underground tanks at service stations
- contaminated site management.

These latter guidelines, on contaminated sites management, were prepared by Montgomery Watson New Zealand (formerly Royds Consulting Limited) and Egis Consulting Australia (formerly CMPS&F), under the direction of the Oil Industry Environmental Working Group (OIEWG).

1.3 Purpose of the guidelines

The present guidelines have been designed to help both industry and regulatory authorities develop uniform and suitable methods of site investigation, contamination assessment, risk assessment, modelling and site management.

The guidelines focus on sites that have stored, handled, or distributed petroleum products. They aim to provide details of methods for investigating potentially contaminated sites, and for identifying whether or not remediation or controls of the site are necessary in order to protect human health and the environment. The guidelines are also intended to provide background information on petroleum products used in New Zealand, assist in understanding the characteristics of hydrocarbon contamination.

The guidelines are not intended for use at sites where releases of pure solvents (e.g. toluene, xylene) have occurred.

1.4 Approach taken to site assessment and management

The guidelines take a risk-based approach to the assessment and management of petroleum hydrocarbon contaminated sites. This risk-based approach is consistent with other guidelines developed in New Zealand, including the Ministry for the Environment's *Guidelines for Assessing and Managing Contaminated Gasworks Sites in New Zealand*, and the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* jointly published by the Ministry for the Environment

Risk assessment is the process of estimating the potential impact of a chemical or physical agent on an ecosystem or human population under a specific set of conditions. Risk assessment is a flexible tool that can be used at several stages in the assessment and management of contaminated sites. General details of the risk assessment process are discussed in more detail in Module 1.

A risk-based approach is flexible and allows decision-making to be appropriately tailored to site-specific conditions and hazards. This leads to more cost-effective solutions and allows the greatest effort to be targeted to where it will be most beneficial.

The guidelines follow the international trend towards integrating risk assessment practices with site assessment and management. To provide for economical use of both small and large facilities, a three-tiered approach has been adopted, similar to that used in the United States and involving increasingly sophisticated levels of data collection and analysis. Generic soil and groundwater acceptance criteria are developed to help determine whether site management is required (Tier 1 assessment) or whether a more detailed assessment involving the development of site-specific criteria (Tier 2 or 3) is advisable.

Sites contaminated by petroleum hydrocarbons differ widely in terms of their physical and chemical characteristics and the risk they pose to human health and the environment. The tiered approach provides a decision-making process whereby the site assessment and need for remediation are related to the conditions and risks specific to each site. This allows focused and cost-effective solutions. In keeping with the approach adopted in other New Zealand guidelines, this document allows for the fact that the use of sites, and associated risk, will vary.

1.5 Other contaminated sites guidelines

Since the early 1990s a significant effort has been made to develop New Zealand-specific guidelines for the assessment and management of contaminated sites. To date, two other guidelines have been produced:

- *Guidelines for Assessing and Managing Contaminated Gasworks Sites in New Zealand* (available in PDF format from the Ministry web site http:www.mfe.govt.nz/issues/contam.htm)
- *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (available from the Ministry for the Environment).

There are also a number of international guidelines commonly used. These include the ANZECC, USEPA, Canadian and Dutch guidelines.

Where possible, it is important that guidelines developed specifically for New Zealand are used in preference to international guidelines, since the former are based on New Zealand conditions.

1.6 Intended audience

The guidelines have been developed for those people involved in assessing and managing sites contaminated by petroleum hydrocarbons, including site owners, consultants, regional councils, territorial authorities, and industry representatives.

This has been prepared as an introduction to the guidelines.

1.7 Status of the guidelines

These are guidelines only, prepared for the use of those involved in assessing and managing site contaminated by petroleum hydrocarbons in New Zealand. They have no statutory effect.

1.8 Other New Zealand guidelines for sites contaminated by petroleum hydrocarbons

The guidelines do not contain detailed information on sampling protocols and analytical methods. Another guideline has been prepared to cover this information:

> *"Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water*" (available from Ministry web site http://www.mfe.govt.nz/issues/contam.htm)

1.9 Update to the 1999 version

Module 7 has been updated in the 2nd edition of these guidelines (October 2011). There is a new section 7.3.1 regarding underground storage tank and underground petroleum equipment removal and replacement. This section was added to bring these guidelines up to date with the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health (to take effect on 1 January 2012).

2 Structure of the guidelines

The guidelines comprise seven modules which provide a comprehensive guide on the assessment and management of sites contaminated by petroleum hydrocarbons. Where relevant, further supporting technical information for each module is provided in a series of appendices. The guidelines cover the following areas:

Module 1 Risk-based approach to site assessment and management

Module 1 presents an overview of the risk-based approach to assessing contaminated sites, including the use of a tiered approach to site assessment, a general review of risk assessment and the development of soil and groundwater acceptance criteria, and an integrated approach to site investigations, risk assessment and site management and remediation.

Module 2 Hydrocarbon contamination fundamentals

Module 2 provides a background and understanding of the physical and chemical factors important when assessing petroleum hydrocarbon contamination.

Module 3 Site assessment

Module 3 gives guidance on suitable methods of site investigation, including information on the design of a sampling programme, the suitability of various types of investigation equipment, sampling techniques, and quality assurance.

Module 4 Tier 1 soil acceptance criteria

Module 4 outlines the key principles in health and environmental risk assessment and the detailed procedures for developing soil acceptance criteria. The generic soil acceptance criteria derived in this section are summarised in “look-up tables” and form the basis of the Tier 1 assessment process.

Detailed procedures for deriving soil screening criteria are presented in this module, providing the basis for developing site-specific criteria used as part of a Tier 2 assessment.

Module 5 Tier 1 groundwater acceptance criteria

The health and environmental risk assessment principles outlined in Module 4 are applied to groundwater in order to derive generic groundwater acceptance criteria for use in Tier 1 assessments.

Module 6 Development of site-specific acceptance criteria

Procedures for developing Tier 2 and 3 site-specific acceptance criteria are outlined. Due to the highly site-specific nature of a Tier 3 assessment, it is not possible to provide detailed guidance, rather some of the key requirements and an indication of the necessary level of detail are presented.

Module 7 Site management

Module 7 contains an overview of the options readily available in New Zealand for addressing site contamination. These options range from control of the site to prevent exposure to site users or the surrounding environment, to treating the site soil, recovering product from the groundwater, and general water management.

3 Acknowledgements

The OIEWG expresses gratitude to the following people for their review of these guidelines. Their comments have significantly improved the quality and usefulness of this document.

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4 Acronyms and abbreviations

ANZECC	Australian and New Zealand Environment and Conservation Council
API	American Petroleum Institute
ASTM	American Society for Testing Materials
AT	Averaging Time
AVOC	Aromatic Volatile Organic Compounds
BAM	Behaviour Assessment Model
BTEX	Benzene, toluene, ethylbenzene, xylene
BW	Body Weight
CCME	Canadian Council of Ministers for the Environment
CDI	Chronic Daily Intake
CNS	Central Nervous System
DQOs	Data Quality Objectives
ED	Exposure Duration
EF	Exposure Frequency
HI	Hazard Index
HSA	Hollow Stem Auger
HQ	Hazard Quotient
IH	Inhalation Rate
LEC	Lowest Effect Concentration
LF	Leaching Factor
LNAPL	Light Non-Aqueous Phase Liquid
LOAEL	Lowest Observable Adverse Effect Level
MAHs	Monocyclic Aromatic Hydrocarbons
MAV	Maximum Acceptable Value
MDEP	Massachusetts Department of Environmental Protection
MfE	Ministry for the Environment
MoH	Ministry of Health
MRL	Maximum Residue Limit
MSDS	Material Safety Data Sheet
MTBE	Methyl tertiary butyl ether
NHMRC	National Health and Medical Research Council
NOAEC	No Observable Adverse Effect Concentration
NOAEL	No Observable Adverse Effect Level
NOEC	No Observable Effect Concentration
NOEL	No Observable Effect Level
NZDWS	Drinking Water Standards for New Zealand
OSH	Occupational Safety and Health
PAHs	Polycyclic Aromatic Hydrocarbons
PARCC	Precision, Accuracy, Representativeness, Completeness and Capability
PID	Photoionisation Detector
PUF	Plant Uptake Factor
PVC	Poly Vinyl Chloride
QC	Quality Control

RBCA	Risk Based Corrective Action
RfD	Reference Dose
RMA	Resource Management Act 1991
RME	Reasonable Maximum Exposure
RPD	Relative Percent Differences
SF	Slope Factor
TDS	Total Dissolved Solids
TEF	Toxic Equivalence Factor
TPH	Total Petroleum Hydrocarbons
TPHCWG	Total Petroleum Hydrocarbons Criteria Working Group
UK	United Kingdom
US	United States
USEPA	United States Environmental Protection Agency
VF	Volatilisation Factor
VOC	Volatile Organic Compound

5 Glossary

Acute

With reference to toxicity, having a sudden onset and lasting a short time (usually within 4-7 days for fish). Of exposure, severe enough to rapidly induce a response. Can be used to define either the exposure or the response to an exposure (effect). An acute effect could be a mild or sublethal.

Adsorption

Process by which a dissolved component becomes attached to the surface of a solid (such as soil particles).

Advection

Pressure driven (convective) mechanism for vapour transport, resulting from bulk movement of media e.g. soil - gas.

Aerobic

Living only in the presence of free oxygen.

Aesthetic

Relating to appearance, taste and smell, such as to be pleasing to human (and non-human) sensors.

Aliphatic compounds

An organic compounds in which the carbon atoms exist as either straight or branched chains. Examples include pentane, hexane, and octane.

Alkane

Hydrocarbon of paraffin group with saturated bonds.

Alkene

Hydrocarbon of olefin group, with one unsaturated bond.

Alluvial

Pertaining to or composed of alluvium or deposited by a stream or running water.

Alluvium

A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope.

Anaerobic

Living only in the absence of free oxygen.

Analytical

Employing the use of algebra and calculus methods to solve an equation, such that the solution is single-valued and continuous in the range of interest.

Anion

A negatively charged ion that migrates to an anode, as in electrolysis.

Anisotropic

Having some physical property that varies with direction.

Aplastic anaemia

A type of bone marrow disorder due to reduction of haematopoietic marrow cells.

Aquiclude

A saturated, but poorly permeable bed, formation or group of formations that does not yield water freely to a well or spring. However, an aquiclude may transmit appreciable water to or from adjacent aquifers.

Aquifer

Layer of rock or soil able to hold or transmit water.

Aromatic compounds

Contain carbon molecular ring structures and include compounds such as benzene, toluene, ethylbenzene, and xylene (BTEX). These compounds are somewhat soluble, volatile and mobile in the subsurface environment and are useful indicators of contaminant migration.

Bailer

A cylindrical device with a check valve on the bottom and a hook for a cord on the top. It is used to recover liquid from a well.

Bedrock

A general term for the rock, usually solid, that underlies soil or other unconsolidated material.

Bentonite

A colloidal clay, largely made up of the mineral sodium montmorillonite, a hydrated aluminium silicate.

Biodegradation

Process by which organic compounds are degraded by micro-organisms into less harmful substances.

BTEX

Abbreviation for benzene, toluene, ethylbenzene and xylenes. These compounds are somewhat soluble, volatile and mobile in the subsurface environment and are useful indicators of contaminant migration.

Capillary fringe

The zone at the bottom of the vadose zone where groundwater is drawn upward by capillary force.

Carcinogen

Cancer-causing agent.

Cation

An ion having a positive charge and, in electrolytes, characteristically moving toward a negative electrode.

CDI

Chronic Daily Intake - estimate of daily exposure to a contaminant averaged over a chronic period, typically one year or a 70-year lifetime.

Chromatogram

Graph produced during a gas chromatogram analysis and showing the constituents that are present and their relative concentration.

Chronic

Exposure/effects over a long period of time. The USEPA considers a chronic exposure to be associated with an exposure period between seven years and a lifetime.

Conductivity (m/day)

The capacity of a geologic material’s ability to transmit water.

Cone of depression

A depression in the groundwater table or potentiometric surface that has the shape of a inverted cone and develops around a well from which water is being withdrawn. It defines the area of influence of a well.

Confined aquifer

A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

Consolidated bedrock

Sedimentary rocks that have been hardened by natural cementation (i.e. shale, limestone, sandstone).

Corrective action

Site management or remediation designed to “correct” an environmental impact.

Cytotoxicity

Damaging to living cells and tissue.

Destructive

Used to describe a treatment technology that transforms contaminants into non-hazardous components such as water and carbon dioxide.

Diffusion

Migration of contaminants by natural movement of particles, resulting in migration from areas of higher concentration to areas of lower concentration without bulk movement of the media (e.g. soil - gas or groundwater).

Dispersion

The spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown

The distance between the static water level and the surface of the cone of depression.

Ecological

Relating to organisms and their environmental surroundings. Concerned with population of species rather than individual organisms.

Epidemiology

Study of the frequency, distribution and causes of disease, injury and other health-related events in human population.

ERF

Mathematical ERROR function.

ERFC

Mathematical function: Complimentary ERROR function.

Exposure pathway

Route for migration of contaminant from the contamination source to the receptor. Includes release mechanism, transport media, exposure point and exposure route (e.g. ingestion).

Ex situ

Used to describe a treatment technology that transforms contaminants into non-hazardous components such as water and carbon dioxide.

Filter pack

Sand or gravel that is smooth, uniform, clean, well-rounded, and siliceous. It is placed in the annulus of the well between the borehole wall and the well screen to prevent formation material from entering the screen.

First order decay

Biodegradation rate assuming a first-order exponential decay curve (i.e. $C = C_o e^{-kt}$).

Flux

Rate of transport, defined as mass per unit area per unit time.

Genotoxicity

Damaging to DNA and therefore capable of causing mutations or cancer.

Granuloma

Small nodule with white blood cells.

Groundwater table

The surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

Haematological

Pertaining to blood.

Haematopoietic

Blood forming.

Half-life

Measure of time required for a source to biodegrade to half its initial concentration (assuming first-order decay).

Hepatotoxicity

The occurrence of adverse effects on the liver following exposure to chemicals.

Heterogeneous

Non-uniform in structure or composition throughout.

Homogeneous

Uniform in structure or composition throughout.

Hydraulic conductivity (m/day)

The rate of flow of water in cubic metres per day through a cross section of one square metre under a unit hydraulic gradient, at the prevailing temperature.

Hydraulic gradient

The rate of change in total head per unit of distance of flow in a given direction.

Hydraulic head

Energy contained in a water mass, produced by elevation, pressure or velocity.

Immunotoxicity

The occurrence of adverse effects on the immune system following exposure to chemicals.

Infiltration

Water migrating vertically from the surface into the soil column in response to a head difference.

In situ

Used to describe a treatment technology that is implemented in the subsurface cf ex-situ.

Ion

An element or compound that has gained or lost an electron, so that it is no longer neutral electrically, but carries a charge.

Isotropic

Said of a medium whose properties are the same in all directions.

Laminar flow

Flow in which the stream lines remain distinct and in which the flow direction at every point remains unchanged with time. It is characteristic of the movement of groundwater.

Lymphocytopenia

Reduction in the number of white blood cells (specifically lympholytes) in the blood.

Lymphoid

Pertaining to lymphatic system.

Mass balance

Equation based on the laws of conservation of mass:

Accumulation = incoming mass - leaving mass + generated mass - destroyed mass.

Morphological

Pertaining to the forms and structure of organisms, or of a particular organ.

Narcosis

A non-specific and reversible depression of the central nervous system characterised by a lower level of consciousness.

Nephrotoxicity

The occurrence of adverse effects on the kidneys following exposure to chemicals.

Neurotoxicity

The occurrence of adverse effects on the nervous system following exposure to chemicals.

Numerical

Method or process of computing a solution using iterative calculation techniques.

Palatability

Pleasantness to taste.

Partition coefficient

Coefficient which describes the ratio of contaminant concentrations in two different phases. Examples include:

K_{oc} - Organic Carbon Partition Coefficient.

K_{ow} - Octanol Water Partition Coefficent.

Partitioning equilibrium

Set of relationships between solid, water and vapour phases in the soil matrix, which determines the distribution of a chemical between the individual phases.

Perched water

Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

Permeability

The property or capacity of a porous rock, sediment or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure.

pH

A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increased alkalinity and decreasing with increased acidity.

Phototoxicity

Toxicity of a substance in the presence of light.

Point of exposure

Reference location on a site at which exposure to a contaminant is assumed to occur.

Pore water

Water phase in the soil matrix.

Porosity

The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected. Ratio of air, water or other fluid-filled volumes to total volume.

ppm

Parts per million (10,000 ppm = 1%)

Probabilistic risk assessment

Risk levels are based on exposure factors defined by probabilistic distributions, rather than single values, to ultimately produce risk levels in terms of a probability distribution curve.

Pseudo steady-state

Assumption of equilibrium in physico-chemical properties such as phase partitioning (steady state), used in conjunction with a non-equilibrium/steady-state mechanism (e.g. depleting source).

Pumping test

A test that is conducted to determine aquifer or well characteristics.

Radius of influence

The radial distance from the centre of a well bore to the point where there is no lowering of the water table or potentiometric surface (the edge of its cone of depression).

Receptor

An organism, plant or physical structure that receives, may receive or has received environmental exposure to a chemical.

Recharge

The addition of water to the zone of saturation; also, the amount of water added.

Reference dose

An estimate of daily exposure to the human population, including sensitive subgroups, that is likely to be without appreciable risk of adverse effects during a lifetime.

Residual saturation

Percentage of the void space of a soil which contains a fluid that cannot be mobilised by gravity forces.

Risk

The probability of an adverse outcome in a person, a species, a group, or an ecosystem that is exposed to a hazardous agent. Risk depends on both the level of toxicity of hazardous agent, and the level of exposure.

Run-off

Precipitation that flows along ground surfaces. Can migrate to stormwater drains, streams, etc.

Sensitive aquifer

An aquifer that has the potential to be contaminated by a leak or spill of petroleum hydrocarbons and which is subject to use or potential use.

Separate phase hydrocarbons

Liquid phase hydrocarbons in soil or above groundwater, where water is not a constituent. Separate phase is usually formed when water phase reaches maximum solubility limit.

Slope factor (SF)

The slope of the dose-response curve in the low-dose region, used to relate the probability of contracting cancer as a result of exposure to that chemical.

Site classification

Classification assigned to a site which characterises the site in terms of the level of threat to receptors, and the timeframe for response.

Soil-gas

Vapour phase in the soil matrix.

Subchronic

Between chronic and subacute. The USEPA considers a sub-chronic exposure associated with an exposure period between two weeks and seven years.

Surfactants

Chemicals that are used to reduce the resistance to flow of certain fluids.

Surrogate

Substitute compound.

TEF

Toxic Equivalent Factor The TEF for a specific compound may be defined as the ratio of the carcinogenic potency of the compound to that of a reference carcinogenic compound.

Teratogenicity

Pertaining to the ability to induce a congenital abnormality in embryos and foetuses resulting in birth defects.

Total dissolved solids, TDS

A term that expresses the quantity of dissolved material in a sample of water, either the residue on evaporation, dried at 356ºF (180ºC), or, for many waters that contain more than 1,000 mg/l, the sum of the chemical constituents.

Transmissivity (m^2/day)

The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values are given in cubic metres per day through a vertical section of an aquifer one metre wide and extending the full saturated height of an aquifer under a hydraulic gradient of one.

Unconfined aquifer

An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.

Unconsolidated materials

Loose earth materials that result from erosion of bedrock.

Vadose zone

The zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table. Also known as unsaturated zone.

Viscosity

The extent to which a fluid resists a tendency to flow.

Volatilisation

Process by which a substance changes its state from solid or liquid to a vapour.

Water table

The surface between the vadose zone and the groundwater; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

Weathering

The in-situ physical disintegration and chemical decomposition of rock materials at or near the Earth's surface.

Well screen

A filtering device used to keep sediment from entering a water well.

Well yield

The volume of water discharged from a well in cubic metres per day.

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Ministry for the
Environment
Manatū Mō Te Taiao

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

MODULE 1
Risk-based approach to site assessment and management

August 1999

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1 Risk-based approach to site assessment and management

Module One presents an overview of the integrated risk-based approach to the assessment and management of soils and groundwater impacted by petroleum products.

1.1 Risk-based approach to the assessment and management of contamination

1.1.1 General

Use of an integrated risk-based approach leads to site assessment and management actions that are appropriate for each site, and that are consistent with the underlying risk management and policy decisions of the regulatory program. Application of the integrated risk-based approach insures that all actions are focused on achieving the desired level of protection for human health, ecological species and resources.

The integrated risk-based approach combines conventional site assessment and management approaches, with health and ecological risk assessment principles and tools. These traditionally separate activities are integrated into a streamlined approach to decision-making.

Health and ecological risk assessments provide the tools to assess the significance of soil and groundwater contamination, and may be used to:

- derive soil and groundwater concentrations that may be used as generic criteria identifying when an unacceptable impact may possibly occur, and
- assess the possible significance of contamination on a site-specific basis.

The use of a risk-based approach reflects the practical need to appropriately allocate limited resources to the assessment and management of sites. The application of a risk-based approach ensures that:

- resources are first applied to managing immediate and unacceptable threats to human health and the environment
- remaining resources are devoted to making sure conditions at all sites do not worsen
- any remaining resources are applied to the management of those sites posing long-term unacceptable threats to human health and the environment.

A tiered approach to the assessment of soil and groundwater contamination has been adopted to facilitate the cost effective use of health and ecological risk assessment principles. The level at which the possible effects of contamination are assessed depends on the likely significance of the effects. The assessment may range from a simple comparison with generic acceptance criteria, to a detailed, site-specific risk assessment.

The principles underlying a risk-based approach to site assessment and management are as follows:

- Decisions regarding site management should be based mainly on mitigation of unacceptable risks to human health or the environment. Such decisions should take into account the uncertainty in the assessment of risk.

- Site assessment activities should focus on collecting only that information required to determine the likely health and environmental impacts associated with the site, and to make risk-based decisions regarding site management.
- Where the risk to human health or the environment is considered unacceptable, a range of risk mitigation strategies should be considered. The selection of site management options should be based on the ability of the proposed strategy to minimise the risk to human health and the environment, the certainty with which the strategy can be implemented and the cost of implementation.
- The resources available for site management are limited and therefore there is a need to appropriately allocate resources based on the risk to human health or the environment.
- The immediacy of action at a site should reflect the magnitude of likely unacceptable impacts and the timeframe within which they may occur.

In summary, decisions regarding the allocation of resources to the investigation and management of sites should reflect the risk to human health and the environment posed by the site rather than on the basis of arbitrary standards.

1.1.2 Other considerations in integrated risk-based decision-making

Frequently decisions regarding investigation and management actions also require consideration of factors other than the risk to human health or the environment. Examples may include, legal liability, economic considerations, public or market perception (e.g. sale of land) and expediency (e.g. minimising the requirement for ongoing management).

1.2 Tiered approach to site assessment and management

The basis for a tiered approach to site assessment and management is presented. The aim of a tiered approach is to streamline the assessment and management of risk at individual sites. The tiered approach starts with a simple, low cost assessment of risk. It then proceeds to increasingly more complex and detailed approaches to the assessment of risk, as warranted by the risk posed and the cost of site management.

1.2.1 Overview

The tiered approach to the assessment and management of petroleum hydrocarbon contaminated sites is based on the assumption that not all sites pose the same risk to human health and the environment. Therefore, resources should be focussed on assessing and managing those sites where a significant impact is likely.

Use of a tiered approach streamlines the risk-based decision-making process and allows appropriate allocation of resources, by adopting increasingly sophisticated levels of data collection and analysis in accordance with the risk posed by the site.

The overall site assessment process, incorporating a risk-based approach to decision making, is summarised as follows:

Initial Assessment

1. Initial site assessment
2. Site classification and initial response action (i.e. does the site pose an immediate danger to health and the environment, and, if yes, what action is required to mitigate the danger).

Tier 1 Site Classification and Assessment Using Generic Tier 1 Criteria

1. Comparison of site conditions with Tier 1 generic soil and water criteria, and selection of a Tier 1 management strategy
2. Evaluation of Tier 1 results.

Tier 2 Development of Tier 2 Site-specific Acceptance Criteria and Site Management Plan

1. Expanded site assessment, reclassification and development of Tier 2 site-specific acceptance criteria
2. Development of Tier 2 risk-based site management plan
3. Evaluation of Tier 2 results.

Tier 3 Detailed Tier 3 Site–specific Risk Assessment and Site Management Plan

1. Expanded site assessment and development of Tier 3 site-specific acceptance criteria
2. Development of risk-based site management plan.

In the development of the tiered risk-based approach, the Tier 1 soil acceptance criteria have been developed in such a way as to be flexible enough that roughly 70%[1] of all sites can be addressed without proceeding to Tier 2 or Tier 3. Here “flexible” means that the Tier 1 acceptance criteria have already been developed for a wide range of possible site characteristics, as opposed to being developed for a single (most conservative) generic scenario as is often the case. The tiered approach to site assessment is illustrated in Figure 1.1.

1.2.2 Initial site classification

The assessment may begin with:

- a review of site history (including records of product loss)
- a review of the physical setting of the site including an initial assessment of the likely fate and transport of contaminants and identification of receptors
- the collection of information regarding contaminant concentrations in soil and groundwater at the site.

As information becomes available regarding site conditions, an initial classification of the site should be conducted, and then refined as further information becomes available. For example, based on information collected, the site may be classified as follows:

- immediate threat to human health, safety or sensitive environmental receptors
- short term (0-2 years) threat to human health, safety or sensitive environmental receptors

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[1] Based on oil industry objectives to streamline the management of sites in New Zealand.

- long term (>2 years) threat to human health, safety or sensitive environmental receptors
- no demonstrable long-term threat to human health, safety or sensitive environmental receptors.

The purpose of the site classification and initial response selection is to ensure that:

- immediacy of action at a site is consistent with threats posed by the site (i.e. short-term threats are addressed immediately)
- unacceptable impacts posed by a site do not get worse with time as the site is being investigated and risk-management decisions are being made.

Decisions regarding:

- immediate action to mitigate impacts
- further investigations
- long-term management of the site,

should be based on the initial site classification and refined classifications as the tiered site assessment process continues. Table 3 "Site Classification Scenarios and Potential Initial Response Actions" in the ASTM RBCA standard[2] provides a useful tool for classification of sites and selection of initial response.

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[2] ASTM (1995) *Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites (RBCA)* E1739-95

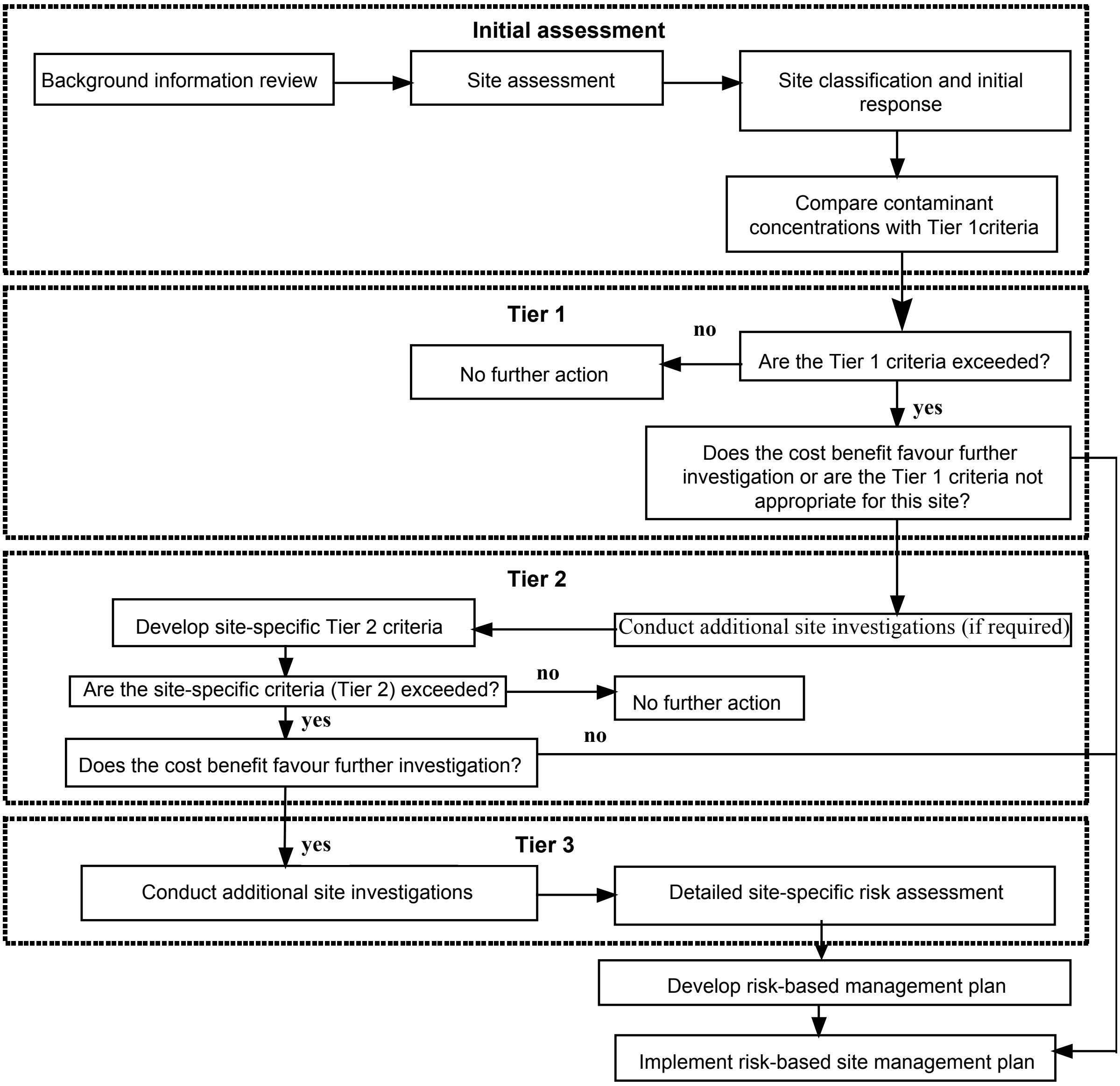

Figure 1.1 **Site assessment and management process**

1.2.3 Tier assessment

1.2.3.1 Assessment based on comparison with Tier 1 generic criteria

To assist in quickly identifying those sites that may pose a significant risk to human health and the environment, acceptance criteria have been developed for a number of generic scenarios, based on conservative assumptions. Where contaminant concentrations at a given site do not exceed the generic acceptance criteria, it may be concluded with a high degree of confidence, that the site does not pose a significant risk to human health or the environment.

The Tier 1 assessment is based on comparison of measured contaminant concentrations in soil and groundwater from the site with generic acceptance criteria developed for a range of land uses and groundwater uses. If the measured contaminant concentrations are less than the acceptance criteria then the site may be suitable for the nominated use.

The acceptance criteria presented in Module 4 are based only on consideration of human health risk. The user must also consider ecological protection, and site amenity (aesthetics). Guidance relating to the assessment of aesthetic impact, associated with soil contamination, is presented in Module 4.

In order to develop widely applicable criteria, many conservative assumptions have been incorporated. Therefore, if the Tier 1 criteria are exceeded this does not necessarily imply the actual risk posed by the site is unacceptable. Instead, it indicates that further investigation and site-specific evaluation of acceptance criteria may be warranted.

In order to increase the flexibility of the Tier 1 assessment process, criteria have been developed for a wide range of geologic settings and land use scenarios. Therefore, it is expected that final site management decisions can be made for the majority of sites using the Tier 1 acceptance criteria, and that few will need to progress to Tier 2 or Tier 3 analyses.

The Tier 1 criteria includes consideration of:

Land use	Agricultural, residential, commercial/industrial (including maintenance workers).
Soil Type	8 soil profiles
Depth of soil contamination	<1 metre, 1-4 metres, >4 metres
Depth of groundwater from ground surface	2-4 metres, 4-8 metres, >8 metres

Guidance on the application of Tier 1 soil and groundwater acceptance criteria is presented in Sections 1.3.3 and 1.3.4.

1.2.3.1 Tier 1 ecological evaluation

The Tier 1 soil acceptance criteria presented in Module 4 are derived primarily with reference to the protection of human health. The development of ecologically-based soil acceptance criteria is subject to considerable debate.

As part of the Tier 1 assessment, the potential for ecological impacts should be considered based on a review of:

- the location of potentially sensitive ecological receptors
- the completeness of relevant exposure pathways.

A checklist to assist in this process is presented in Appendix 4I. Where the potential exists for a significant ecological impact to occur, a site-specific evaluation of ecological impact or ecological risk should be undertaken.

1.2.3.2 Evaluation of Tier 1 results

When chemical concentrations at a site do not exceed the Tier 1 acceptance criteria, no further action is required. When chemical concentrations at a site exceed acceptance criteria, either:

- implement a management strategy to eliminate routes of exposure or to reduce chemical concentrations to the acceptance criteria, or
- progress to Tier 2 assessment to determine acceptance criteria more appropriate for site conditions, and then compare site conditions with these criteria.

Progress to a Tier 2 assessment when:

- the Tier 1 criteria can be shown to be inappropriate
- the Tier 2 criteria are likely to be significantly different from the Tier 1 criteria, or
- the cost of the Tier 2 analysis is less than the cost of management associated with the Tier 1 acceptance criteria.

1.2.4 Tier 2 - Developing site-specific acceptance criteria and site management plans

If the Tier 1 assessment indicates that there is potential for a significant risk to human health and the environment, then a Tier 2 assessment may be initiated. Usually a Tier 2 assessment would be initiated where the likely savings from use of site-specific criteria outweigh the cost of the Tier 2 assessment.

As part of Tier 2 assessment, the basis for the generic acceptance criteria used in the Tier 1 assessment may be reviewed in order to determine their applicability at a given site. For example:

- The limiting consideration with respect to naphthalene may be ecological effects. However, in the context of an urban residential site the decision may be made that full protection of the ecosystem within the boundary of the site is not required.
- The limiting consideration in assessing benzo(a)pyrene contamination is ingestion of contaminated soil and at a particular the site benzo(a)pyrene is not present in the surface soils, therefore higher contaminant concentrations may be acceptable on a site-specific basis.

As part of the Tier 2 assessment, site-specific acceptance criteria may be developed using an approach consistent with that adopted for the Tier 1 criteria (or using a range of other suitable risk assessment models), incorporating information on the exposure assumptions designed to reflect site-specific considerations.

Where consideration of site-specific factors suggest the assumptions used to derive generic, Tier 1 acceptance criteria are appropriate, it is expected that Tier 2 acceptance criteria would be similar to the Tier 1 criteria, although the point at which they are applied may differ.

Following the development of Tier 2 site-specific acceptance criteria and the assessment of contamination, a risk-based site management plan may be developed. As with the Tier 1 process, part of the Tier 2 decision-making process is the need to evaluate the results of the Tier 2 assessment and the cost-benefit relationship associated with implementation of the site management plan in relation to proceeding to the Tier 3 assessment.

1.2.5 Tier 3 - Detailed site-specific risk assessment and site management plans

A Tier 3 assessment may be initiated where:

- a Tier 2 assessment indicates that a significant risk to human health and the environment may exist, and
- the cost of remediation or other risk management strategies warrants further detailed consideration.

A Tier 3 assessment involves detailed, site-specific consideration of the relevant exposure pathways, and may entail additional sampling and analysis of environmental media.

A Tier 3 assessment is likely to be relatively costly and therefore is expected to only be implemented where possible refinements in the management strategy justify the additional expenditure.

1.2.6 Comparison of tiers

As example of the varying levels of effort involved in subsequent tiers of investigation, the level of sophistication in fate and transport modelling associated with each tier is illustrated as follows:

Tier 1	Generic criteria based on one-dimensional fate and transport modelling. No site-specific modelling.
Tier 2	One-dimensional or simple two-dimensional fate and transport modelling. Site-specific validation of input parameters, point of compliance or application of criteria may change.
Tier 3	Detailed two-dimensional or three-dimensional fate and transport modelling with site-specific validation of model predictions where possible.

See also Figures 1.2 and 1.3, which illustrate the relationships between the tiers.

1.2.6.1 Protection

Each of the Tiers is designed to provide a high level of protection to human health and the environment. While additional information may allow higher values for the acceptance criteria to be established in some cases under the Tier 3 assessment, the Tier 3 criteria are likely to be no less protective, i.e. the less stringent Tier 3 criteria reflect a lower degree of uncertainty rather than a lower level of protection.

1.2.6.2 Conservatism and uncertainty

Tier 1 acceptance criteria typically incorporate a high degree of conservatism in order to be more generally applicable to a wide range of site conditions and land-use scenarios. Therefore, there is a high degree of uncertainty associated with this indication of risk. The conservative nature of Tier 1 criteria biases the uncertainty so that we can be confident that actual risks posed by the site are most likely to be less than the risks indicated by a comparison with Tier 1 criteria. With progress to higher Tiers, there is less uncertainty in the relationship between acceptance criteria and adverse risks posed by the site. This is because site-specific characteristics are incorporated into the development of the acceptance criteria.

1.2.6.3 Cost of investigation and assessment

A Tier 1 assessment involves a simple comparison of measured contaminant concentrations with screening criteria presented in a “look-up” table, and therefore is the lowest-cost approach to assessment. The Tier 3 assessment may require considerable amounts of detailed site-specific information incurring significant additional cost. While the cost associated with assessment of contamination increases from Tier 1 to Tier 3, the objective is to spend the appropriate amount of money on the assessment of contamination in order to minimise the overall cost of site management.

It is anticipated that decisions concerning the future of most sites will be based on Tier 1 acceptance criteria, as these have been derived for a wide range of site conditions and land-use scenarios. The additional cost associated with a Tier 3 assessment is only likely to be justifiable at a small number of sites in New Zealand.

The above considerations are illustrated in Figures 1.2 and 1.3.

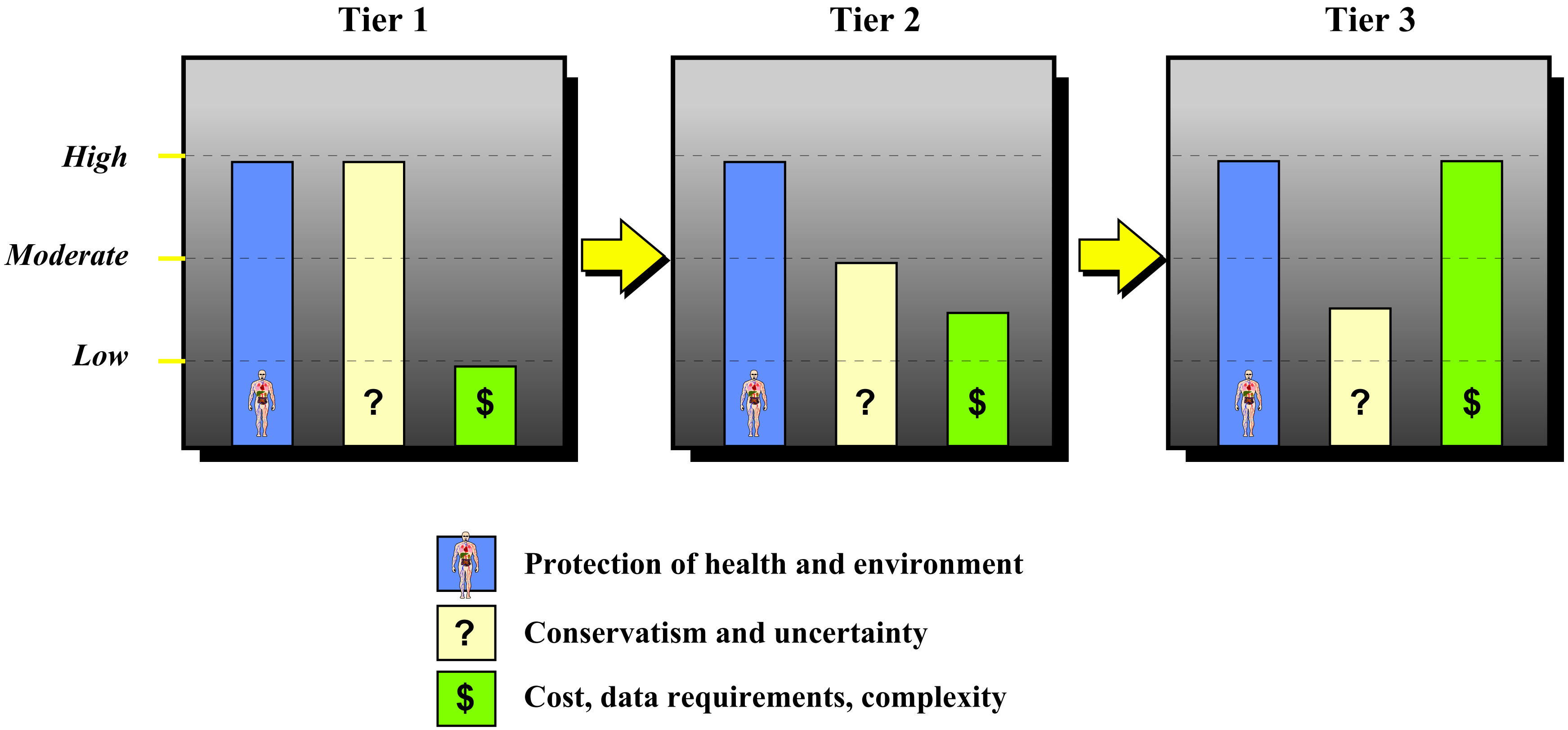

Figure 1.2 Comparison of cost, uncertainty and conservatism for tiered approach

Source: '*Guidance Manual for Risk-Based Corrective Action* Tier 2 RBCA" June, 1995

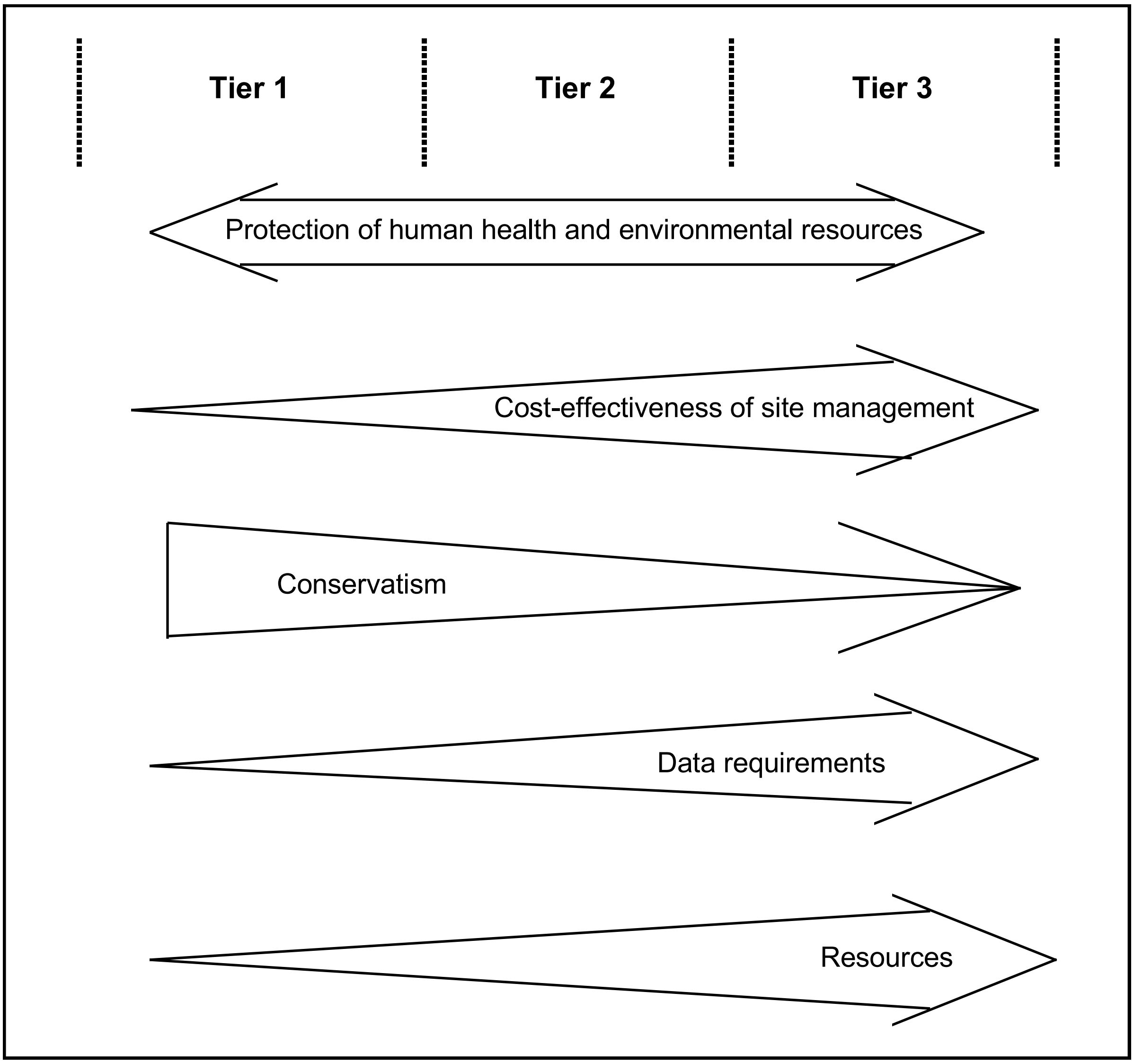

Figure 1.3 **Summary of tiered site analysis**

1.3 Considerations in risk-based site assessment

The use of generic Tier 1 acceptance criteria and the tiered approach to site assessment is illustrated. In particular, the use of soil screening criteria, based on groundwater protection, to determine whether groundwater sampling is required is discussed.

1.3.1 Overview

The development of acceptance criteria depends greatly on the context within the overall site assessment process. The use of the tiered approach to site assessment is outlined in Figure 1.4.

The decision to proceed from one tier to the next is primarily a cost-benefit consideration. In deciding whether to proceed from Tier 1 to Tier 2, or Tier 2 to Tier 3, the following considerations must be balanced:

- the likely cost saving associated with reduced remedial requirements resulting from a site-specific assessment of risk
- the cost associated with conducting the more detailed, site-specific risk assessment.

1.3.2 Risk-based investigation design

The overall aim of the site assessment and management process is to manage and minimise the risk to human health and the environment, through the cost-effective implementation of risk mitigation strategies. Risk assessment allows the most significant risks to be identified and addressed, and the more significant pathways to be identified, facilitating effective targeting of risk mitigation strategies.

Risk assessment provides the tools for assessing the significance of possible health and environmental impacts associated with soil and groundwater contamination which is the fundamental aim of site-assessment. It is essential that the site investigation programmes, including sampling and analytical work, be designed in the context of the information required for risk assessment.

As part of a tiered approached to site assessment and risk-based decision-making, the information collected as part of each tier is confined to that necessary to assess the risk and make decisions regarding site management.

For example, the information required may include:

Tier 1	Contaminant concentrations in soil and groundwater, delineation of extent of contamination.
Tier 2	As above, contaminant concentration in groundwater at the nearest point of use or potential use (may be measured or predicted), soil and aquifer properties, contaminant concentrations in other exposure media (e.g. soil, air), site-specific activity and use patterns.
Tier 3	As above, site specific.

1.3.3 Application of Tier 1 soil acceptance criteria

Module 4 presents soil acceptance criteria based on an assumed exposure scenario for each of the land uses. Each exposure scenario includes consideration of a range of exposure pathways which are assumed to be complete. Where contaminant concentrations exceed the nominated Tier 1 soil acceptance criteria, consideration should be given to the completeness of each of the assumed exposure pathways and the relevance of the exposure assumptions. For example:

- If an exposure pathway assumed as part of the derivation of acceptance criteria for a given land use is found to be incomplete (e.g. ingestion of soil by normal site users cannot occur because the site is paved) then the route-specific acceptance criteria presented in Module 4 should be reviewed to determine the limiting exposure route. Where a limiting exposure route is found to be incomplete, the next lowest route-specific criterion may be adopted.
- Where an exposure route based on cross-media transfer of contaminants is limiting (e.g. produce uptake, volatilisation), additional measurements may be taken to confirm the accuracy of the modelling underlying the criteria (although this would normally only be undertaken as part of a Tier 2 assessment). Where less efficient cross-media transfer occurs, higher criteria may be applicable.

- The point of exposure is in practice often located further from the site than assumed in the development of the Tier 1 acceptance criteria. Natural attenuation processes have been shown to reduce dissolved phase contaminant concentrations (particularly BTEX concentrations) significantly with time and distance from the point of release. Where an on-site source remains, natural attenuation has been shown to limit the maximum extent of the dissolved phase plume and to reduce contaminant concentrations with time once the source has been removed.

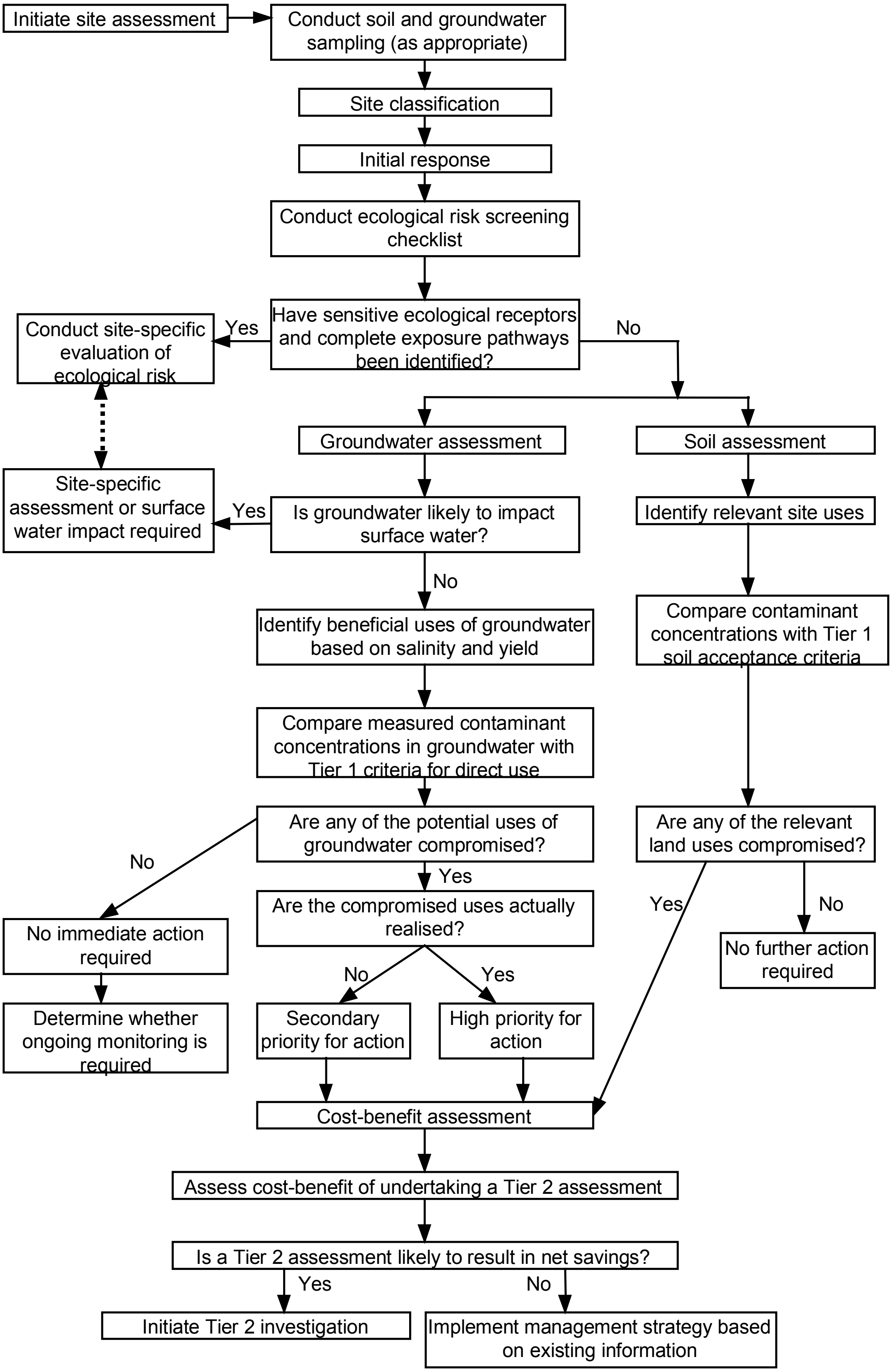

Figure 1.4 **Sample application of Tier 1 acceptance criteria**

- the impact of natural attenuation should be considered in estimating the-long term concentrations likely to be observed at a remote point of exposure.[3] Detailed consideration of natural attenuation including predictive modelling may form part of a Tier 2 assessment.

Where contaminant concentrations at a site exceed the Tier 1 acceptance criteria, the Tier 1 criteria should be critically reviewed, to determine whether the limiting exposure route is valid, before proceeding to a Tier 2 assessment. An exposure pathways diagram is presented in Module Four to assist in the critical evaluation and selection of complete pathways.

1.3.4 Consideration of groundwater contamination

Sampling and analysis of groundwater should be undertaken whenever there is the potential for groundwater contamination. An aquifer where use may potentially be affected by a petroleum release is referred to as a sensitive aquifer.

A sensitive aquifer is defined as an aquifer which is:

- not artesian (in practice true artesian 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 of the release (clean sands and gravels, fractured rock and other formations allowing very rapid migration of contaminants require further consideration), and
- of a quality appropriate for use, is capable of yielding water at a useful rate and from which extraction and use of groundwater may be reasonably foreseen,
  or
- within 100 metres of a sensitive surface water body[4].

In many circumstances sampling and analysis of groundwater is a more reliable indicator of a significant petroleum release than soil sampling and analysis alone. In this context groundwater monitoring can be a useful tool in identifying significant environmental issues, particularly where there is potential for a significant source to be missed by soil sampling.

For further details regarding the definition of a sensitive aquifer and the assessment of groundwater contaminant refer to Module 5.

1.4 Risk-based site management

A risk-based approach to the design and implementation of site management strategies arises out of an understanding of exposure pathway analysis. For a risk to human health to occur, a complete exposure pathway must exist between the source of contamination and the receptor.

---

[3] While consideration may be given to adopting an alternative point of exposure based on the actual patterns of groundwater use, the requirement to protect the groundwater resource for possible future use should be considered.

[4] A distance of 100 m reflects the observation that at most sites natural attenuation processes limit the extent of the dissolved phase plume to less than 100 m. Where due to the migration of free product or other site-specific conditions, contaminated groundwater extends more than 100 m from the source of contamination, contaminant concentrations in the groundwater would be sufficiently reduced such that dilution of groundwater on discharge to surface water would prevent an adverse impact. Sensitive surface waters with limited dilution of groundwater discharge may require separate consideration.

Where an exposure pathway is incomplete then there is no risk. An exposure pathway consists of a:

- source
- transport mechanism
- point of exposure, and
- exposure route.

The development of an accurate conceptual model of the site is an important step in identifying complete exposure pathways.

Where the risk-based assessment of contamination indicates that an unacceptable risk to human health or the environment may exist, depending on the cost-benefit relationships and other considerations, the next step may involve:

- further investigation and site-specific assessment to refine the risk estimates and determine the requirements for further action. The process of increasingly higher tier assessment is discussed earlier.
- implementation of management strategies to mitigate the risk to human health and the environment.

Strategies for risk reduction should focus on rendering relevant exposure pathways incomplete or less efficient. For example:

- implementation of institutional controls that limit site access (relocating or eliminating points of exposure) or activities that may be undertaken at the site (possibly eliminating some exposure routes, or at least the rate of exposure)
- installation of barriers which interrupt relevant exposure pathways (e.g. capping layers)
- removal or destruction of the source of contaminants.

In terms of the effectiveness of risk reduction, each of the above strategies may be equally appropriate, with the selection of a strategy based on the reliability of risk reduction, practicality, cost and other considerations.

Where there is some uncertainty regarding the results of the assessment, ongoing monitoring and management may also be implemented to ensure that an unacceptable risk does not exist e.g. limiting future monitoring to confirm predictions regarding the behaviour of a dissolved phase hydrocarbon plume.

Natural attenuation is an important process limiting the effectiveness of exposure pathways. Frequently, natural attenuation is sufficient to render the transport mechanism ineffective and the exposure pathway incomplete. Natural attenuation of dissolved phase contaminants can limit the migration of, and extent of impact from, certain chemicals. In the case of BTEX compounds, studies have shown that natural attenuation processes generally limit the extent dissolved phase plumes to <100 metres (although examples of plume extending >100 metres under certain conditions have been documented). This may be sufficient to render groundwater migration pathways incomplete, when considering the impact on receptors (e.g. groundwater abstraction bores), further than 100 metres from the source. However, not all compounds are significantly attenuated, e.g. chlorinated solvents, MTBE.

Appendix 1A
Overview of risk assessment

1.1 Background

The use of risk assessment for assessing the significance of soil and groundwater contamination in New Zealand forms the basis for guidance released to date, and a risk-based approach is implied in the Resource Management Act 1991 (RMA). The RMA is framed in terms of "adverse effects" on the environment. However, "adverse effect" is not rigorously defined. Risk assessment is consistent with the focus on effects in the RMA, providing a tool for the assessment of the adverse impacts. The RMA also incorporates requirements for the sustainable management of resources, again focusing on effects. After the RMA, the guidance document of most relevance to the assessment of contaminated land in New Zealand is the ANZECC/NHMRC (1992) *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites* (ANZECC Guidelines).

While the ANZECC Guidelines have found most direct application in Australia, New Zealand has also adopted the ANZECC Guidelines as part of its policy framework. In practice the ANZECC Guidelines play a minor role in New Zealand policy, the primary requirements being found in the RMA. However, the ANZECC Guidelines do set out a risk based approach to the assessment of health and environmental impacts and this has been adopted in New Zealand by the Ministry for the Environment and the Ministry of Health.

The use of risk-based approaches for the assessment of health and environmental effects associated with contaminated land is widespread. In the development of these guidelines, reference has been made to the following guidance:

- USEPA guidance for Superfund, including the *Risk Assessment Guidance for Superfund, Parts A and B"; and the "Technical Background Document for Soil Screening Guidance*
- ASTM *Standard Guidance for Risk-Based Corrective Action Applied at Petroleum Release Sites* E 1739-95;
- Ministry for Housing, Spatial Planning and the Environment (The Netherlands) *Environmental Quality Objectives in the Netherlands* and associated documentation.

The development of similar risk-based guidelines for the New Zealand timber industry by the Ministry for the Environment and Ministry of Health (*Health and Environmental Guidelines for Selected Timber Treatment Chemicals* MfE, MoH, 1993) provides a useful precedent and provides several policy positions of importance in the development of guidelines for the oil industry.

1.2 Definitions

Some definitions of importance in the field of risk assessment and criteria development are presented below:

Risk:	The probability of an adverse outcome in a person, a species, a group, or an ecosystem that is exposed to a hazardous agent. Risk depends on both the level of toxicity of hazardous agent, an the level of exposure.

	Various levels of risk may be defined as a guide to decision making including: • Negligible or *de minimus* risk • Unacceptable risk • Tolerable or acceptable risk Refer to Module 4 for a discussion of risk acceptability in the context of human health and ecosystem protection.
Ecological Risk Assessment	Ecological risk assessment is the process of estimating the potential impact of a chemical or physical agent on a specified ecosystem under a specific set of conditions.
Health Risk Assessment:	Health risk assessment is the process of estimating the potential impact of a chemical or physical agent on a human population under a specific set of conditions.
Risk Management:	The process of evaluating alternative actions and selecting options in response to risk assessments. The decision making may incorporate scientific, social, economic and political information. The process requires value judgements, e.g. on the tolerability of risk and the reasonableness of costs.
Hazard:	The capacity to produce a particular type of adverse health or environmental effect, e.g. one hazard associated with benzene is leukemia.
Toxicity:	The quality or degree of being poisonous or harmful to plant, animal, human or other life.
Exposure:	Contact with a chemical, physical or biological agent.
Exposure Assessment:	The estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to a chemical substance or contaminant.
Ecosystem:	An area of nature including living organisms and non-living substances interacting to produce an exchange of material between the living and non-living parts. The term ecosystem implies interdependence between the organisms comprising the system.
Receptor	An organism, plant, human or physical structure which may be exposed to a chemical or other hazardous agent.

1.3 General risk assessment process

The risk assessment process may considered as a four step process, as follows:

- **Data Collection, Evaluation and Hazard Identification**

  The results of sampling and analysis of soil, groundwater and other environmental media must be collated and analysed to determine nature and extent of contamination at the site.

A preliminary assessment of the chemicals of concern at the site must be undertaken based on the chemicals which have been stored or handled at the site, the concentrations measured in soil and groundwater, and preliminary consideration of the hazard associated with each chemical.

- **Exposure Assessment**

  Exposure assessment involves:

  - identification of receptor groups both on-site and off-site (i.e. those exposed)
  - identification of complete exposure pathways
  - estimation of concentrations in media to which humans or environmental species may be exposed (e.g. indoor air)
  - estimation of the exposure likely to be experienced by receptors, whether human or ecological.

- **Toxicity Assessment**

  Toxicity assessment involves an assessment of the possible adverse effects that may be associated with exposure to a given chemical or mixture of chemicals, and the level of exposure associated with the onset of appreciable adverse effects. The level of exposure at which appreciable adverse effects may occur is characterised using dose-response factors.

  In considering possible adverse effects on human health, information is drawn from epidemiological studies (i.e. studies of human populations occupationally or environmentally exposed), animal bioassays (conducted in the laboratory) and a range of cellular tests, e.g. genotoxicity assays.

- **Risk Characterisation**

  The results of the exposure assessment and toxicity assessment are combined to provide an estimate of risk to human health, or the environment.

The risk assessment process is illustrated in Figure 1A1.

The above process was originally developed in the context of health risk assessment, but it also serves as a useful framework for the assessment of risk to the environment.

The objective of any site assessment program is to manage or minimise risk rather than simply to assess the risk to human health and the environment. Risk assessment should not be seen as an end in itself but rather as a tool for risk management. This view affects the way in which risk assessment is approached and is consistent with the tiered approach to risk, which minimises the effort expended in risk assessment where the risk is low and maintains the focus on risk assessment.

1.3.1 Health risk assessment

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

Historically risk assessment has focussed primarily on assessing the risk to human health, although now the focus is broadening.

An important tenet of health risk assessment is that the underlying objective is to effectively protect “almost all” individuals in the exposed population. This objective is evidenced in the commonly adopted levels of acceptable cancer risk used for regulatory purposes; usually in the range one in 1,000,000 to one in 10,000 per lifetime, i.e. one additional case of cancer per 10,000 - 1,000,000 people per lifetime.

Health risk assessment seeks to determine the intake of a chemical by an individual, and whether it is less than or above a nominal dose that is considered acceptable. With respect to soil contamination exposure may be estimated via a range of routes, including ingestion of soil, inhalation of volatiles or particulates, dermal absorption and food-chain exposure.

In assessing possible adverse effects on human health consideration is given to a range of carcinogenic and non-carcinogenic effects although often the carcinogenic effects are limiting.

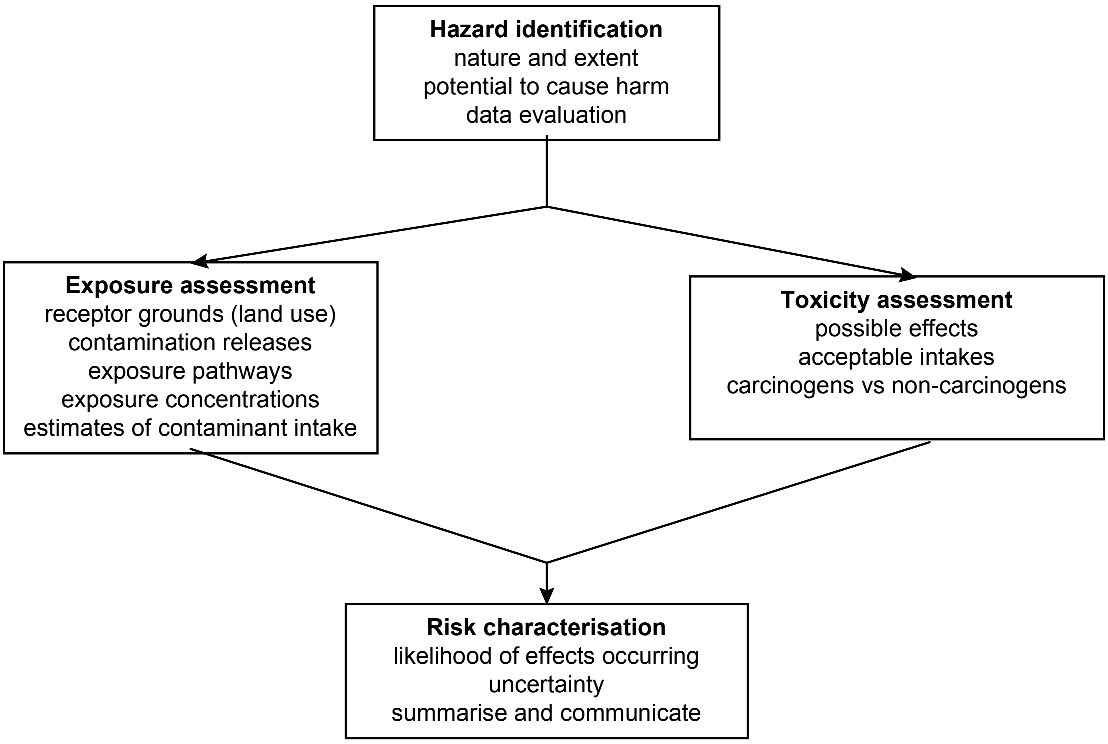

Figure 1A1 Health and environmental risk assessment model

1.3.2 Ecological risk assessment

Ecological risk assessment is the process of estimating the potential impact of a chemical or physical agent on a specified ecosystem under a specific set of conditions.

While the development of ecological risk assessment methods have been slower than the methods for health risk assessment, the use of ecological risk assessment is gaining importance, particularly in New Zealand in the context of the RMA.

Ecological risk assessment necessarily focuses on the protection of populations of species and ecosystems rather on than individual organisms. In contrast, health risk assessment has an objective of providing effectively full protection to nearly all individuals. Rather than nominating doses or intakes that are deemed to be without any appreciable risk of adverse effects, No Observable Effect Levels and Concentrations (NOEL and NOEC) for a range of representative species are used directly, usually without the imposition of the same number of safety factors used in health risk assessment. Ecological risk assessment may focus the protection of representative species, or where more detailed consideration is warranted, the interactions through the ecosystem and food-chain effects, may be considered.

Ecological risk assessment can be undertaken on a range of levels, including:

- species level
- population level (i.e. to protect populations of individual species)
- community level (i.e. focus on protection of communities of multiple species)
- ecosystem level.

The range of levels at which ecological risk assessment may be undertaken increases the complexity of such assessments compared to that of health risk assessment.

While health risk assessment usually focuses on the risk to users users of the site, users of adjacent sites and possibly remote groundwater users the ecological risk assessment necessarily considers the impact on the broader ecosystem and surrounding land use and sensitivity may be more important that that on-site.

The size and significance of an ecosystem are important considerations in the ecological risk management process, demanding value judgements regarding the level of protection to be afforded a given ecosystem.

1.4 Risk management

The process of risk management involves deciding whether the predicted health or environmental risk is acceptable, or whether some form of risk mitigation is required. In doing so, it is important for the risk manager to consider social and economic issues that may influence the acceptability of risk.

Risk management necessarily involves value judgement and balancing competing demands, e.g. risk reduction, cost and public opinion.

The establishment of acceptable risk levels to assist in the risk based decision making necessarily involves an element of value judgement. A number of precedents are available to assist in such decisions and these are discussed in Module 4.

It can be useful to compare the typically adopted level of acceptable risk in an environmental context, i.e. one in 10,000 to one in 1,000,000 per lifetime, with that tolerated in different circumstances (refer Table 1A1). However, care must be exercised in such comparisons as risk perception influences the acceptability of environmental risk. For example, the public may be more concerned about imposed risks than risks that they voluntarily accept or those over which they have some control. Risks derived from human-produced sources such as those associated with synthetic chemicals are generally regarded differently by the public to those from natural sources or events. The public are generally more concerned with consequences than likelihood of the event or effect occurring.

Table 1A1 Summary of estimated fatality risk

Activity/Hazard	Lifetime Risk	Annual risk (per million)
Death from cancer (all causes)	~ 0.2	
Leukemia	0.004	50
Voluntary activity		
Smoking (20 cigarettes/day)	0.35	5000
Drinking (1 bottle wine/day)	0.005	75
Taking contraceptive pill	0.001	20
Involuntary Activity		
Run over by road vehicle- NSW	0.005	80
- USA	0.004	50
- UK	0.004	50
Flood (USA)	0.0002	2.2
Bushfire (Australia)	0.00007	1.0
Lightning (UK)	0.000007	0.1
Typical acceptable cancer risk for contaminated land	0.0001 to 0.000001	

The relatively low levels of acceptable risk in the management of contaminated land reflects the objective of protecting all individuals, and the uncertainty in chemical risk assessment (which is also addressed by the incorporation of safety factor when deriving risk estimates).

Ministry for the
Environment
Manatū Mō Te Taiao

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

MODULE 2
Hydrocarbon contamination fundamentals

August 1999

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2 Hydrocarbon contamination fundamentals

The purpose of this module is to provide background and understanding of the fundamental factors important to the assessment of hydrocarbon contamination.

Information is given on:

- **Petroleum handling facilities (Section 2.1)** - describing the types of sites for which these guidelines are designed to be used.
- **Petroleum hydrocarbon characteristics (Section 2.2)** - outlining the physical and chemical nature of petroleum products.
- **The subsurface environment (Section 2.3)** - giving information on the physical and chemical nature of the receiving environment (soils, rock, and groundwater).
- **Forms of hydrocarbon contamination (Section 2.4)** - describing the characteristics of each form of contaminant and the interaction between them.
- **Subsurface hydrocarbon migration (Section 2.5)** - outlining the behaviour of the hydrocarbons in the subsurface environment as exhibited in such processes as dispersion, dilution, degradation, sorption, etc.
- **Exposure effects and toxicity (Section 2.6)** - covering health and other potential effects.
- **References and further reading (Section 2.7).**

2.1 Petroleum handling facilities

The types of petroleum handling facilities, and the sources of contamination are outlined below.

2.1.1 Types of sites

These guidelines are designed help when assessing the sites which typically might give rise to hydrocarbon contamination in New Zealand. Such sites include:

- existing and former service stations
- truck stops
- airport bulk supply depots
- refueling facilities depots which service industry, farms, aerodromes, councils etc.
- oil and bulk storage terminals.

2.1.2 Sources of contamination

The types of facilities which might give rise to contamination on a site are as follows:

- underground storage tanks
- above ground storage tanks
- pumps or dispensers
- fuel lines between tanks and pumps
- fill points and lines (normally remote from the tanks)
- air vent pipelines
- waste oil tanks
- drum storage and filling areas
- stormwater interceptors.

Contamination may arise at any of the above facilities depending on their age, type of construction and method of operation, for example, through:

- corrosion or stress of metal parts
- improper installation
- overfilling of tanks
- poor maintenance of drainage systems
- surface spillage.

Depending on the facility, the contamination may result from a slow leak over time or a fast release (spill). The spill or leak may occur at or near the surface, or at depth.

2.2 Petroleum hydrocarbon characteristics

This section discusses in detail the physical and chemical properties and characteristics of petroleum products and common petroleum hydrocarbon compounds. A knowledge of these general properties is useful when performing a site assessment, as it will lead on to an understanding of petroleum hydrocarbon compound behaviour in the environment.

Petroleum is a liquid mixture of thousands of different substances, most of them hydrocarbons, formed from the decomposition of marine plants and animals and transformation resulting from heat and pressure changes beneath the earth's surface. The chemical composition and physical properties of crude and refined petroleum vary significantly depending on the location of origin and, for the refined products, on the nature of the refining processes.

The composition and properties of individual hydrocarbon compounds and of blends, directly affect changes in phase state (solubilisation, volatilisation, photochemical and microbial oxidation), migration behaviour (dispersion, dilution, sorption, etc.), and impact on receptors (surface coating, biological toxicities) following a release. It is therefore necessary to understand the behaviour of both the individual hydrocarbon compounds and the blends.

Hydrocarbons are often described by the number of carbon atoms in their molecules, e.g. methane is C_1 because it has one carbon atom. The chemical structure of some of the more common or significant constituents of petroleum are depicted in Figure 2.1. As indicated in Figure 2.1, petroleum hydrocarbons are categorised as aliphatic or aromatic depending on the arrangement of the hydrocarbon molecules. Aliphatic hydrocarbons are arranged in a straight chain and aromatic hydrocarbons are arranged in a six-sided ring. Aromatic hydrocarbons are further categorised depending on the number of rings. Monocyclic aromatic hydrocarbons (MAHs) consist of one ring. The significant MAH constituents of petroleum include benzene, toluene, ethylbenzene and xylenes (BTEX). Dicyclic hydrocarbons are comprised of two rings and polycyclic aromatic hydrocarbons (PAHs) are comprised of more than two rings.

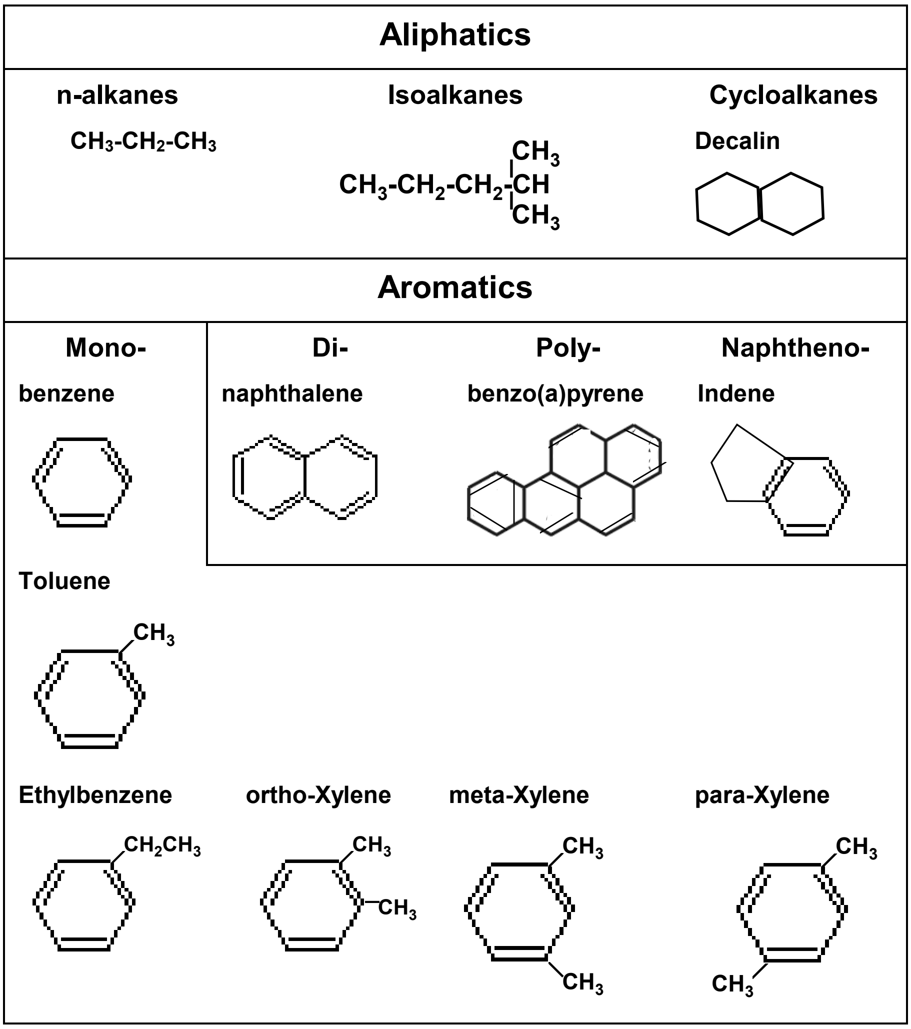


Figure 2.1 Chemical structures of selected hydrocarbons

The range of molecules in various petroleum products is summarised in Table 2.1. The petroleum products wit a range of molecules that include C_6 and greater (i.e. petrol, kerosene, etc.) are comprised of both aliphatic and aromatic hydrocarbons.

Table 2.1 Characteristics of some common petroleum products

Product	Average specific gravity	Primary range of molecules	Entire range of molecules
Natural gas	(vapour)	C_1 to C_2	C_1 to C_4
Propane	(vapour)	C_3	C_3 to C_4
Petrol	0.75	C_5 to C_{12}	C_4 to C_{14}
Kerosene	0.79	C_{10} to C_{16}	C_6 to C_{18}
Jet fuels	0.80	C_{12} to C_{16}	C_6 to C_{20}
Diesel fuel	0.85	C_{10} to C_{20}	C_6 to C_{25}
Lubricating oil	0.90	C_{20} to C_{30}	C_{12} to C_{30+}
Heavy fuel oil	0.96	C_{20} to C_{30}	C_{15} to C_{30+}

Section 2.2.1 provides a description of how crude is converted to refined products such as petrol, kerosene, diesel oils, etc., and presents the physical and chemical properties of the refined products. The physical and chemical properties of individual hydrocarbon compounds are discussed in Section 2.2.2.

2.2.1 General properties of petroleum products

Crude oil is converted by physical and chemical processes into a wide range of refined products including petrol, kerosene, heating oils, diesel oils, lubricating oils, waxes and asphalts. The various physical and chemical processes used in refining fall into two broad categories: separation processes which separate the complex mixture into various fractions, and conversion processes which alter the molecular structure of the hydrocarbon components themselves. In refined products, the major hydrocarbons are alkanes, naphthenes, aromatic compounds and alkenes.

Distillation is the fundamental process involved in refining petroleum. Practically all crude oil that enters a refinery undergoes distillation where it is heated to temperatures as high as 425°C and is separated into fractions. Each fraction contains a mixture of hydrocarbons that boil within a particular range. Processing generates both petroleum products made up of blends of hundreds of compounds, and pure compounds (petrochemicals), such as butane and benzene. The following are the common names associated with several of these fractions along with their predominant uses:

1. Gases boiling below 20°C are taken off at the top of the distillation column. This fraction consists of low molecular weight hydrocarbons, mainly propane, butane, and 2-methylpropane. These three hydrocarbons can be liquefied under pressure at room temperatures. The liquefied mixture is known as liquefied petroleum gas (LPG).
2. Naphthas are mixtures of C_4 to C_{10} alkanes and cycloalkanes which have boiling points between 20°C and 220°C. The naphthas also contain some aromatic hydrocarbons such as benzene, toluene, ethylbenzene and xylenes. The light fraction, with boiling points of 20°C to 150°C, is the source of straight-run petrol and on average makes up about 25% of crude petroleum.
3. Kerosene is a mixture of C_9 to C_{15} hydrocarbons with boiling points of 140 - 300°C.
4. Gas oil has a boiling point range of 190 - 400°C and is a mixture of C_{15} to C_{25} hydrocarbons. Diesel is obtained from this fraction.
5. Lubricating oil and heavy fuel oil distill at temperatures over 320°C and are primarily a mixture of C_9 to C_{30} hydrocarbons.

6. Bitumen (asphalt in the US) is the black tarry residue that remains after the removal of the other fractions.

Petrols, middle distillates, heavy fuel and lube oils, and bitumen are discussed in more detail below.

2.2.1.1 Petrols

Petrols and finishing oils are blends of petroleum hydrocarbons and additives that improve fuel performance, engine life and product identification. The automotive petrols (unleaded and leaded super, unleaded regular) and aviation petrols are part of this group. These fuels can contain more than 250 different compounds. The composition varies due to the crude oil source, refining processes, reformulation, seasonal variations, mixing during transport, and the types of additives used. The main hydrocarbon components in petrols are C_4 to C_{10} aliphatics (e.g. pentane, hexane, and octane), short-branched chain alkanes, cycloalkanes, and aromatics (e.g. BTEX). In general, petrol is a mixture of chemicals with boiling points lower than 215°C. Table 2.2 lists some of the main constituents on a percent by volume basis for New Zealand petrols. The BTEX constituents present in a New Zealand petrol are shown in Table 2.3.

Table 2.2 Main constituents of New Zealand petrols

Constituent	96 Octane (% w/v)	91 Octane (% w/v)
Mono aromatics	42.5	39.1
Polyaromatics	0.2	0.15
Alkanes	43.8	48.7
Olefins	3.4	3.8
Cyclic aliphatics	10.2	11.3

% w/v = percent weight by volume

Table 2.3 BTEX constituents in a New Zealand petrol

Constituent	96 Octane (% w/v)	91 Octane (% w/v)
Benzene	3.3	2.3
Toluene	12.2	9.9
Ethylbenzene	2.1	1.4
Xylenes	12.2	10.2

% w/v = percent weight by volume

Several additives have been used to improve the performance of petrols. Until recently, lead alkyl compounds were added to petrol to produce anti-knock properties as measured by the octane rating of the petrol. However, lead left deposits in engines, so lead scavengers were then added to petrols to flush out the lead. Lead occurs naturally in the subsurface and it should be used cautiously as an indicator.

The organic lead added to petrol in New Zealand contains tetramethyl lead. Petrol imported in an already refined ready-to-use state may contain both tetramethyl lead (TML) and tetraethyl lead (TEL). Both TML and TEL are fat-soluble compounds, which cause intoxication not only by inhalation but also by absorption through the skin. These alkyl compounds are highly toxic. When exposed to sunlight or allowed to evaporate they decompose to trimethyl or triethyl lead salts, which are also poisonous compounds, and ultimately, within a few hours, to inorganic lead oxides.

2.2.1.2 Middle distillates

The middle range distillate group includes diesel, kerosene, jet fuel and lighter fuel oils. These products may contain more than 500 different compounds; however, these compounds tend to be more dense, less volatile, less water soluble, and less mobile than the compounds in the petrol boiling range. The middle distillates also contain less of the lighter-end aromatics such as BTEX. Benzene is present at concentrations in the order of 0.5% by weight.

Kerosene is a mixture of C_9 to C_{15} hydrocarbons. Diesel is obtained from the gas oil fraction and is a mixture of primarily C_9 to C_{25} hydrocarbons. Diesel is composed mainly of straight chain alkanes with a flash point between 43 - 88 ^{o}C. Diesel fuel contaminated soils are not expected to contain high concentrations of aromatics such as BTEX. Typically, with older releases, BTEX constituents will have degraded or dispersed to leave very low, or possibly undetectable concentrations.

2.2.1.3 Heavy fuel and lube oils

The heavier fuel oils and lubricants are similar to the middle distillates in their types of hydrocarbon structure. They distill at temperatures over 320^{o}C, are relatively viscous, relatively insoluble in groundwater, and have low mobility in the subsurface.

2.2.1.4 Bitumen

Bitumen is the black tarry residue that remains after the removal of the other fractions from the distillation process. It contains long chain and polycyclic hydrocarbon structures of predominantly C_{25} or higher and with molecular weights generally around 500 - 600. Bitumen is quite stable and immobile and has been used overseas to encapsulate hazardous wastes. Bitumen does contain polynuclear aromatic hydrocarbons (PAHs), but these are generally bound up by the polycyclic and long chain aliphatics and hence are generally not available (i.e. readily released to the environment).

2.2.1.6 Chromatograms

A chromatogram is the end product of an analytical process in which the components of a mixture are separated from one another and are then sequentially detected over a period of time. In the case of TPH analysis, the order in which the components are detected is directly reflected in the order of their boiling points. The chromatogram ideally displays the presence of each component as an isolated peak, starting with the lowest boiling component on the left immediately after the large solvent peak (solvent is used in the extraction process prior to analyses). In reality, most semi-refined petroleum products contain such a large number of hydrocarbon components that full separation is not practicable. Thus, the chromatogram essentially features a series of peaks and/or mounds with progression along a horizontal axis. These peaks may be fully separated (resolved), or partially overlapping (merged), or when a very large number of components is present a mound is the dominant feature (unresolved). Although the horizontal axis will be displayed in units of decreasing time with progression to the right, it is better considered as indicating increasing boiling point.

For reference, four typical chromatograms are included in Figure 2.2. These plots are of fresh petrol, kerosene, diesel and lubricating oil products. Product aging will change chromatograms to a point where they are unrecognisable as the original product plot (Figure 2.3). The lighter end hydrocarbon molecules in the C_6 to C_9 range will have dispersed or degraded, transforming the appearance of the plot. Hence great care must be taken when trying to identify a product from its chromatogram, particularly when the product is aged or product mixtures may be present. The aging rate varies greatly with site-specific conditions.

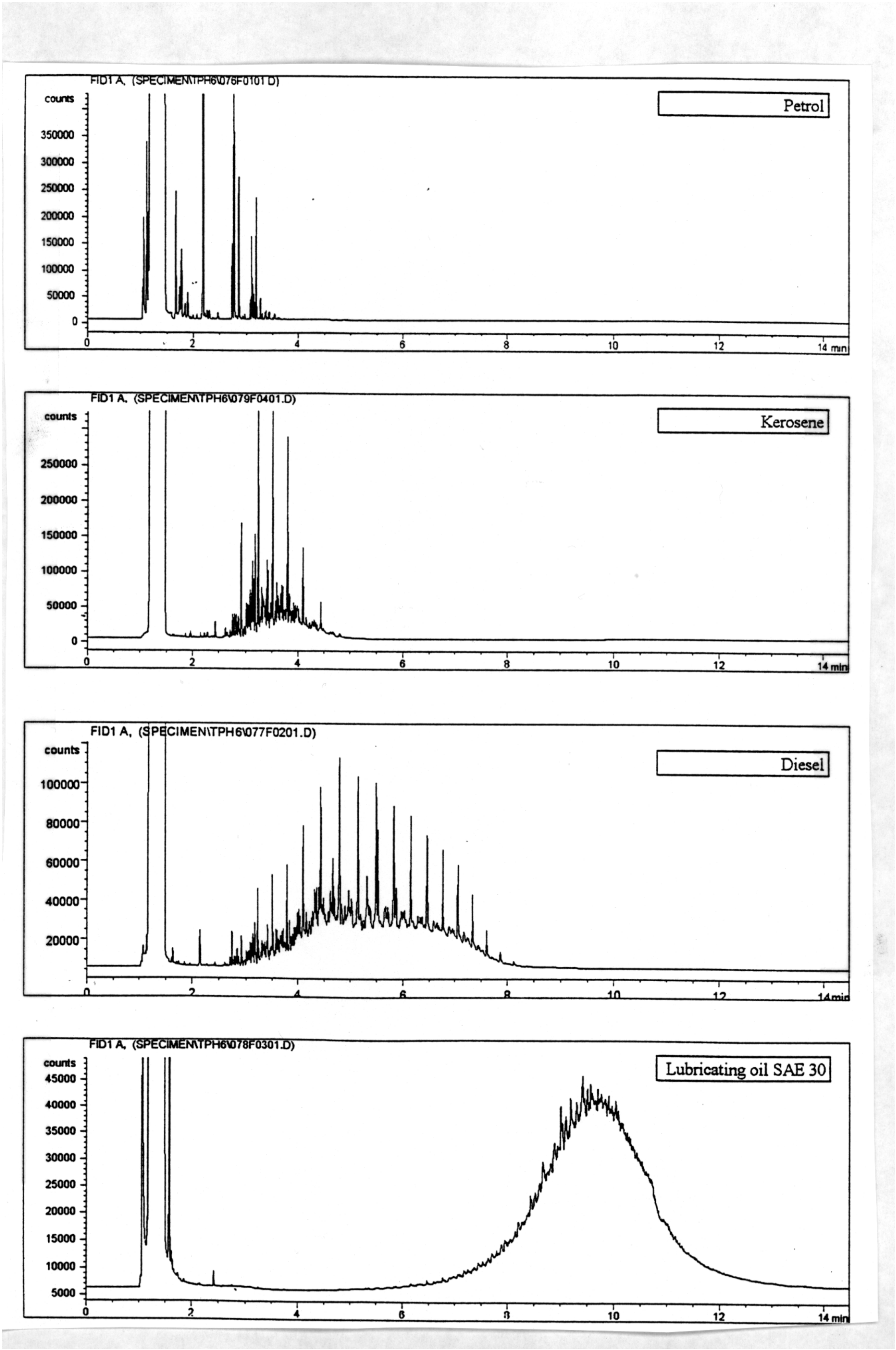


Figure 2.2 Specimen chromatograms
(courtesy of Allan Aspell and Associates)

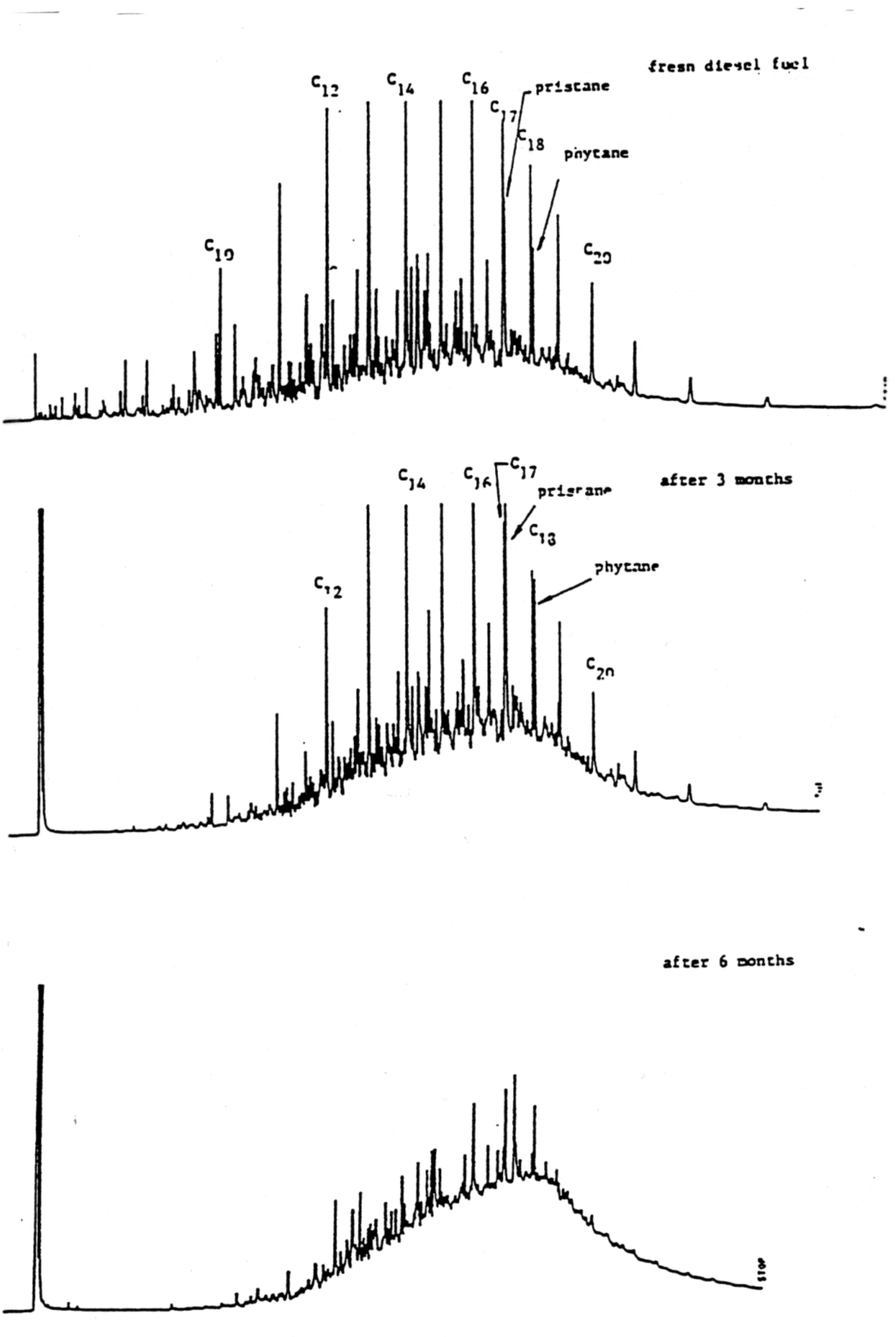


Figure 2.3 Specimen gas chromatograms of fresh and weathered diesel showing changes in n-alkane to isoprenoid ratio and emergence of the "hump".

(courtesy of Allan Aspell and Associates)

2.2.2 Physical and chemical properties of hydrocarbons

The molecular weight, density, solubility, boiling point, and vapour pressure for several of the individual hydrocarbon compounds in petrol, diesel and fuel oils are presented in Table 2.4.

Table 2.4 Physical and chemical properties of selected hydrocarbons

Constituent	Molecular weight	Density relative to water (specific gravity)	Solubility[a] in water, ppm (at °C)	Boiling point, °C	Vapour pressure, mm of Hg at 1atm and (at °C)
Pentane	72.15	0.626	360 (16)	36	430 (20)
Hexane	86.17	0.66	13 (20)	68.7	120 (20)
Decane	142.28	0.73	0.009 (20)	173	2.7 (20)
Cyclopropane	42.08	0.72	37,000	-33	760 (-33)
Cyclopentane	70.14	0.751	<1,000	-	200 (13.8)
Cyclohexane	84.16	0.779	55 (20)	81	77 (20)
Benzene	78.11	0.878	1,780 (20)	80.1	76 (20)
Toluene	92.10	0.867	515 (20)	110.8	22 (20)
ortho-Xylene	106.17	0.86	175 (20)	144.4	5 (20)
meta-Xylene	106.17	0.86	175 (20)	139	6 (20)
para-Xylene	106.17	0.86	175 (25)	138.4	6.5 (20)

Source: Nyer, 1993

a solubility in mixture is lower than pure solubility in water

ppm parts per million

Characteristic property trends within and between the main hydrocarbon compound groups associated with petroleum are listed below:

- Alkanes and aromatics are non-polar compounds and have only limited solubility in water.
- The number of carbon atoms in a compound can greatly affect its properties. Alkane chains up to 17 carbons long are liquids and have densities less than that of water at around 20°C (ambient temperatures), whereas alkane chains 18 or more carbons long are solids at room temperature.
- Alkane solubility and vapour pressures decrease and boiling points increase with an increase in the number of carbon atoms present in the compound.
- The higher the vapour pressure, the more easily the compound is volatilised.
- The cycloalkanes are similar to straight or branched chain alkanes in properties. Densities are less than that of water, solubilities and vapour pressures decrease with an increase in the carbon number and the boiling point temperatures increase.
- The simplest PAH, naphthalene, has a water solubility of 30 mg/L. Solubility decreases with increasing molecular weight of the PAH.

In general, the viscosity of a petroleum product increases as the density increases and the mobility in the subsurface decreases.

Solubility values for particular hydrocarbon compounds are given in Table 2.4. However this data can be misleading because the water solubility of a specific compound as part of a blend tends to be significantly less than the solubility of the pure compound in water. For example, benzene solubilised from petrol can be found at 5% of the pure component solubility toluene at 15% and xylenes at 10%.

2.3 The subsurface environment

This section provides an understanding of the properties and interactions between the various subterranean materials and structures which is required to assess contamination distribution and management options.

The subsurface is a dynamic environment containing various material states (solid, liquid, gaseous) and living organisms (animals, plants, micro-organisms). Structures of human origin such as tunnels, service trenches, building basements and foundations may also be present at a site.

2.3.1 Geological material characteristics

There is a great variation in soil and rock types, which can significantly affect the movement of contaminants in the ground. The various classification systems and definitions are given below.

2.3.1.1 Material types

There are a number of classification systems describing geological material types in use, including geological, engineering and soil conservation. Terms such as soil and rock have specific and sometimes different meanings in each of these systems. In this document, the engineering (geomechanical) classification system, the most widely used, is adopted (NZGS, 1988).

The geological materials that potentially can be exposed to contamination by subsurface petroleum hydrocarbon releases generally fall into two broad categories, soil and rock materials. These are defined here (following geomechanical and engineering terminology) as:

Soil

Sediments or other unconsolidated accumulations of soil particles that can usually be separated by gentle mechanical means.

Rock

A firm or consolidated naturally occurring aggregate of soil particles and/or minerals connected by strong bonds. The term implies a formation which is in situ.

Under this definition soils include:

Unconsolidated sediments

Loose materials resulting from the weathering and erosion of rock. The material may have traveled great distances to reach its current location through wind, water, ice, and gravitational forces. The individual sediment particles may vary in size from the very large (boulders, metres in diameter) to the very small (microscopic). Some volcanic deposits, such as pyroclastic materials (ash, lapilli) fall within this grouping.

Fill

Fill is any material used to backfill an excavation or low lying area, or raise the level of an area above its natural level. Fill material is deposited by human rather than natural forces. Fill can consist of boulders, gravels, sands, silts, clays, or demolition materials such as bricks, concrete and timber.

Subsoil

The subsoil is the boundary zone between soil and bedrock, and may exhibit properties of both.

The particle size ranges of the various soil types in New Zealand (geomechanical protocol) are given in Table 2.5.

Table 2.5 Soil particle size ranges

Soil Fraction	Particle Size Range (mm)
Clay	< 0.002
Silt	0.002 - 0.06
Sand fine	0.06 - 0.2
Sand medium	0.2 - 0.6
Sand coarse	0.6 - 2.0
Gravel fine	2.0 - 6.0
Gravel medium	6.0 - 20.0
Gravel coarse	20.0 - 60.0
Gravel very coarse	60.0 - 200.0
Boulders	> 200.0

Source: NZGS, 1988

Rock material includes:

- sedimentary rocks that have been hardened by natural cementation (shale, limestone, sandstone)
- igneous rocks that have crystallised from a molten state (basalt, granite)
- metamorphic rocks that have recrystallised under extreme pressures and temperatures (slate, gneiss, marble).

Information on local ground conditions can be obtained by reference to regional councils, New Zealand geological maps, soil maps, local drillers, and experienced consultants.

2.3.1.2 Liquid and vapour conducting properties

The two key physical properties of geological materials that affect the migration of liquids through them are effective porosity and hydraulic conductivity. In assessing the fate and transport of contaminants it is important to have an understanding of these concepts.

Porosity

The open spaces between particles or within the structures of geological material formations are called pores. Porosity, or total porosity, is the ratio of the volume of all the pores (or void spaces) in a material or formation (including unconnected pore spaces) to the total volume of the material or formation. Porosity is expressed as a percentage and is affected by such parameters as grain size and shape, and the way in which the various materials are put together. Figure 2.4 shows typical types of porosity associated with different rocks

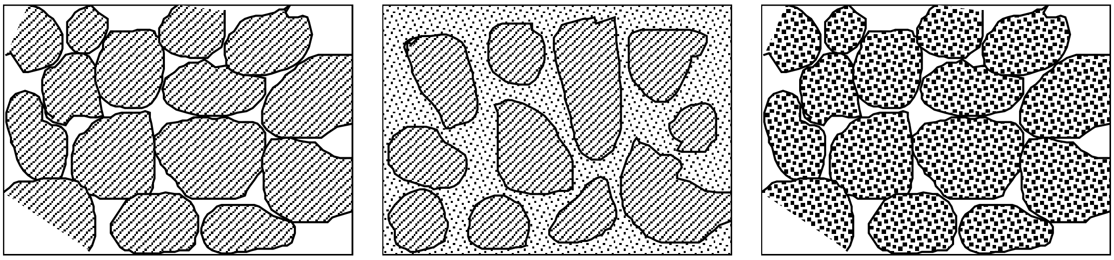
Two types of porosity are defined reflecting the way in which the pores were formed:

- Pores formed during the original deposition of the materials create primary porosity (interstitial pores, Figure 2.4, a to d)
- Pores formed after the creation of the deposit or formation create secondary porosity (fractures, joints, faults, solution channels; Figure 2.4, a e and f). The porosity of bedrock is usually low, but near the surface geological processes tend to create fractures which create a secondary porosity through which fluids can flow. Dissolution of rock material by groundwater can also create secondary porosity, such as the development of cave systems in limestone.

Porosity can range from near zero to higher than 60%. The higher values are found in recently deposited sediments, whereas the lower values are encountered in dense crystalline rocks or highly compacted soft rocks such as shales.

The porosity of deposits consisting of well rounded particles of equal size will be greater than the porosity of deposits containing well rounded or angular particles of different sizes. Small grain sizes fill the gaps between the larger particles and take up more of the space between particles. Generally the wider the range of grain sizes, the lower the porosity.

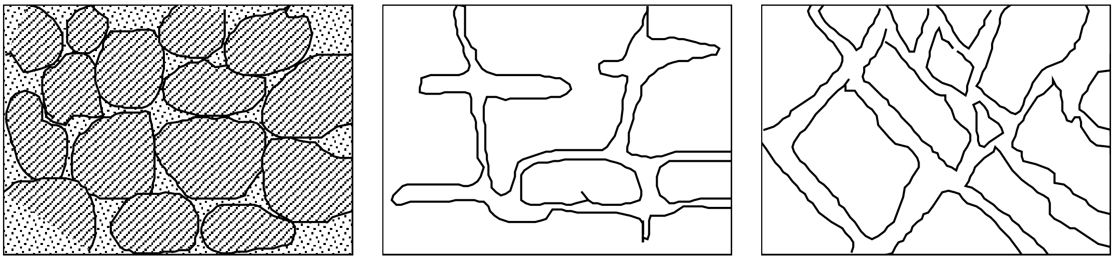
The shape of grains also affects the porosity. Spherical grains flow more freely and pack together more tightly than other shapes such as plates or rods where bridging between particles can occur. Clays, for example, are composed of many different particle shapes and do not tend to pack together very well. Hence clay soils tend to have high total porosities.



(a) Well-sorted sedimentary deposit having high porosity

(b) Poorly sorted sedimentary deposit having low porosity

(c) Well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has very high porosity



(d) Well-sorted sedimentary deposit with porosity diminished by the deposition of mineral matter in the interstices

(e) Rock rendered porous by solution

(f) Rock rendered porous by fracturing

Figure 2.4 Relationship between texture and porosity
Source: Domenico and Schwartz, 1990

As a guide, general ranges of porosities for given soil types are given below in Table 2.6.

Table 2.6 Typical soil porosity values

Material	Typical Porosity Values %
SOILS	
Gravel, coarse	24 - 36
Gravel, fine	25 - 38
Sand, coarse	31 - 46
Sand, fine	26 - 53
Silt	34 - 61
Clay	34 - 60
SEDIMENTARY ROCKS	
Sandstone	5 - 30
Siltstone	21 - 41
Limestone, dolomite	0 - 20
Karst limestone	5 - 50
Shale	0 - 10
CRYSTALLINE ROCKS	
Fractured crystalline rocks	0 - 10
Dense crystalline rocks	0 - 5
Basalt	3 - 35
Weathered granite	34 - 57
Weathered gabbro	42 - 45

Source: Domenico and Schwartz, 1990

In examining the liquid conducting potential of a geological material, it is necessary to know what volume of the pore space can allow the transmission of a liquid. Effective porosity is defined as the ratio of the volume of *interconnected* pores (or void spaces) in a material or formation to the total volume of the material or formation. Although it can be difficult to measure, effective porosity is the property of greatest interest in contaminant fate and transport modeling.

Effective porosity is a measure of connectivity through the solid medium and is more closely related to hydraulic conductivity than is total porosity. Many rocks have a high total porosity, but most of this pore space is unconnected, e.g. vesicular basalt. Similarly, clays have high total porosities but have smaller intergranular voids and hence have lower effective porosities than coarser grained materials. Examples of materials with differing total and effective porosities are given below.

Table 2.7 Variation in total and effective porosity

Material	Total porosity %	Effective porosity %
Clay	34 - 60	1 - 18
Chalk	2 - 20	0.05 - 0.5
Limestone, dolomite	0 - 20	0.1 - 5
Sandstone	5 - 30	0.5 - 10
Shale	0 - 10	0.5 - 5
Granite	0.1	0.0005

Sources: Domenico and Schwartz, 1990; API 1996

Permeability and Hydraulic Conductivity

Permeability is a measure of the ability of a geologic formation to transmit any fluid. The term is used in the petroleum industry where the fluids of interest are oil, gas and water.

Hydraulic conductivity is also a measure of the ability of a geologic formation to transmit (conduct) a fluid, but is dependent on the type of fluid. For example, water has a higher hydraulic conductivity than more viscous fluids such as crude oil or diesel.

Permeability and hydraulic conductivity are frequently used interchangeably, but hydraulic conductivity is the more appropriate technical term in the context of this document. Permeability is commonly used as a qualitative term describing the ease with which a fluid can move through a geologic formation.

As can be seen in Table 2.8, hydraulic conductivities for different materials can range over about 12 orders of magnitude, with the lowest values being in unfractured igneous and metamorphic rocks and the highest values being in gravels, karstic or reef limestones, and permeable basalts. In general, a hydraulic conductivity of approximately 1×10^{-9} m/sec or less is considered a material of low permeability. Materials included in this group are clay, chalk, till, shale, and unfractured igneous and metamorphic rock. If these rocks or sedimentary deposits are fractured, then significant secondary porosity exists, and the conductivity can rise above this defining limit by up to three orders of magnitude. Hydraulic conductivities of fractured geologic materials are typically greater than for materials having intergranular pores, but significant overlap in values is possible.

Table 2.8 Hydraulic conductivities

Material	Hydraulic Conductivity (m/sec)
SOILS	
Gravel	$3x10^{-4}$ - $3x10^{-2}$
Coarse sand	$9x10^{-7}$ - $6x10^{-3}$
Medium sand	$9x10^{-7}$ - $5x10^{-4}$
Fine sand	$2x10^{-7}$ - $2x10^{-4}$
Silt, loess	$1x10^{-9}$ - $2x10^{-5}$
Till	$1x10^{-12}$ - $2x10^{-6}$
Clay	$1x10^{-11}$ - $4.7x10^{-9}$
Unweathered marine clay	$8x10^{-13}$ - $2x10^{-9}$
SEDIMENTARY ROCKS	
Karst and reef limestone	$1x10^{-6}$ - $2x10^{-2}$
Limestone, dolomite	$1x10^{-9}$ - $6x10^{-6}$
Sandstone	$3x10^{-10}$ - $6x10^{-6}$
Siltstone	$1x10^{-11}$ - $1.4x10^{-8}$
Shale	$1x10^{-13}$ - $2x10^{-9}$
CRYSTALLINE ROCKS	
Permeable basalt	$4x10^{-7}$ - $2x10^{-2}$
Fractured igneous and metamorphic	$8x10^{-9}$ - $3x10^{-4}$
Weathered granite	$3.3x10^{-6}$ - $5.2x10^{-5}$
Weathered gabbro	$5.5x10^{-7}$ - $3.8x10^{-6}$
Basalt	$2x10^{-11}$ - $4.2x10^{-7}$
Unfractured igneous and metamorphic	$3x10^{-14}$ - $2x10^{-10}$

Source: Domenico and Schwartz, 1990

2.3.2 Subsurface water characteristics

The basic concepts which give an understanding of the types of groundwater and their behaviour are outlined in this section. In general, before the introduction of any contaminant materials such as petroleum hydrocarbons, into the subsurface environment, the pore spaces in the subsurface are filled with air, water and other minor liquid and gaseous components. (There are of course areas where natural contamination of the pore spaces by other types of fluid will occur, such as in the case of natural petroleum hydrocarbon gas or liquid deposits and seeps, or near surface geothermal activity.)

Fluids in the subsurface are present in two forms: within pore spaces (interstitial water) and in chemical combination with rock.

The subsurface fluids in the pore spaces can be characterised according to their vertical distribution as defined below.

2.3.2.1 The vertical distribution of subsurface water and air

The vertical distribution of subsurface water and air is important in understanding liquid contaminant and vapour migration.

The vertical distribution of fluids is generally described in terms of a water profile (see Figure 2.5). The divisions in this profile are as follows:

Unsaturated zone

Unsaturated and saturated refer to the degree with which the pore spaces are saturated with water. A degree of saturation less than 100% indicates that air is present in some of the voids. The unsaturated zone is also known as the zone of aeration, and the vadose zone. In the unsaturated zone the pores are not completely filled with water (air is present), all fluids are under negative pressure, and water is held back by capillary forces. The unsaturated zone contains partially water-saturated pores, fully water-saturated pores, and air filled pores. Water moves downward due to gravity, and outwards and upwards due to capillary forces. Soil gases can move in all directions.

Soil gases are vapours which accumulate in the pore spaces. In this context they are the volatile fractions of the petroleum product. The movement of vapours is primarily driven by concentration gradients and diffusion.

Water in the unsaturated zone is defined by the forces influencing it. Gravitational water drains down through the zone due to the force of gravity, hygroscopic (adsorbed water) water remains adsorbed to the surface of soil particles, vadose water moves upward due to transpiration, and capillary water moves under the influence of surface tension forces.

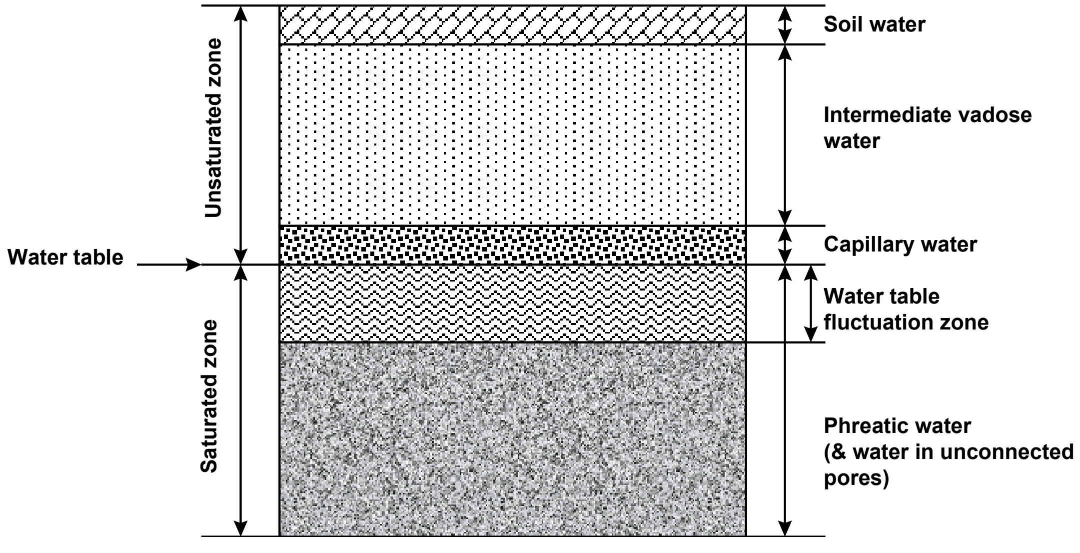


Figure 2.5 The water profile
After Domenico and Schwartz, 1990

The unsaturated zone is broken up into three sub-zones: soil water, intermediate vadose zone and the capillary zone:

The **soil water zone** varies with soil and vegetation types, extending from the ground surface down to the bottom of the major root zone. The amount of water in this zone depends on the amount of recent rainfall and infiltration. Parts of this zone can reach a near saturated state immediately following rainfall, while the intermediate vadose zone below remains unsaturated.

The **intermediate vadose zone** extends from the soil water zone down to the capillary fringe and contains water in the form of thin films adhering to pore linings. The zone can vary in thickness from being non-existent in areas of high water table and high precipitation to more than a hundred metres thick in arid regions.

The **capillary zone or fringe** extends from the water table up to the limit of capillary rise. It varies inversely with pore size and proportionally to surface tension. Capillarity comes about through the combination of the surface tension of the liquid and the ability of certain liquids to wet the surfaces they come in contact with. Capillary rise can range from 2.5 cm for a fine gravel to greater than 200 cm for silt. Just above the water table, nearly all the pores contain capillary water. The water content decreases with an increase in elevation depending on the soil type, and the air filled porosity increases as the water content decreases.

The **water table** lies at the boundary between the unsaturated and saturated zones. Water above the water table is below atmospheric pressure, whereas the water below the water table is at pressure greater than atmospheric. The water table is the water surface below ground at which the pressure is exactly equal to atmospheric pressure, and is the level to which water will rise in a well drilled into the saturated zone. The water table elevation fluctuates naturally throughout the year with changes in recharge and discharge patterns (e.g. seasonal trends, large rainfall).

Saturated zone

In the saturated zone (also known as the phreatic zone) the pores are generally full of water, although some pores may contain air that has become trapped by soil particles or beneath impermeable layers. The water is at a pressure greater than atmospheric. The saturated zone extends from the water table down to the bottom of the groundwater flow system. Here water is present as phreatic (groundwater) water, which is contained within connected pores, and hence is able to move or flow, and within unconnected pores.

2.3.2.2 Groundwater movement

Groundwater movement is the primary method by which liquid hydrocarbon contaminants migrate or are distributed outwards from the source. Groundwater is one component of the hydrologic cycle depicted in Figure 2.7. Groundwater is the water in the saturated zone which is able to flow. The velocity at which groundwater will travel through the saturated zone is dependent on the properties of geologic material such as hydraulic conductivity and porosity, and the hydraulic gradient. The main sources of groundwater in an area are from local precipitation and infiltration, or from underground flow from a recharge area. The recharge area may be an area of high precipitation or part of a river system which is itself delivering water from another remote area of precipitation.

Water from precipitation or overland flow enters the groundwater system in an area of recharge through infiltration and flows down-gradient under gravity to a discharge area such as a river, spring or abstraction well (see Figure 2.7).

The water table is a continuous surface that slopes downwards from the recharge area to the discharge area.

In general, shallow water tables will follow the fall of local surface topography. The elevation of the water table will naturally fluctuate following seasonal trends in recharge and discharge patterns as part of the hydrologic cycle under the influence of such actions as evaporation, evapotranspiration, precipitation, runoff, and underground flow. The water table fluctuation may range from near zero to many metres, depending on the area.

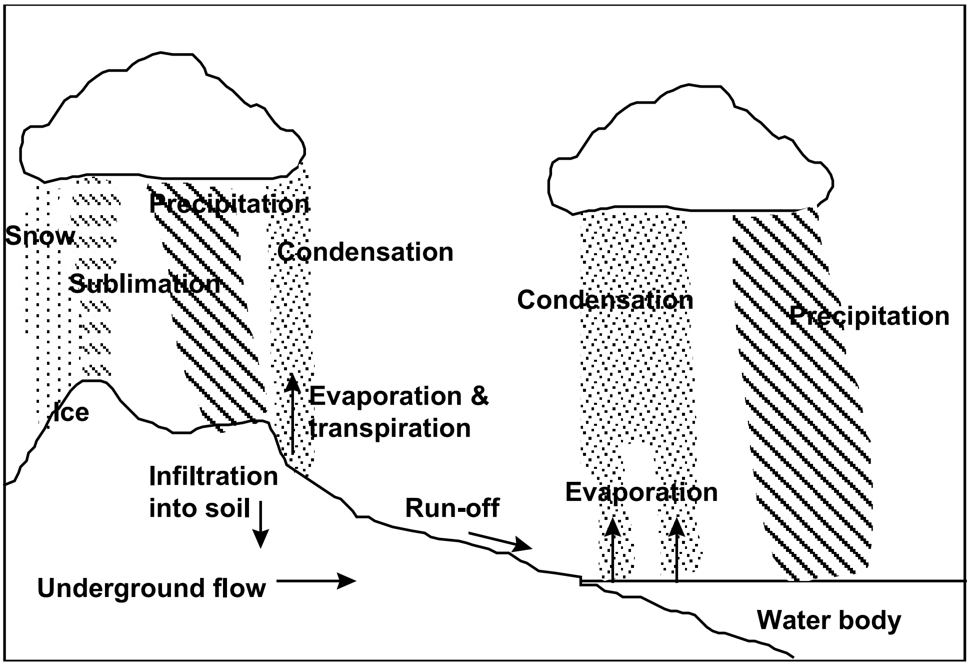


Figure 2.6 The hydrologic cycle

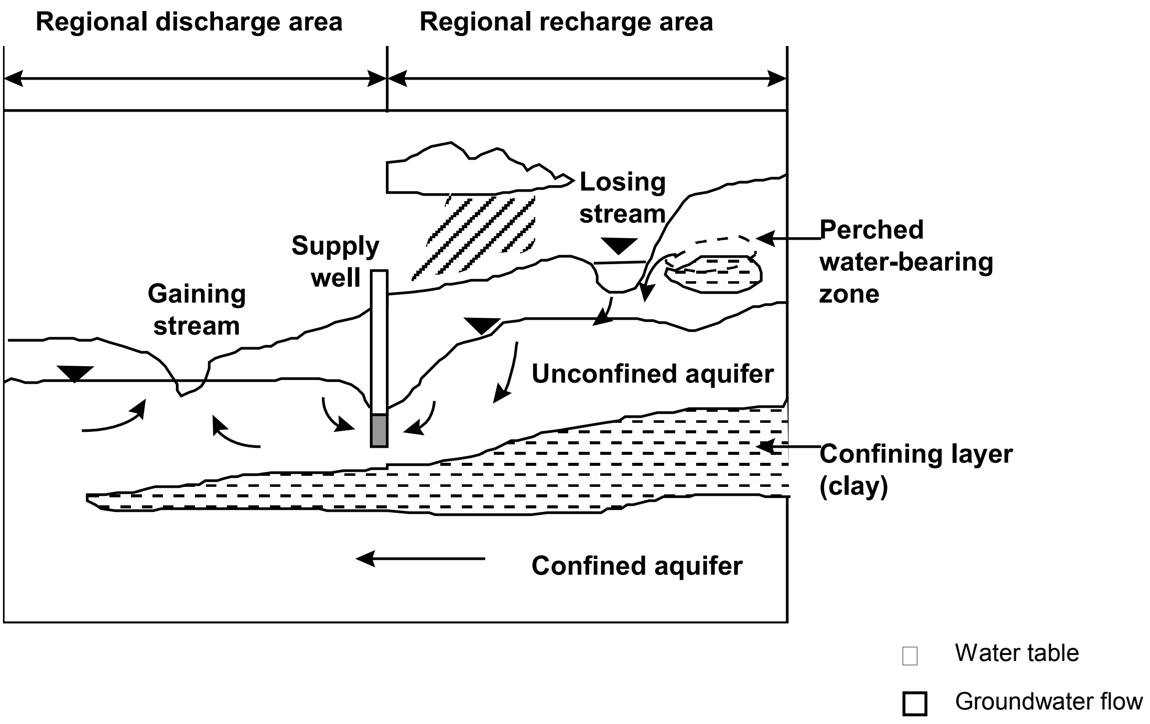


Figure 2.7 Groundwater circulation

Source: API, 1996

2.3.2.3 Groundwater aquifers

Aquifers are important in New Zealand, since in some areas a large percentage of drinking-water supplies as well as stock and irrigation water are derived from this course hence the concern with respect to potential contamination of aquifers.

An aquifer can be defined as a water-bearing formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. The term significant is subjective and depends on the quantity and quality of water needed for a particular purpose.

Aquifers generally extend over wide areas and the flow of groundwater, in to and out of them, is characterised by the permeability of geologic formations that overlay or underlie them. They may contain aquicludes, a relatively impermeable confining unit, that has a very low hydraulic conductivity and prevents virtually any flow of water through the formation (for example a clay soil) and aquitards; poorly permeable formations or deposits such as a sandy clay soil that allows only very low flow of water into adjacent aquifers (that is, it retards fluid movement). Aquifers can be present in unconsolidated or consolidated materials.

Aquifers can also be characterised by the effective porosity of the aquifer geologic materials. This will indicate the water storage capacity of the aquifer. Aquifers are capable of yielding large volumes of water when composed of sands and gravels, or only small amounts from silts and clays (per unit volume of the material basis). Aquifers can be thought of as groundwater storage reservoirs that receive recharge from sources such as rainfall, and discharge by gravity or by pumping from wells.

Aquifers may be classified as unconfined or confined, depending on the location of the top of the aquifer with respect to the water table. An unconfined aquifer is one where the water table exists within the aquifer and rises and falls with changes in the volume of water stored. Unconfined aquifers are usually close to the ground surface and are more frequently affected by hydrocarbon releases than confined aquifers. Recharge of unconfined aquifers usually comes from downward seepage through the unsaturated zone, through lateral groundwater inflow and from upward flow of water from deeper confined aquifers. A perched water table is an example of an unconfined water body that is sitting on top of an impermeable layer, such as a clay lens, separated from the saturated zone.

Confined aquifers occur where groundwater is confined by a formation of relatively low hydraulic conductivity (aquiclude or aquitard) and the water in the aquifer is at a lower level of elevation than the recharge area. That is, water at the top of the aquifer is at greater than atmospheric pressure. In a well penetrating the confining layer, the water level will rise above the bottom of the confining layer. If the water level rises above the land surface, a flowing well or spring known as an artesian well or spring results. Recharge of a confined aquifer can occur through infiltration in recharge areas or by slow leakage of water down through the confining layer from an aquifer above.

A confined aquifer can conduct water from a recharge area to locations of natural or artificial discharge. The level that water rises to in a well penetrating into either an unconfined or confined aquifer is equivalent to the total hydraulic head (the hydrostatic pressure level) of water in the aquifer at that location. The total hydraulic head is usually expressed in terms of water elevation for both unconfined and confined aquifers. The sum of elevation head and pressure head equals total head. Flow within an aquifer occurs from locations of high head to locations of low head. In going from the recharge zone to the discharge zone through the aquifer, the hydrostatic pressure level forms what is known as the hydraulic grade line, or the piezometric or potentiometric surface. A confined aquifer becomes unconfined when the piezometric surface drops below the bottom of the upper confining layer.

Equipotential lines can be drawn (in plan view) through the water table levels for an unconfined aquifer or through the piezometric levels for a confined aquifer. Lines drawn perpendicular to the equipotentials indicate the direction of groundwater flow in the direction of decreasing head (down-gradient). Almost all water table (or potentiometric) surfaces are sloped indicating that groundwater is moving.

2.4 Forms of hydrocarbon contamination

Following release to the subsurface, petroleum hydrocarbons will be present in a combination of solid, liquid, dissolved, and vapour phase as described in this section.

2.4.1 Liquid phase

In the subsurface, hydrocarbons in liquid phase can occur in the following ways:

- mobile or free (free product) liquids moving down through the unsaturated zone
- immobile residual liquids in the unsaturated zone
- immobile residual liquids trapped in the saturated zone
- free product on top of water table.

The particular form taken or distribution between forms depends on the extent to which hydrocarbon saturation is possible in the pore spaces and on the wetting characteristics of the geologic materials, or in terms of processes, the degree to which adsorption or absorption affects the contaminant plume and how much of the liquid is retarded and becomes immobile.

The amount of petroleum product that can be retained by the subsurface materials is dictated by capillary interactions between the soil and petroleum product. The amount that can be retained under gravity drainage conditions is often referred to as the residual saturation, and it is dependent on the soil particle size, soil type, liquid density, and surface tension.

The degree of adsorption depends on:

- chemical equilibria
- soil organic carbon content
- product and soil chemical composition
- the existence of preferential pathways.

In the unsaturated zone the exposed surfaces of most geologic materials will be coated with a thin film of water, which acts as a wetting fluid. Liquid hydrocarbons can also act as a wetting fluid coating the water film and soil particles as it migrates through the vadose and capillary fringe zones. Residual saturation levels of hydrocarbons resulting from such wetting are generally higher in fine-grained soils than in coarse-grained soils.

Typical average values of residual hydrocarbon concentrations the unsaturated zone for some petroleum products and soil types are given in Table 2.9.

Table 2.9 Typical residual hydrocarbon concentrations in the unsaturated zone

Soil type	Petrols		Middle distillates		Fuel oils	
	L/m^3	mg/kg	L/m^3	mg/kg	L/m^3	mg/kg
Coarse gravel	2.5	950	5	2,200	10	4,800
Coarse sand	7.5	2,800	15	6,500	30	15,000
Fine sand/silt	20.0	7,500	40	17,000	80	39,000

Source: API, 1996

2.4.2 Dissolved phase

Dissolved phase hydrocarbons exist in the following areas:

- water infiltrating through the unsaturated zone
- the residual films of water covering solid surfaces or filling pore spaces
- groundwater within the saturated zone.

2.4.3 Vapour phase

Hydrocarbon vapours in the subsurface can be present in:

- pore spaces in the unsaturated zone not already occupied by liquids. This is the predominant area of distribution for vapours. In these zones, vapours are potentially highly mobile
- the free liquid hydrocarbon plume
- water in the underlying capillary fringe and saturated zone.

In the first two instances above, as small bubbles vapour becomes entrained in the liquids. The bubbles are relatively immobile, but may move slowly with liquid flow, dissolve into the groundwater or be released into the soil air.

Under certain conditions, methane, carbon dioxide and hydrogen sulphide may be present as a result of microbial degradation of hydrocarbons.

2.5 Subsurface hydrocarbon migration

The ways in which petroleum hydrocarbons migrate within the subsurface are central to assessing the fate and transport of the contaminant. This section provides basic background information on migration processes which are used in contaminant modeling and hence in developing criteria for site assessment.

As discussed in Section 2.4, a spill or leak of hydrocarbons will exist in the subsurface as free product, dissolved in groundwater and/or as a vapour. Some of the main processes affecting hydrocarbons in the hydrogeological environment include sorption (adsorption and absorption), chemical degradation, diffusion (dilution and dispersion), volatilisation, and biodegradation. These processes affect the rate at which the hydrocarbon contaminant migrates through the subsurface by dispersing or retarding the hydrocarbon compounds.

2.5.1 Physical and chemical processes

The following are definitions of chemical and physical processes which will have an impact on hydrocarbon fate and transport.

Adsorption involves surface to surface chemical bonding with organic compounds (organic carbon) and inorganic compounds (e.g. clay particles). It is affected by reaction equilibrium, the organic carbon content of the soil (f_{oc}), chemical composition, and preferential pathways. Non-adsorbed compounds move with groundwater. Adsorption effects the migration of chemicals in the subsurface. For example, the leading edge of a dissolved chemical plume moves slower than groundwater flow due to adsorption.

One way to compare the migration and adsorption potentials of various compounds is through the use of K_{oc} (organic carbon / water partition coefficient) values. A K_{oc} value is a measure of the tendency of an organic compound to be adsorbed by the soil. The higher the K_{oc}, the higher its potential to be adsorbed and the lower its potential to migrate. Table 2.10 presents K_{oc} values for some of the constituents in petrol.

The distribution coefficient, K_D, which is the ratio of the chemical concentration in the solid phase to that in solution at equilibrium, is equal to K_{oc} x f_{oc} where f_{oc} is the organic carbon content of the soil.

Table 2.10 Adsorption coefficients for selected constituents of petrol

Constituent	K_{OC} value
n-Pentane	568
n-Hexane	1097
n-Heptane	2361
Benzene	50
Toluene	339
ortho-Xylene	255
Naphthalene	1288
Benzo(a)pyrene	891,000

Source: Nyer, 1993; Karickhoff et al, 1979; and Meylan et al, 1992

Diffusion is the process whereby molecular or ionic constituents migrate in the direction of decreasing concentration. If there is a gradient, the rate of diffusion will be greater and will be from higher towards lower areas of concentration. Characteristics such as temperature or density can also drive diffusion.

Advection is the transportation of chemical constituents by groundwater movement. It is dependent on geologic material, hydraulic conductivity and groundwater flow rates.

Dispersion results from advection (i.e. there is no dispersion if there is no advection), and is generally a result of the fact that fluids must flow around soil particles. It may occur on the micro- or macro scale and is often referred to as a mechanical mixing process.

Chemical degradation through abiotic transformations due to naturally occurring chemical reactions may result in attenuation of a plume. BTEX compounds are not expected to be subject to this, but several halogenated compounds undergo hydrolysis and dehydrohalogenation reactions in groundwater.

Volatilisation is the process by which a compound passes from a liquid state into a vapour or gaseous phase. This is one process by which compounds are transported away from the soluble groundwater plume, through the capillary fringe, and into the soil gas of the vadose zone. Under hydrogeological conditions the mass of a contaminant like benzene removed through this mechanism is expected to be very low (the order of a few percent). Optimum conditions for volatilisation would be directly from the unsaturated zone, or in groundwater of shallow depth and high temperature. Volatilisation can be very significant in the removal of hydrocarbons from shallow or exposed soil sequences. Light hydrocarbons tend to be more volatile than heavier ones. Volatilisation can be significant in that it allows migration to areas of higher oxygen where biodegradation can occur.

2.5.2 Biological processes

Biological processes which result in the degradation of hydrocarbon compounds can have a significant effect on these contaminants in the ground. Therefore they can be important when considering site assessment, and management options. Subsurface micro-organisms are generally present in the form of a fixed biofilm on the surface of geologic material, and in most circumstances these organisms can utilise carbon and energy in organic chemical pollutants as a food source. This results in the biodegradation or biotransformation of the organic chemical.

Many micro-organisms such as bacteria and fungi can metabolise either completely or partially the hydrocarbons from petroleum. Microbial oxidation is dominated by bacterial action which appears to be species dependent.

Degradation of the various fractions of petroleum hydrocarbon products varies considerably; n-alkanes, isoalkanes, BTEX, and two- and three-ring PAHs are readily degraded with eventual conversion to carbon dioxide and water. Other fractions like the cycloalkanes and more complex PAHs can degrade very slowly.

Biodegradation is dependent on the right environmental conditions being available for the micro-organisms. Some of the factors affecting biodegradation rates include:

- the composition and size of the soil microbial population
- the presence of suitable and bioavailable source of energy (carbon)
- the presence of oxygen
- conducive soil conditions: i.e. a pH between 6 and 9, warm temperatures, and high moisture content
- the presence of essential elements including: N, P, K, Ca, Mg, S, Fe, Mn, Cu, and Zn
- the toxicity of the compounds and the concentrations to which micro-organisms are exposed.

If any one of these factors is lacking, it will limit microbial activity and hence reduce biodegradation. Availability of oxygen is typically the most limiting factor to biodegradation in natural settings. At some sites, where natural attenuation has been observed, biodegradation of the BTEX constituents by indigenous, subsurface microbes appears to be the primary mechanism.

Biodegradation of aromatic compounds under aerobic conditions (> 1 - 2 mg/L dissolved oxygen in groundwater) is a significant mechanism for the natural attenuation of BTEX compounds. Howard et al (1991) indicate that biodegradation half-lives for benzene in groundwater can range from 10 days to 24 months for varying conditions. (The half-life is the amount of time required for the concentration of a compound to degrade to half its concentration). Half-lives are highly site-specific.

Anaerobic biodegradation rates are much slower than aerobic rates and consistent degradation of hydrocarbons under these conditions has not been demonstrated. For this reason, contamination may persist in areas where the available oxygen is depleted.

2.5.3 Liquid phase migration

In order to assess hydrocarbon contamination properly, an understanding of the transport mechanisms of the various hydrocarbon phases is required. Following a release, free liquid product (also called light non-aqueous phase liquid (LNAPL)) will move under the force of gravity down through the unsaturated zone towards the water table. A significant proportion of the free liquid (i.e. LNAPL) will become trapped as residual saturation due to capillary forces. Lateral or horizontal spreading occurs within the unsaturated zone due to the divergence of flow around grains and because of the attractive forces between liquid hydrocarbons and solid granular surfaces.

Downward and lateral migration of the free liquid hydrocarbons will occur at different rates depending on:

- the rate and volume of the release

- the density of the hydrocarbons
- soil and rock porosities
- the attractive forces between the water and the hydrocarbons.

Low hydraulic conductivity layers will slow or can stop downward migration and promote lateral dispersion of hydrocarbon liquids. Downward migrating liquids (water or hydrocarbons) can become perched above these layers. If there is sufficient volume of liquid, or if the impermeable layer is sloped downward, the liquid will migrate around laterally discontinuous perching layers, and will then continue downward migration (see Figure 2.8).

The volume of the release, the depth to the water table, and the sorptive capacities of the geologic materials will determine whether the release reaches the capillary zone. Figure 2.8(a) depicts a release where free liquid does not reach the water table. Figure 2.8(b) shows the distribution of a release where liquid has reached the water table.

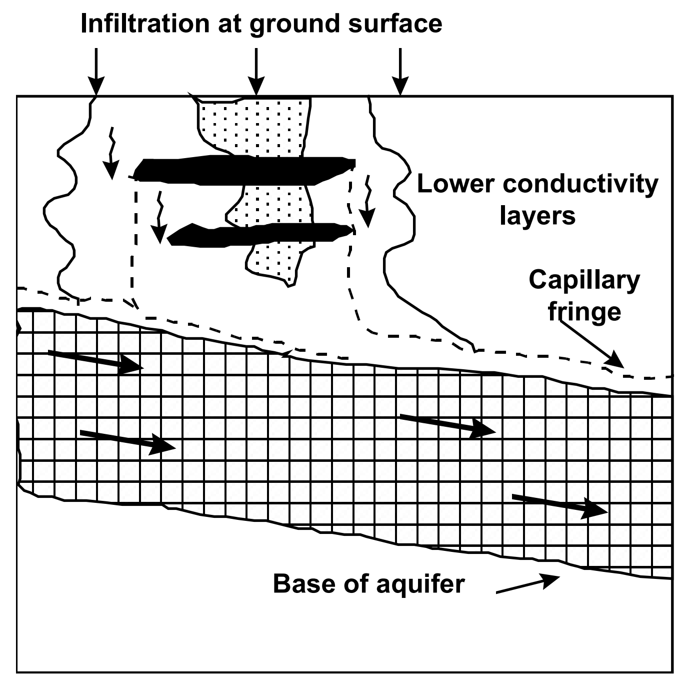
When the free liquid hydrocarbons first reach the capillary fringe the petroleum product accumulates on the capillary fringe, not the water table. This compresses the capillary rise, displaces water, and creates a free liquid hydrocarbon plume with a petroleum product table. Lateral spreading of the plume near the top of the capillary fringe can occur more rapidly than the movement of groundwater below the water table. This phenomenon occurs because the initial rate of migration is controlled by the pressure head of the free liquid hydrocarbons and not by groundwater.

After reaching the capillary zone, the plume begins to migrate downgradient under the influence of gravity and groundwater flow. If the plume is small relative to the depth of the capillary zone, migration can be inhibited by the capillaries. The rate of downgradient movement varies depending on the volume of the spill, groundwater flow velocity, product lost from the plume due to phase transformation and retardation and biological degradation processes, and the hydraulic conductivity as the plume proceeds.

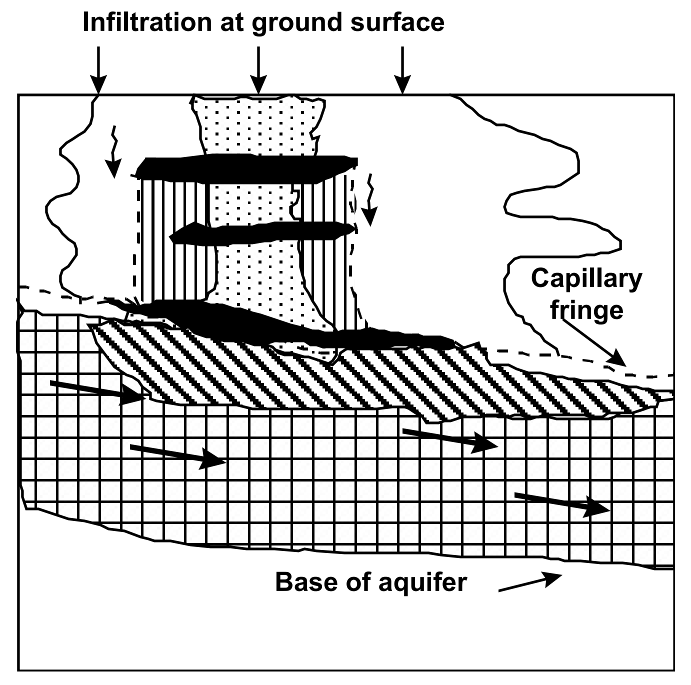
The size of the plume is affected by:

- release volume and rate
- porosities of soils and rocks
- hydraulic conductivity
- water table gradient
- the depth to the water table
- time of release.

Fine-grained materials have larger surface areas which tend to retain more of the liquid in a residual form and reduce the volume of free product. Coarse-grained materials and formations containing fractures and other secondary porosity features have smaller surface areas. Liquid hydrocarbons migrating through these materials are less likely to be immobilised by capillary forces (e.g. residual saturation values are smaller for these materials).



(a) Release in which the LNAPL does not make direct contact with the regional groundwater zone



(b) Release characterised by LNAPL reaching the regional groundwater zone

Hydrocarbon phase
□ Vapour phase
■ LNAPL
▒ Residual LNAPL
▥ Dissolved phase in vadose zone
▧ Dissolved phase in groundwater
▦ Uncontaminated groundwater

Generalised water flow
→ Groundwater flow
⤳ Unsaturated flow

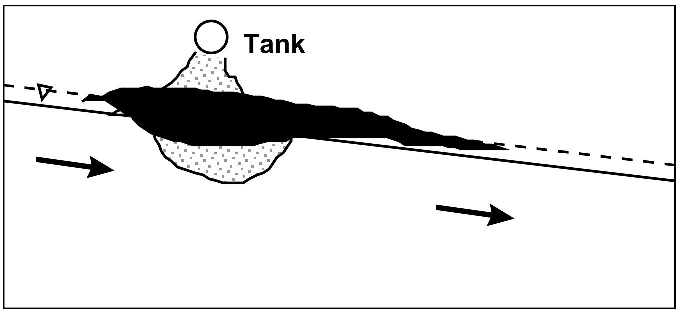
Figure 2.8 Distribution of hydrocarbons from (a) a small and (b) a large release
Source: API, 1996

The water table gradient (and other factors affecting flow, such as permeability) also affects the shape of the plume. The steeper the gradient, the narrower the plume.

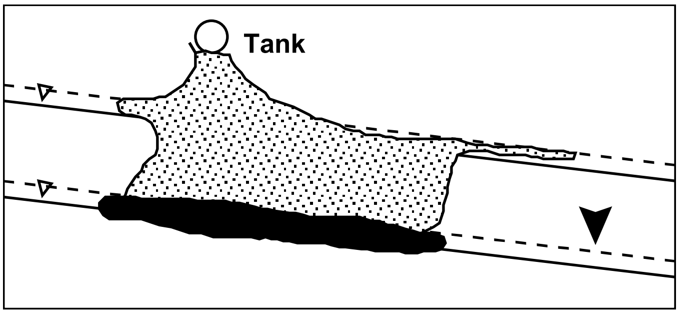
Fluctuations in the water table level promote vertical spreading of the plume (refer Figure 2.9). When the water table drops, free product associated with the capillary zone will descend leaving residual hydrocarbon liquid in the expanded unsaturated zone above the water table. This is known as smearing. Any subsequent rise of the water table will cause the capillary fringe and a portion of the associated product to move upwards. This may result in lateral spreading at a higher level.

The water table fluctuations can affect the amount of product detectable, and available for removal, in monitoring and recovery wells by altering the quantity of liquid hydrocarbons in a mobile state that can flow into a well. This leads to seasonal fluctuations in detectable hydrocarbon product thicknesses in wells. Smearing will also result in a continuing source of dissolved phase contamination.

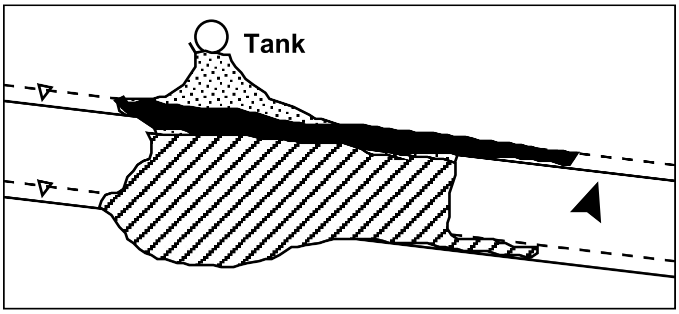
Free liquid hydrocarbons can migrate into underground structures such as wells, underground service trenches and ducts, foundations, basements, and natural groundwater discharge areas like springs, creeks and rivers.



Static water table



Falling water table



Rising water table

▒ Residual LNAPL (above water table)
■ LNAPL
▨ Residual hydrocarbons (below water table)

Figure 2.9 Spreading of hydrocarbons as a result of water table fluctuations
Source: API, 1996

2.5.4 Dissolved phase migration

The transformation of liquid phase hydrocarbons into dissolved phase occurs when the liquid hydrocarbons contact subsurface water. This contact can happen when:

- water infiltrates through an unsaturated zone which contains residual adsorbed phase hydrocarbons
- groundwater flows into contact with a free hydrocarbon plume
- groundwater flows past residual liquid or absorbed hydrocarbons in the saturated zone.

The concentration of dissolved hydrocarbon compounds in water and the rates of transfer to the groundwater system are determined by:

- the presence or absence of oxygen
- the rate of microbial degradation
- the depth to the water table
- soil and rock hydraulic conductivities
- recharge rates
- water table fluctuations
- groundwater velocity
- residual hydrocarbon concentrations
- the blend of hydrocarbon compounds in the free product liquid

The processes of advection, dispersion, and diffusion control the movement of dissolved phase hydrocarbons. The effect of dispersion and diffusion is to dilute the contaminant concentrations in the dissolved hydrocarbon plume. Mechanical mixing is the main dispersive mechanism, chemical diffusion has minimal effect except in cases of very low hydraulic conductivity or very low flow velocities.

Dispersion increases in heterogeneous material because groundwater velocities are different through differing subsurface media which results in greater mixing.

2.5.5 Vapour phase migration

Vapour phase migration is particularly important with respect to hydrocarbon accumulation in indoor air and other enclosed spaces such as utility corridors and sewers. Vapour phase hydrocarbons in the subsurface result from the volatilisation of liquid hydrocarbons. This can occur with:

- free liquid and residual liquid hydrocarbons in the unsaturated zone, and
- dissolved hydrocarbons downgradient from the release site.

The migration of vapour is controlled by many parameters including:

Chemical and physical properties of the released product:

- vapour pressure
- solubility
- concentration
- density
- viscosity

Hydrogeologic properties:

- hydraulic conductivity
- depth to groundwater
- groundwater flow direction

- water temperature
- porosity
- moisture content

Miscellaneous:

- barometric pressure
- rainfall duration and intensity
- non- natural structures.

In general, vapour tends to follow the most conductive pathways and travel from areas of greater to lesser pressure, and from higher to lower concentrations.

2.6 Exposure effects and toxicity

The importance of the potential health and environmental effects of hydrocarbons are obvious in a site assessment process. The following sections give a brief overview of these matters. More detailed information on health and environmental effects is included in Module 4.

Petroleum products vary in their toxicity according to the content of low-boiling compounds, unsaturated compounds and aromatics. The higher the concentration of these constituents, the more toxic the product. Toxicity appears to increase along the series alkanes - alkenes - aromatics.

Available data on the toxicity of cycloalkanes and cycloalkenes suggests that these compounds are more toxic than alkanes and that in some cases they are more toxic than aromatics.

2.6.1 Potential health effects

The uptake of hydrocarbons in animal or human tissue is governed by similar principles to other lipophilic substances. Adsorption occurs through respiratory surfaces, the gastrointestinal tract and external surfaces, with the hydrocarbons generally being deposited in lipid-rich tissues.

The New Zealand Drinking-water Standards (NZDWG) and the World Health Organization (WHO) Guidelines for Drinking-water Quality establish acceptable concentrations for a range of organic constituents of health significance. Guideline values are based on toxicity and/or carcinogenicity. Of these, benzene is most significant in terms of petroleum hydrocarbon contamination. Its limit is set at 10 µg/L (ppb) and is based on animal carcinogenicity test data and occupational exposure data for leukaemia. This level corresponds to a maximum additional cancer risk of 1×10^{-5} (one additional death from leukaemia per 100,000 over a lifetime (70-year) exposure).

The problems associated with ingestion of chemical constituents (i.e. via drinking water or similar) arise primarily from their ability to cause adverse health effects after prolonged exposure. Of particular concern are the contaminants that have cumulative toxic effects (i.e. heavy metals) or carcinogenic effects (WHO 1996a, b).

The World Health Organization states that Tolerable Daily Intakes (TDI) are regarded as representing intakes for a lifetime. They are not so precise that they cannot be exceeded for short periods of time. Short-term exposure levels exceeding the TDI are not cause for concern provided the individual's intake over time does not appreciably exceed the set level. The large uncertainty factors generally involved in establishing a TDI serve to provide assurance that exposures for short periods are unlikely to have any deleterious effects on health (WHO 1996a, b)

2.6.2 Potential ecological impact

Resistance to degradation, or persistence, is an important characteristic influencing the impact of a substance in an organisation or on the environment. The persistence of some hydrocarbons in aquatic organisms have been measured in terms of half-lives as ranging from 2 - 7 days in laboratory tests and 1 - 60 days in field tests. There is still no consistent opinion on whether petroleum hydrocarbons are able to biomagnify. However it appears likely that more resistant fractions are potentially available for biomagnification.

Following a review of toxicity data, compounds have been ranked in order of increasing effect, as follows: decane, octane, heptane, hexane, pentane, cyclo-octane, naphthalene, para-xylene, cyclohexane, benzene, and cyclohexene.

As there are differences in toxicity between different hydrocarbon compounds, it is impossible to accurately predict toxic effects of contamination for which only total hydrocarbon data are available. Generally, alkanes exhibit comparatively little toxicity or other adverse physiological impacts. Such effect is usually due to the aromatic substances present. The lower molecular weight compounds are usually the more water soluble component of a product and hence attention has been focused on the water soluble fractions of petroleum and related products.

Concentrations in the environment are usually comparatively low and sublethal effects are usually more significant. As a guide, general ranges for effects on marine organisms for given concentrations of soluble aromatic hydrocarbons is shown in Table 2.11.

Table 2.11 Range of effects in marine organisms for soluble aromatic hydrocarbons

Concentration	Effect
0 - 20 ppb	Bioaccumulation may occur
10 - 200 ppb	Behavioural pattern changes
100 - 60,000 ppb	Growth and reproduction changes
1,000 + ppb	Lethal to larval and juvenile stages
100,000 + ppb	Lethal to adults

Source: Connell and Miller, 1984

2.6.3 Physical risks

Risk of fire or explosion exists on sites containing volatile hydrocarbons. The build-up of flammable vapours, particularly in low-lying and/or poorly ventilated areas, can result in atmospheres sufficiently rich in vapours for an explosion to occur, if an ignition source is introduced. The lower limit at which explosion could occur, referred to as the lower explosive limit (LEL), for many flammable compounds is approximately 1 % by volume in vapour.

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Ministry for the
Environment
Manatū Mō Te Taiao

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

MODULE 3
Site assessment

August 1999

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3 Site assessment

This module discusses the approach and scope for assessing a site to determine the nature and extent of contamination and provide the data needed to evaluate the potential risks to human health and the environment. Specific details on field investigation techniques, sampling strategies and protocols, and quality assurance procedures are also included in this module.

It is difficult to provide prescriptive guidance regarding site assessment as every site is different and the environmental professional must be allowed flexibility to ensure adequate data is gathered given site-specific constraints. The aim of the sampling plan is to provide regulators and site owners with some indication of the type of data that must be gathered to adequately characterise a site.

In designing and carrying out any site investigation it is important to establish at the outset the aims or goals of the investigation. Pertinent questions to ask include:

- What are you trying to accomplish?
- What is already known about the site/situation?
- What will the data be used for?

The answers to these questions will help to define the level of site work required, the media to be targeted, the analytical requirements and the need for consultation with the regulatory authorities.

Site investigations are normally carried out in two phases: the initial site assessment and the detailed site investigation. The level of effort for the initial site assessment and detailed site investigation is dependent on the complexity of the site. An initial site assessment typically involves a desk top study and a site visit. Very little sampling, if any, is typically performed during the initial site assessment. The initial site assessment is used to assist in focusing the detailed site investigation.

The purpose of the detailed site investigation is to characterise the nature and extent of contamination and subsurface at the site so that an evaluation of the potential health and environmental hazards can be assessed. The information gathered during the detailed site investigation may also assist in selecting appropriate technologies for managing the site, if necessary. Intrusive and non-intrusive field investigation techniques are used to define the extent of contamination. Soil samples are almost always collected. Groundwater, surface water and sediment samples can also be collected if they could be affected. It is typically most cost effective to perform the detailed site investigation in stages.

Section 3.1 discusses the approach and typical scope of an initial site assessment. The approach and scope of a detailed site investigation is discussed in Section 3.2. Field sampling strategies are discussed in Section 3.3. Field sampling techniques and protocols necessary to ensure all data have an appropriate degree of accuracy and reproducibility and that the samples collected and field measurements taken are appropriately representative of actual field conditions are discussed in Section 3.4. Quality assurance/quality control issues are addressed in Section 3.5.

3.1 Initial site assessment

The initial site assessment comprises a desk study, site reconnaissance (if possible), development of a conceptual model, design of the detailed investigation, and a report summarising the results of the initial site assessment (optional). The complexity and level of effort of the initial site assessment depends on the complexity of the site and the objectives of the investigation programme. This section presents the steps required for a thorough initial site assessment at a relatively complex site.

A desk study involves gathering and compiling as much information as possible about the site so that a conceptual model can be developed. The conceptual model details the nature and extent of contamination, the potential migration pathways and identifies potential receptors as much as possible. Data gaps and uncertainties are identified during the preparation of the conceptual model which assists in designing the detailed investigation. The detailed investigation is then designed to confirm (or refine) the conceptual model and fill the data gaps. Finally, a report is prepared that summarises the information gathered, presents the conceptual model and outlines the detailed investigation.

3.1.1 Desk study

The background information gathered should include as much as possible of the following:

- the chronological history of previous uses, industries supported, and activities or processes carried out on the site
- the nature of the probable/possible contamination (petrol, diesel, petrochemicals etc.) including list of chemicals used on site
- any published or otherwise known information in order to establish whether adjacent property owners are, or have been, potential sources of contamination, including consents held for the site, if applicable
- location, age and construction material of above-ground and underground chemical or fuel storage tanks on the site. If integrity testing of storage tanks has been undertaken, the results of such tests should be reviewed.
- locations and construction details of underground services (which could potentially impact on the investigation or future remediation activities)
- present zoning of the site and details of the zone categories of properties surrounding the site
- contour or topographic maps
- likely future use of the site
- identification of equipment and areas where the likelihood of contamination resulting from historical or current work practices is high, including accidental spillage of chemicals
- source information (e.g. current and past site management) in order to establish the history of previous releases and waste disposal practices
- the results of any previous investigations of the site or surrounding land
- locations of surface water bodies (creeks, rivers, estuaries, wetlands), particularly where these may be adversely affected by contaminated groundwater or surface drainage from the

site. Surface water bodies should be evaluated to determine environmental values, beneficial uses, sensitivity to change, and physical, chemical and biological characteristics

- hydrogeological information which should include:
  - the extent and use of aquifers in the area
  - estimated depth to groundwater
  - probable direction of groundwater flow and gradient
  - soils and soil properties (soil type, porosity and hydraulic conductivity)
  - location of any springs
  - sources of local municipal water supply, and the location of registered private or industrial wells or bores
  - tidal information.

Potential sources for the information discussed above can include:

- maps (current and historical), including topographical maps, geological survey maps and town plans
- statutory authorities: local authorities, port companies, Ministry of Health, Department of Labour, Land Information New Zealand etc.
- trade information from directories, trade associations, etc.
- photographic records
- current and past site managers and workers
- technical information and material safety data sheets (MSDS)
- company records.

3.1.2 Site reconnaissance

A visual inspection of the site supplements the information gained from the desk study and allows an appreciation of the practicalities involved in the ensuing investigation. Information gathered might typically include:

- site access restrictions (commercial and physical)
- location of buildings and hard-standing
- location of overhead power cables and canopies
- availability of water and electricity supplies
- confirmation of location of underground services
- proximity and type of potential exposure pathways (e.g. old bores and wells not on council records, nearby schools, sensitive ecological habitats)
- anecdotal site history information
- site topography and surface run-off patterns/collection
- site ground surface covering
- signs of surface straining

- condition of nearby vegetation
- age and condition of tanks
- neighbouring land uses
- construction of foundation of nearby buildings (e.g. slab on grade, piling)
- any signs of off-site migration of products.

The information gathered in the desk study and the site reconnaissance should enable a conceptual model of the site to be developed.

3.1.3 Conceptual site model

The objective of a conceptual site model is to detail the nature and extent of contamination, the potential migration pathways and to identify potential receptors to the extent possible based on information gathered from the desk study and site visit. Data gaps and uncertainties are identified during the preparation of the conceptual model, which assists in designing the detailed investigation.

The conceptual model can be a simple site diagram in plan and cutaway views showing the potential sources of contamination (such as underground storage tanks, fuel pumps and piping), general geology beneath the site including expected depth to groundwater, likely migration pathways (such as service trenches, migration to groundwater and migration to nearby surface waters), potential exposure points (such as nearby wells, surface water and basements), and potential receptors (such as children, site visitors, and workers). Analytical results from previous investigations should also be shown on the diagram, if available.

The complexity of, and level of effort expended on, the conceptual model depends on the complexity of the site and objectives of the investigation programme.

3.1.4 Design of a detailed investigation programme

Once the conceptual model has been prepared, a detailed investigation programme can be designed to confirm (or refine) the conceptual model and fill the data gaps. The detailed investigation should be flexible to allow incorporation of new data into the conceptual model to further refine it as the investigation progresses. It is typically most cost effective to perform a detailed investigation programme in stages. The overall aim of the first stage is to determine whether contaminants are present at, or moving from, the site at concentrations that constitute an unacceptable adverse environmental or health risk as cost effectively and quickly as possible.

The detailed investigation programme, specified as part of the initial site assessment, should list the types of sampling to be performed, the number of samples to be collected, the proposed location of each sample, and the laboratory analyses to be performed. See Section 3.2 for a discussion of the scope of a detailed site investigation.

3.1.5 Initial assessment report

The initial assessment report is optional. If the site is complex enough to warrant a thorough evaluation of data gathered during this phase, then the report should summarise the information gained from the desk study (Section 3.1.1), present the conceptual model for the site (Section 3.1.3) and outline the sampling strategy for the detailed site investigation. The initial assessment report should contain the following information:

- **Introduction.** This section should detail the purpose of the initial site assessment, describe the site in detail and provide an outline of the report. The description of the site should include location of underground service trenches.
- **Background.** This section should outline the resources used and summarise the data obtained in the desktop study. Information such as historical land uses at the site, local and regional land uses, regional geology and hydrogeology, and a list of chemicals used on site should be included in this section.
- **Conceptual model.** This section should detail the nature and extent of potential contamination, the potential migration pathways and identify potential receptors to the extent possible as discussed in Section 3.1.3.
- **Recommendations.** This section should include recommendations for the type of sampling needed to further define the nature and extent of contamination. The conceptual model and experience should be used as the basis for determining which environmental media should be targeted (e.g. soil, groundwater, surface water, sediment) and at which locations on the site.
- **Appendices.** All data (e.g. maps, drainage plans, historical photographs, etc.) obtained from the sources discussed in Section 3.1.1 should be provided in appendices.

3.2 Detailed site investigation

The purpose of the detailed site investigation is to characterise the nature and extent of contamination and subsurface conditions at the site. The information gained from the detailed site investigation will be used to assess the risks to human health and the environment from a potential release at the site and screen technologies for managing the site.

The detailed site investigation must be planned carefully to ensure that all needed data is obtained in the most cost-effective manner. In many cases, a detailed investigation is performed in stages. Given the variability in size and complexity of petroleum hydrocarbon sites, it is not possible, or appropriate, to provide detailed advice on the development of field investigation programmes. However, the following must be considered:

- **objectives of the site investigation including data quality objectives**: A clear objective of why the data is being collected and what it will be used for will help focus the investigation. The data quality objectives (described in Section 3.6) list how the data will be used, the type of data needed (i.e. screening or definitive), the detection limits required, and how data quality will be assessed.
- **the number, type, and locations of the samples to be collected**: The rationale behind the sampling strategy should be well defined as should the types of analyses required for each sample. The conceptual model and experience should be used as the basis for determining which environmental media should be targeted (e.g. soil, groundwater, surface water, sediment) and at which locations on the site. Various sampling strategies are discussed in Section 3.3
- **the most appropriate (and cost-effective) field sampling procedures for each of the targeted environmental media:** Decontamination of equipment between sampling should be considered as should protocols such as identification, preservation, handling, packaging,

and shipping requirements. Field investigation techniques and sampling protocols for petroleum hydrocarbon contaminated sites are discussed in Sections 3.4 and 3.5 respectively.

- **permits and resource consents required to perform the field work:** Typically, a consent (and fee) would be required if a bore or well were constructed on site.
- **identification of health and safety issues (Section 3.4.1):** Fire and explosion hazards at a site should be evaluated before the field investigation. Other hazards to consider include confined space entry and entering an excavation.

A site sampling plan can be prepared prior to any field activity to define the steps required to meet the objectives of the site investigation. The level of detail of this plan should be commensurate with the complexity of the sampling program. In some cases, the sampling and analysis plan can be a one- or two- page document. For activities that are generally similar, such as tank removals, an overall sampling and analysis plan can be prepared for a particular type of work and then referred to in a letter along with any exceptions that may be required for a specific site.

Concurrent with preparation of the sampling plan, all necessary permits and resource consents should be obtained and personnel training should be performed. Once the sampling and analysis plan has been agreed to by all responsible parties and the permits have been obtained, the field activities can begin. Information obtained in the field, such as depth to groundwater or site-specific geology, should be assessed against the conceptual model. Field sampling strategies can then be modified if necessary.

At the completion of the detailed site investigation, a contamination assessment report should be prepared. The contamination assessment report should contain the following sections:

- **Executive summary.** This section should discuss the purpose of the investigation, summarise the findings of the investigation and risk assessment, and present the conclusion and recommendations.
- **Introduction.** This section should detail the purpose of the site investigation and describe the site in detail. The site description should include a detailed history of the site including the location of any known or suspected petroleum hydrocarbon storage or use, or any other activities which may have posed a risk to human health or the environment.
- **Background.** This section should include information such as historical local and regional land uses, regional geology and hydrogeology, climatology, and a list of chemicals used on site. The regional hydrogeology section should include a discussion of the proximity of surface waters and other sensitive receptors.
- **Field investigation.** This section should describe the sampling performed at the site including how the samples were collected, the location and number of samples collected, and the analyses performed.
- **Field and analytical results.** This section should summarise the information obtained during the field investigation including site-specific geology, hydrogeology and analytical results. The discussion of the site geology and hydrogeology should include physical characteristics of the soil (variation with depth) and groundwater (depth, flow rate, flow direction). Figures showing sample locations with analytical results are especially helpful.

- **Conceptual model.** This section should detail the nature and extent of potential contamination, the potential migration pathways and should identify potential receptors as discussed in Section 3.1.3. The conceptual model in the contamination assessment report should be an updated version of the one presented in the initial assessment report.
- **Risk assessment.** An evaluation of the potential risks to human health and the environment should be presented in this section. Typically, a Tier 1 assessment would be performed. A Tier 1 assessment involves comparing site concentration data with the appropriate acceptance criteria. See Modules 4-6 for information on how to perform a risk assessment.
- **Site management options.** It may also be desirable to include in the contamination assessment report an evaluation of the site management options for mitigating the adverse risks to human health and the environment. Site management options for petroleum contaminated sites are discussed in Module 7.
- **Appendices.** The following information should be included in appendices:
    - boring logs
    - well detail diagrams
    - laboratory reports
    - copies of permits and/or resource consents.

3.3 Sampling strategies

Once the conceptual model is developed for a site, a cost-effective sampling strategy can be developed. The components of a sampling strategy should include number, type and locations of the samples to be collected for all environmental media of concern as well as the types of analyses required for each sample.

The overall sampling strategy may involve several sampling rounds if little information is known regarding the contaminant source or if the site is large. For example, a soil gas survey may be undertaken at a site to provide an initial assessment of the extent of contamination. The results of the soil gas survey may be used to identify locations of test pits or boreholes for soil sampling in follow-on investigations. Analytical data obtained from the soil investigation can be used to determine the need for additional soil sampling to further define the extent of hydrocarbon contamination and the need for additional groundwater sampling. If information is available regarding the nature of the release and site-specific geology and hydrogeology, or sampling indicates no significant contamination is present, then only one sampling round may be necessary to characterise the site adequately.

The rationale for choosing the number of samples, sampling method, location, and analyses for soil is discussed in Section 3.3.1. The rationale for choosing the location and number of groundwater monitoring wells and recommended analyses for groundwater is discussed in Section 3.3.2.

3.3.1 Soil

The rationale for choosing the sampling method, location, number of samples, type of sample, and analyses for adequately characterising the unsaturated zone is discussed in this section.

3.3.1.1 Sampling method and location

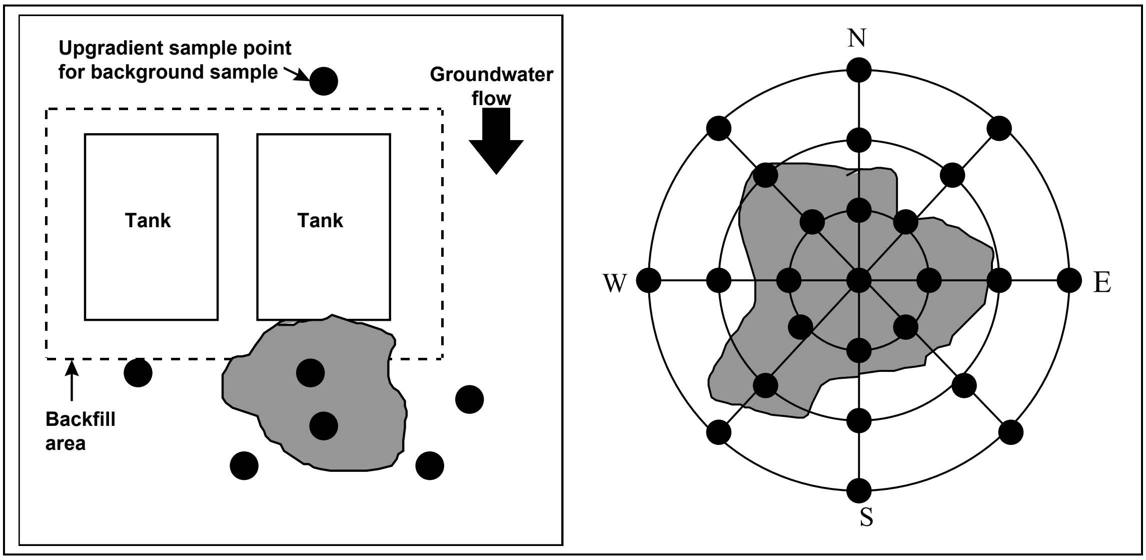
The overall aim of the first round of sampling in the assessment process is to determine as cost effectively as possible whether contaminants are present at, or moving from, the site at concentrations that constitute an unacceptable adverse environmental or health risk. The most cost-effective and timely approach is to target the areas most likely to be contaminated. However, the effectiveness of a targeted sampling strategy is dependent on the thoroughness of the information gathered during the desk study (Section 3.1).

In general, when the source of contamination is known or is suspected to be limited to a specific area, sampling points are located relative to the suspected source. This usually involves judgmental sampling if hydrogeological information is available, or it may involve systematic grid sampling emanating from the contaminant source if hydrogeological information is not known. The differences between judgmental and grid sampling are illustrated in Figure 3.1 and Table 3.1.

The method selected will depend on the conceptual model of the site. In practice, a combination of methods may be used for different parts of a site. For example, where no identifiable source exists, or the existence of petroleum hydrocarbons appear to be widespread, a grid might be laid out and samples taken either systematically or randomly, depending on the objectives of the study. To delineate or determine the lateral extent of hydrocarbons from a known source, a judgmental approach might be used with results fed back into the conceptual model as the investigation progresses. Samples would be collected initially close to the contaminant source. If petroleum hydrocarbons are detected at these sampling points, additional samples may be collected at points farther from the suspected contaminant source (with spacing judged from the conceptual model) until no contamination is found.

Systematic sampling may be used in cases where the chance of an omission could cause a significant detrimental decision or outcome, or where time is a factor. Systematic sampling is also used during evaluation of remediation options such as land farming (Section 7.5.3 of Module 7) or where little or no information is available on a site.

Simple random sampling is often used in sampling for land farm monitoring, biopile remediation, soil excavation piles, testing of fill material and in cases of site acquisitions where little or no historical and or hydrogeological information is available.



Example of judgmental sampling

Example of a systematic grid relative to a suspected source

Figure 3.1 Sampling methods
Source: Schwerko (1994)

Table 3.1 Advantages and disadvantages of site sampling approaches

Method	Advantages	Disadvantages
Systematic grid (5 - 30 m)	Statistically reliable site coverage.	Grid may cover low risk areas of site. Costly. May under - represent high risk areas.
Random	Less expensive alternative. Reduces the number of sample points and limits the choice of sampling locations to random selection.	All areas of the site have an equal probability of sampling. Does not target, therefore may miss high risk areas.
Judgmental (aka selective)	Focuses on critical areas in a cost effective-manner. Scale of investigation can be scoped / refined on the basis of field screening results.	Requires well-developed conceptual model.

3.3.1.2 Number of sample points and samples

The purpose of an investigation is to obtain an accurate assessment of the contamination (or lack of it) in a particular area. This is accomplished through the analysis of representative samples. The larger the number of points sampled, the greater the degree of confidence (statistical probability) that the analytical data represents the true overall picture, but the higher the cost of the investigation.

The number of sampling points is chosen to adequately characterise the vertical and lateral extents of contamination and should concentrate on areas highlighted by the desk study and site reconnaissance as likely to contain hydrocarbon contamination. The actual number of sampling points will depend on the following factors:

- size of the site
- extent of suspected release
- degree of confidence required (data required for regulatory purposes or on-site decision)

- costs
- future land use
- availability of suitable equipment
- time-scale.

There is no prescribed requirement on the number of sample points needed at each site. However, documents are available from the oil companies, the American Petroleum Institute (API), US Environmental Protection Agency (USEPA), and American Standard and Testing Methodologies association (ASTM) which can be used as a guide in selecting the number of sample points.

The number of soil samples collected from each sampling point is chosen to adequately characterise the extent of contamination and can vary depending on various factors:

- homogeneity of the soil
- depth of the excavation or depth of suspected contamination
- the quantity of product known or suspected to have been released
- existence of pathways by which contamination might migrate vertically
- number and kind of analyses to be run
- analytical precision and accuracy needed to meet the project objectives.

The suggested minimum numbers of soil samples for a variety of possible scenarios are summarised in Table 3.2. In general, five soil samples (one on each side and one at the base) are enough to adequately characterise a tank pit. If groundwater is encountered in the pit during excavation, the soil samples should be collected at the water interface, because that is the area likely to have the highest concentrations of contamination.

To determine the depth of petroleum hydrocarbons in soil during drilling or in test pits, samples should be collected at fixed intervals (e.g. 0.3 - 1.5 metres), at any change in lithology, and any other depth at which impact is observed via sight, smell or field screening methods such as hand-held organic vapour analysers. Samples should be collected until the groundwater table is reached or when the presence of hydrocarbons is no longer indicated by the field screening method. At least one sample should be collected below the point at which contamination is indicated by the field screening method to confirm the vertical extent of contamination.

Table 3.2 Minimum recommended number of soil samples

Location	Number of Samples	Action
Aboveground storage tank bunded area	2 per tank 2 per bund	Collect samples from 200 mm into natural soils at inlets, outlets, vents, drains, or other areas where product could collect.
Underground storage tank pit	5 per tank pit	Collect samples from 200 mm into natural soils on each wall of excavation and at the base.
Bowser area	1 per bowser island	Collect samples from 200 mm into surrounding soils.
Underground fuel line	1 per 5m of line	Collect samples from 200 mm into surrounding soils. Target sampling at stained areas.
Above ground fuel line	1 per 10m of line	Collect samples from 200 mm into surrounding soils. Target sampling at stained areas and at joints.
Drum storage and cleaning areas	1 per 25 m^2	Collect samples in areas of known spill/leaks or otherwise below area at two intervals: 200 mm and 300-600 mm.
Used battery storage area	1 per 25 m^2	Collect samples from 200 mm into natural soils.
Waste disposal area	1 per 25 m^2	Collect samples from 200 mm into natural soils.
General excavation	1 per 25 m^2 of excavation wall area	Collect samples from 200 mm into natural soils on each wall of excavation and at the base.
General borehole drilling	5 per borehole	Collect samples at fixed intervals (e.g. 0.3 to 1.5 metres), at any change in lithology, and any other depth at which impact is observed or measured.

3.3.1.3 Types of samples

Either discrete or composite soil samples can be obtained. Compositing is a technique where soil is collected from several locations, mixed together, and then sampled. Discrete samples are preferred. The samples should be collected in a way that will avoid the introduction of bias. Samples collected for the analyses of volatile compounds should be separate from samples collected for other analytes.

In general, composite samples are taken when an “average” value is being evaluated. For example, composite samples are appropriate during land farming (Section 7.5.3 of Module 7) to screen large areas or for evaluating the concentration of total petroleum hydrocarbons (TPH) in stockpiles of material.

Samples collected for the analysis of volatile organic components (BTEX, lighter fuels) should not be composited since compositing can cause the loss of the more volatile components. Transferring samples between containers or during compositing compromises the integrity of the samples because residue can be left on the container. Compositing is also not recommended when hot spots of petroleum hydrocarbons need to be delineated.

3.3.1.4 Types of analyses

The types of analyses to be performed on soil samples collected at petroleum hydrocarbon impacted sites are based on the product type and are summarised in Table 3.3. The results from these analyses are required to perform the risk-based evaluations discussed in Modules 4-6. In general, all of the samples would be analysed for TPH and the results would be fractionated as follows: C_7 to C_9, C_{10} to C_{14}, and C_{15} to C_{30}. Module 4 discusses the reasoning behind the fractionation of TPH. Because the TPH method recommended does not include reporting of C_6, soil samples associated with a petrol spill must also be analysed for aromatic volatile organic compounds (AVOCs) which include BTEX.

A Tier 1 risk analysis (as discussed in Module 4) for soils impacted with diesel can usually be performed using the TPH values. However, in some cases it may be necessary to obtain analytical results for the polycyclic aromatic hydrocarbons (PAHs) present in diesel. All of the results should be reported on a dry weight basis.

TPH can be performed on the soil samples as a gross indicator of fuel contamination. The TPH analytical method can be used to obtain a chromatographic boiling point distribution of the petroleum hydrocarbons in the sample. This fingerprint can be very helpful in tracing spills from multiple sources as it allows the identification of the type(s) of hydrocarbon present. A document titled *Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water* (OIEWG, 1999) is available from the Ministry's web site www.mfe.govt.nz/issues/contam.htm). Refer to it for the latest information on laboratory analyses.

If product type is unknown, it is recommended that a few of the samples be subjected to TPH, AVOC, and PAH analyses.

Table 3.3 Recommended laboratory analyses for soil samples

Suspected Source	Parameter	Method
Petrol Aviation fuel Light-end petroleum fractions	AVOCs Banded TPH (C_6 to C_9, C_{10} to C_{14}, $>C_{15}$)	Refer to sampling and analytical guidelines document
Diesel Kerosene Middle distillates	PAHs Banded TPH	Refer to sampling and analytical guidelines document
Heavy-end petroleum fractions Bunker fuels Residual fuels Crude oil	PAHs	Refer to sampling and analytical guidelines document

AVOCs = aromatic volatile organic compounds (e.g. BTEX)
PAHs = polynuclear aromatic hydrocarbons
TPH = total petroleum hydrocarbons

3.3.2 Groundwater

Groundwater monitoring systems are installed to determine the concentrations of petroleum hydrocarbons in groundwater and to collect hydrogeological and geological data around and downgradient from the potential hydrocarbon source. The rationale for choosing the location and number of groundwater monitoring wells and recommended analyses for groundwater are discussed in this section.

3.3.2.1 Location and number

The number and location of groundwater monitoring wells will depend on the conceptual model and scope of the investigation. The placing of wells and determination of sampling depths are complicated processes and should be performed under the supervision of qualified geologists or hydrogeologists. Consideration must be given to:

- potential or known sources (e.g. tanks, pipe work, soakage pits etc.)
- confidence in conceptual model (e.g. flow direction)
- potential upstream sources (necessitating background monitoring)
- anticipated spread of contamination
- bore separation to determine hydraulic gradient.

Well locations and completion depths must be selected to ensure that all probable petroleum hydrocarbon flow paths are monitored. A minimum of three monitoring wells per site is typical; the actual appropriate number of wells will depend on the conceptual model. A minimum of three spatially-distributed wells are necessary to determine flow direction and hydraulic gradient.

Sampling points may be located around the perimeter of the tank, pipe, or other potential sources of contamination or wherever the greatest probability of petroleum hydrocarbons exists. If petroleum hydrocarbons or a release are discovered, the sampling plan may need to be modified to include additional sampling points to determine the extent of the contamination. If potential sources of petroleum contamination exist upgradient of a site, it may be desirable to install a monitoring well to monitor the quality of water entering the site.

Groundwater contaminant concentrations vary over time in response to rainfall, and other seasonal changes. Groundwater from monitoring wells must be sampled periodically to provide sufficient data to obtain an accurate picture of the groundwater quality. For example, a spill during winter may create a smear zone which is stranded above the water table in summer. Summer sampling may fail to identify the magnitude of the contamination, whereas sampling after rainfall or in winter might present a worst-case scenario.

Quarterly or semi-annual sampling for the first year from the monitoring wells would typically provide sufficient data to develop a baseline of the nature of the contamination. Seasonal fluctuations in groundwater levels can affect contaminant concentrations. Less sampling may be acceptable, depending on whether hydrocarbons are detected. In some situations, particularly where groundwater is used as a drinking-water supply, more frequent monitoring may be required. Annual sampling after the first year is recommended until contaminant concentrations on- or off-site reach acceptable levels to assess the effectiveness of the site management or remediation option(s). Groundwater levels should be measured whenever groundwater quality samples are collected.

3.3.2.2 Type of analyses

The types of analyses to be performed on groundwater samples collected at petroleum-contaminated sites are based on the product type and are summarised in Table 3.4. The results from these analyses are needed to perform the risk-based evaluations discussed in Modules 4-6. Tests for total petroleum hydrocarbons (TPH) can also be performed on the groundwater samples as a gross indicator of fuel contamination. The TPH analytical method can be used to obtain a chromatographic boiling point distribution of the petroleum hydrocarbons in the sample to characterise the type of hydrocarbon product present. This fingerprint can be very helpful in tracing spills from multiple sources. See the OIEWG sampling protocols (available from the Ministry's web site www.mfe.govt.nz/issues/contam.htm) for more information.

Table 3.4: Recommended laboratory analyses for groundwater samples

Suspected Source	Parameter	Method
Petrol Aviation fuel Light-end petroleum fractions	AVOCs	Refer to sampling and analytical guidelines document
Diesel Kerosene Middle distillates	AVOCs PAHs	Refer to sampling and analytical guidelines document
Heavy-end petroleum fractions Bunker fuels Residual fuels Crude oil	PAHs	Refer to sampling and analytical guidelines document

AVOCs = aromatic volatile organic compounds (e.g. BTEX)
PAHs = polynuclear aromatic hydrocarbons

3.4 Field investigation techniques

This section describes the most common field investigation techniques used to characterise a site potentially impacted by petroleum hydrocarbons. These techniques include soil gas surveys, test pits, boreholes, and groundwater monitoring wells.

Prior to initiating any field investigation, health and safety issues must be considered. Typical health and safety issues found at petroleum sites are discussed in Section 3.4.1. Soil gas surveys, test pits, boreholes, and installation of monitoring wells are described in Sections 3.4.2 through 3.4.5 respectively.

3.4.1 Health and safety issues

Under the Health and Safety in Employment Act 1992, a place of work must be investigated to identify the hazards present, these hazards must be assessed for their significance, and those identified as significant must be eliminated, isolated or minimised as appropriate. Existing documentation regarding safety practices, such as oil industry hot work and confined space permitting procedures and the codes of practice for petroleum sites, should be reviewed thoroughly before investigating site contamination.

A hazard which may be encountered at petroleum hydrocarbon contaminated sites during field investigations is the build-up of explosive levels of gases and vapours in boreholes, test pits or structures. Specific control measures must be applied to minimise these hazards. Hence welding must be strictly prohibited on site. Casings for boreholes should be prepared off-site and, for shallow holes, casings should be removed by winching or jacks without the need for cutting. In no circumstances should welding or cutting be carried out in an operating service station. If such work is absolutely necessary the pumps must be closed and special precautions must be taken. All ignition sources (e.g. sparks from concrete cutters etc.) should be maintained at least 8 metres away from any operating pumps.

Entry into a pit or other confined space at a petroleum hydrocarbon contaminated site may be especially hazardous since, if no remedial measures have been taken, the build-up of hydrocarbon vapours within the space can reach levels within the explosive range, and may easily exceed levels which represent a significant toxicity hazard. In addition the vapours, which are heavier than air, will displace the air and may give rise to an atmosphere within the space which is significantly deficient in oxygen. There is also the potential for pit walls to collapse affecting the safety of workers and the integrity of nearby structures.

To avoid health and safety risks the space should be thoroughly ventilated before a worker enters. Oxygen and hydrocarbon vapour levels should be monitored using appropriate equipment, and the entering worker should be continuously observed by a second worker stationed outside the space. Under certain conditions, microbial generation of methane and carbon dioxide may also cause a safety hazard on a site. Hydrogen sulphide may also be an issue at some sites. Full protective clothing should be worn by the entering worker. A work permit may be required from the site owner to perform welding at a site.

3.4.2 Soil gas surveys

Soil gas surveys can be a useful tool in determining the spread of volatile organic compounds (VOCs) resulting from hydrocarbon spills or leaks. They are generally undertaken as a preliminary screening tool to identify potential hot spots of soil contamination and free product to assist in the design of a detailed investigation using trenches or boreholes and monitoring wells. Soil gas survey results provide a relative measure of contamination at a site. Before conducting any soil gas survey, the user must have knowledge of the subsurface lithology.

The process involves driving a hollow spike, or otherwise creating a hole through which gases can pass, and drawing the soil gas to the surface where it is passed through a measuring device. Sampling depth is limited by the ability to drive a stake into the ground and is normally 1-2 metres. The sampling technologies typically used to measure organic vapours are:

- portable PIDs (photoionisation detectors) and FIDs (flame ionisation detectors
- portable gas chromatograph
- gas detection tubes (such as Draeger tubes).

It is important to carry out field checks and recalibration while these instruments are in use.

Soil gas surveys are best suited to light hydrocarbon products in shallow soils that contain principally volatile compounds (such as petrol). It is also a requirement that the underlying strata are relatively permeable. The survey is also most appropriate where a shallow water table exists. Interpretation of the results tends to be complicated where contamination at depth is suspected, where historic or multiple spills have occurred, and where relatively heterogeneous/impermeable strata are present. Caution should be taken due to the possibility of false positives with soil gas surveys.

Where soil gas surveys are undertaken the initial grid spacing between holes should be 3-10 metres depending on the size of the site and the nature of the underlying strata. The grid spacing should be reduced near sample locations that show evidence of hydrocarbon vapours to provide more definitive data for drawing isoconcentration contours of the results.

3.4.3 Test pits

Test pits are holes excavated using a mechanical digger such as a backhoe or excavator for the purpose of obtaining soil samples. Test pits are used for near-surface soil sampling to enable site contamination to be characterised. Test pits have the advantage that they enable a full appreciation of ground conditions throughout the vertical extent of the excavation. If contamination is encountered, it can be more easily and cost effectively traced using an excavator than a drilling rig by extending the hole or relocating to a nearby position.

Disadvantages include:

- The depth of the pit is limited to the reach of the mechanical excavator being used.

- Monitoring wells can not be easily installed.
- Large areas are required for the digger, hole and excavated soil, which restricts use at most service station sites.
- Adequate recompaction of backfill is required.
- The expense of replacing forecourts can be prohibitive.

Factors to consider when choosing an excavator include the reach of the excavator arm, the size of bucket available, whether the machine is track or wheel mounted, and whether the buckets can be changed using a quick-release system.

3.4.4 Boreholes

Boreholes are used for soil sampling where test pit excavations cannot be made and where monitoring wells may also be installed. Various drilling methods are available for drilling boreholes and collecting samples. The choice of drilling method is typically made based on depth of bore, type of geology likely to be encountered, and number of samples to be collected during drilling.

On sites covered by concrete paving, drilling should be preceded by concrete coring of a size to accommodate both drilling activities and subsequent well completion, including installation of wellhead protectors. To prevent the fallback of cuttings into the hole, accumulated drill cuttings should be removed from the borehead area as drilling progresses. For open-hole drilling methods, a short length of casing should be installed at the surface to minimise fallback.

Material handling and quality control measures should be directed towards clean drilling conditions and the elimination of down-hole contamination as a result of drilling operations. Specific quality control measures for machine drilling are as follows:

- The drilling rig to be used should be in sound working order and free of oil leaks and cleaned prior to arriving at the site.
- A cleaning pad should be established on the site where the drilling rig and other large equipment can be cleaned without risk of contamination to sampling locations. Power and water are needed nearby to allow use of a steam-clean unit.
- All drilling equipment should be cleaned between boreholes.

All drill cuttings should be properly disposed of. If the soil is obviously stained then it should be sent to a landfill or local treatment facility. If the soil is relatively clean it can be backfilled. Care should be taken to prevent cross-contamination between confining layers. Grouting holes that pierce through confining layers are recommended to reinstate the integrity of the confining layer.

Logs of the soil encountered should be prepared on standard borehole log sheets. The soil should be logged using the Unified Method of Classification and Standard Abbreviations from the New Zealand Geomechanics Society *Guidelines* (1988). Drilling methods are described below. Soil classification is discussed in Section 3.4.5.

3.4.1 Hand auger

Hand-held or motor driven augers are comprised of an auger head on a metal shaft. This is manually or mechanically turned to advance the head into the ground. Soil collects in the auger head, which must be frequently withdrawn to remove the soil to allow the auger to advance. Soil samples can be collected from the soil that has collected in the augerhead or a split-spoon type sampler can be advanced into the ground.

Bores should be advanced at a larger diameter than the sampling auger so that a temporary PVC casing can be placed in the hole and the base of the bore should be cleared before sampling. Further advance is then made by removing the casing and augering out the larger diameter.

Advantages	Light, portable and inexpensive to operate. Enables soil samples to be taken and the sediment or rock to be accurately identified. Small diameter monitoring wells can be installed.
Disadvantages	Limited as to soil type and depth. Cannot be used in gravel, rock or fill material which contains solid objects or other obstructions. Suitable only for stiff sands, clays or similar fine-grained, homogeneous material. Not suitable where collapse is likely, e.g. in running sands. Labour intensive.

3.4.4.2 Continuous flight auger

A continuous flight auger is comprised of a shaft with a continuous screw. The screw advances into the ground and passes the disturbed soil up the outside of the screw to the surface. A split-spoon type sampler that can be advanced into the ground is the preferred method of collecting samples. However, soil samples can be collected from the soil that has been advanced to the surface. As with hand augering, a temporary casing can be installed during sampling.

Advantages	Quick and cost effective for shallow holes in suitable soils. Can be used to install monitoring wells provided the stratum is stable below the water table.
Disadvantages	Difficult to obtain a representative sample if a split-spoon type sampler is not used. Cannot penetrate large boulders or hard rock. Cross-contamination (due to smearing and fallback) is possible even if the auger is withdrawn from the hole and a split-spoon type sampler used. Not generally suitable for well installation in unconsolidated sediments beneath the water table due to bore collapse when the auger is withdrawn. Suitability for sampling at depth is limited to very stable ground conditions.

3.4.4.3 Hollow stem auger

Hollow stem auger (HSA) method is the preferred drilling method. The auger flight is fixed to a hollow tube or stem. The drilling augers are rotated and advanced using drill rods and a bit which is connected to the centre plug. This plug is inserted into the hollow centre of the cutterhead to prevent soil from coming up inside the auger. As the auger rotates, material being removed by the drilling bit is carried by the flights to the surface via the annular space between the wall of the borehole and the exterior auger wall. Either split-spoon type samplers or core-barrel samplers can be used to collect soil samples from inside the hollow stem.

Advantages	Extraneous material (such as air or mud) is not introduced into the formation. Facilitates accurate formation logging and identification of water bearing zones. Minimises well development requirements and facilitates collection of samples for geotechnical analysis.

Disadvantages	Not suitable for use where gravels or hard rock are likely to be encountered. Limited drilling depth.

3.4.4.4 Air rotary drilling

Air rotary drilling is accomplished by rotating a cutting bit into the ground at the end of a length of drill pipe. The air escaping through orifices on the drill bit carries the cuttings to the surface via the annular space between the wall of the borehole and the drill pipe. Air used for drilling should be filtered to remove compressor oil. Air rotary drilling allows fairly accurate logging and identification of water bearing zones and minimises well development requirements. Either split-spoon type samplers or core-barrel samplers can be used to collect soil samples and lithologically log the borehole.

Advantages	Fast in consolidated and semi-consolidated rock. Facilitates fairly accurate formation logging and identification of water bearing zones when split-spoon type samplers are used. Minimises well development requirements and facilitates collection of samples for geotechnical analysis.
Disadvantages	Representative samples difficult to take because of introduction of air. Cannot penetrate fine-grained cohesive material without the addition of water. May present a health risk from dust and vapours in highly contaminated ground. The size of the rigs may prevent access at some sites.

3.4.4.5 Mud rotary drilling

Mud rotary drilling is accomplished in much the same way as air rotary drilling, except mud is used to carry cuttings to the surface rather than air. The use of mud should generally be avoided. This method does not allow accurate logging and identification of water-bearing zones or sampling for geotechnical analysis. Drilling mud should be mixed in portable mud tubs and should be composed entirely of pure bentonite. The mud should not contain any polymer additives or chemical constituents which may interfere with the chemical analyses to be completed at the site.

Advantages	Good for deep holes. Suitable for clay, silt, compacted sand and silt, and soft rock.
Disadvantages	Possible smearing of bore walls with mud or other drilling fluid reducing permeability and possibly requiring extensive development. Mud may interfere with water quality samples and invade permeable zones in the strata. Expensive.

3.4.4.6 Driven well

A steel casing is driven into the ground. When the desired depth is reached a well is installed and the casing withdrawn. Alternatively the casing is left in the ground.

Advantages	Inexpensive and widely available.
Disadvantages	Soil sample recovery not possible. The casing can obscure changes in strata and water-bearing zones. Suitable for unconsolidated soils only; boulders and bedrock cannot be penetrated. Can be slow.

3.4.4.7 Cable tool (shell and auger)

In this system an open-ended steel shell is driven into the ground and retracted when full. Samples are taken using a sampling cone which is fitted in place of the shell once the required depth is reached.

Advantages	Cable tool drilling is suitable for all soil types and can be used for almost any depth and size. Monitoring wells can be easily installed. Enables recovery of undisturbed samples.
Disadvantages	This is a slow drilling method and can be expensive compared to other methods.

3.4.5 Soil classification

Logging of soils must follow a consistent methodology and format to reduce the subjective nature and widely varying content of descriptions. In part, this arises from the numerous different systems brought to the multi-disciplinary field of site assessment. Engineering, geological and soil science disciplines have different emphases, and accordingly, there are different strengths and weaknesses associated with these approaches.

The most widely used soil classification system in New Zealand is that outlined in the New Zealand Geomechanics Society's 1988 "*Guidelines for the Field Description of Soils and Rocks in Engineering Use*". This system is based on use of a standard series of soil descriptors. Soil grain size distribution is described with the use of proportional terms for particle size ranges as a percentage of the soil mass. It also includes the Unified Soil Symbols reflecting the dominant soil type and the properties of grading. For consistency, it is recommended that the terminology set out in these guidelines is adopted for all site assessment work.

A more detailed system for graphically representing soil conditions is contained in the New Zealand Geological Survey 1982 report "*Revised Guide to Recording Field Observations in Sedimentary Sequences*". This system has standard bore log symbols for a comprehensive range of soil types and should be used as the standard guide to recording observations on the graphic representation column of bore logs.

3.4.6 Groundwater monitoring wells

Groundwater monitoring wells are typically constructed of 32, 50 or 100 mm, Class D polyvinyl chloride (PVC) with 3-5 metres screen intervals, as shown in Figures 3.2 and 3.3. Conventional solvent glues should not be used because they could introduce chemicals into the water and would affect interpretation of sampling results. Instead, mechanical screw fittings should be used on all casing and screen joints. If necessary, screen and casing should be adequately cleaned to remove trace contaminants.

Screen lengths and slot size should be determined on site, under the supervision of a qualified hydrogeologist, after drilling has established the location of the water-bearing zone. Slot sizes should be selected based on the geology at the site. The slots should be small enough to prevent subsurface material from entering the well yet large enough to not impede groundwater or product flow. In general, a nominal slot width of 0.5 mm with two rows of slots per screen length and average spacing of 5 mm and between slots is adequate. The slots should be machined and the machined cuttings removed before the screen is employed. A minimum of 0.5 metres of unslotted casing with a well-end cap should be provided below each screen, to act as a sump for collection of any fines that may pass through the screens.

The top of the screen should be placed between 1.0 and 1.5 metres above the water table as logged during drilling or at the discretion of the field engineer/geologist where the depth to groundwater is less than 2.0 metres. The intention is to identify the presence of any floating product and allow for seasonal fluctuations of the water table level. There should be at least 1.5 metres of standing water in the well at all times.

Following screen and casing installation, graded sand (generally in the 1-4 mm range, depending on soil type) should be placed around the screen and to a height of approximately 200 mm above the uppermost screen slots. Sand filter material should be pre-washed and screened to eliminate foreign material. A clean pipe must be used for deep holes to ensure correct placement of the sand.

A layer of filter cloth or fine sand should be installed between the filter pack and the bentonite seal to prevent vertical bentonite intrusion into the gravel pack. The bentonite seal should be placed directly above the filter pack and should extend for a minimum thickness of 300mm or as dictated by soil conditions. Final levels of both screen filter packs and bentonite seals should be verified by direct measurement using a slimline probe lowered down the annular space between borehole wall and casing.

Holes should be backfilled or grouted above the bentonite seals to approximately 250mm below ground level. The final completion at the surface should comprise a concrete collar seal and protective covers to provide security of the well and prevent accidental damage. The wells should be equipped with lockable covers. Where vehicular traffic poses a problem, the installation should be fitted flush with the ground surface using a toby cover for protection. In this event, a sump should be provided around the top of the casing to allow build up of drainage water around the borehead to be purged before opening the bore. Generalised design drawings are provided in Figures 3.2 and 3.3.

3.4.6.1 Pitfalls to monitoring well design

Possible problems to be avoided with well design and installation are:

- insufficient depth so that water and product are not encountered throughout the year, or adequate samples cannot be recovered
- screen placement at the wrong depth to supply the required information (e.g. screen too low so that floating product is excluded)
- use of hand-slotted screens with insufficient slot coverage to detect floating product
- use of filter packs or filter fabrics which reduce hydrocarbon movement into the well
- use of monitoring well materials which might absorb contaminants or release contaminants into the groundwater (e.g. PVC solvent glues)
- cross-contamination of otherwise clean strata or aquifers through poor bore construction and/or penetration of confining layers
- poor surface sealing at the bore head so that contaminants enter the bore from the surface
- consideration should be given to stratification of contamination within groundwater

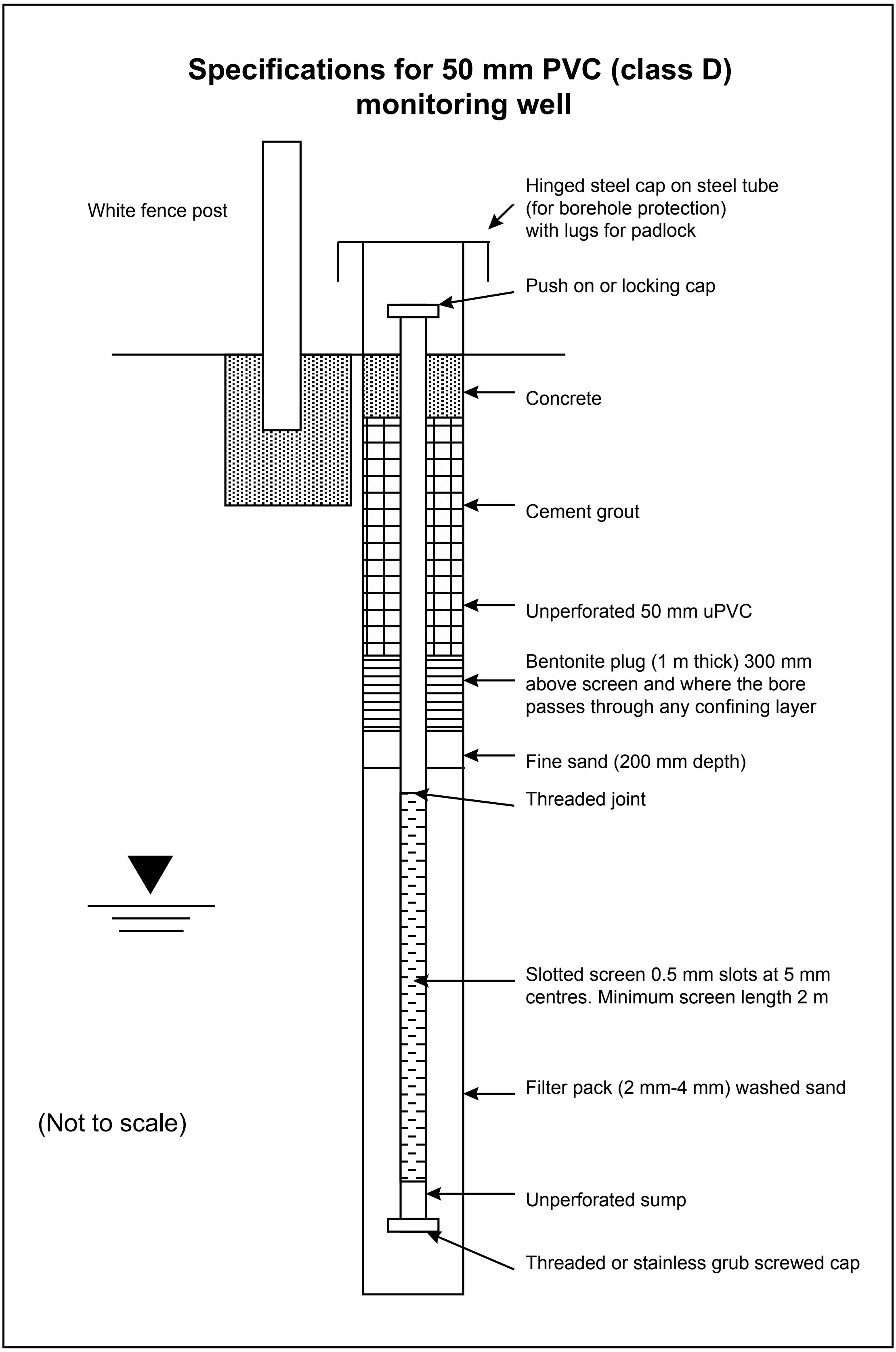


Figure 3.2 **Details of monitoring well**

Specifications for 50 mm PVC (class D) monitoring well with toby box and road cover

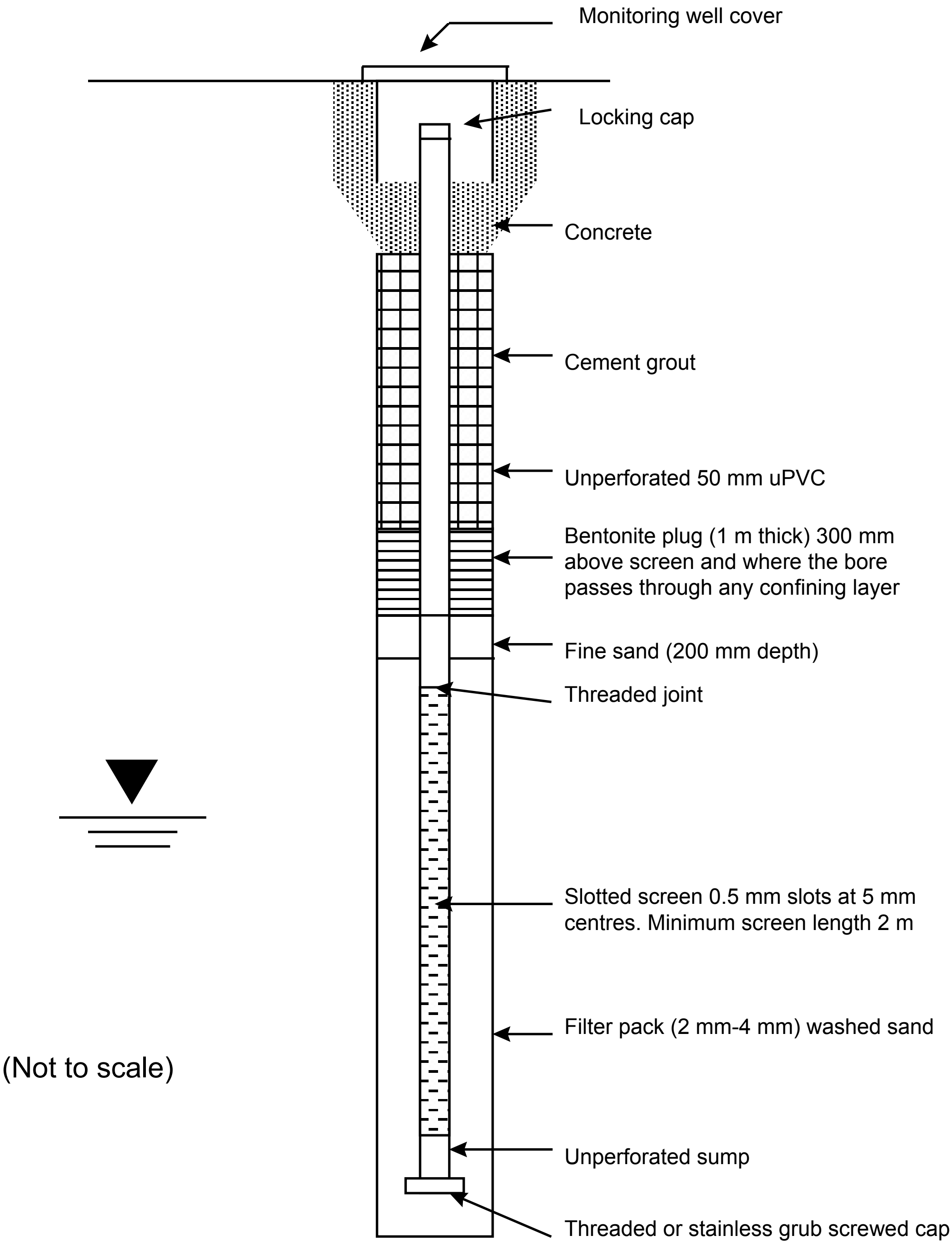


Figure 3.3 **Details of monitoring well with toby and road cover**

3.4.6.2 Well development and aquifer testing

Well development is necessary after drilling and installation to remove sediment disturbed by the drilling rig. A number of well development methods are available:

- surging with bailer or surge block
- compressed air pumping with gentle surging
- bailing
- pumping
- combinations of the above.

Provision must be made for disposal of development water. In general, the water is relatively clean and can be discharged to the ground. If free-phase product is present, the water must be collected and properly disposed in accordance with local regulations and practices. Any monitoring well with free product must be developed carefully to prevent product being drawn down into the gravel screen and affecting subsequent water sampling. Product should be bailed-off prior to any significant draw down of water level during development.

Adequate development must be verified on the basis of stabilisation of basic water chemistry parameters including electrical conductivity, pH, temperature, and turbidity. Records of development must be maintained. Effectiveness of development should be checked by measuring total bore depth before and after pumping. Additional development or rehabilitation may be required if substantial sediment enters the borehole, sump or screen areas.

On completion of development pumping, water levels may be in a depressed condition in the borehole. The groundwater recovery should be monitored with the rate of water level rise recorded against time. The pumping time and recovery data can be used to estimate hydraulics conductivity.

After the well has been developed, aquifer testing can be performed to evaluate aquifer parameters such as hydraulic conductivity and flow velocity. The general principal of aquifer testing is to remove water from a well and monitor and record the rate of water level decrease or rise with time in that well and nearby wells.

Slug tests are the least expensive aquifer testing method but are limited to zones with low to moderate transmissivity. Slug testing involves introducing or removing a slug of known volume into a well and recording the water level changes that result from either the instantaneous insertion or instantaneous withdrawal of the slug. The rate of recovery observed in the well is a function of the hydraulic properties of the aquifer and of the well itself. The transmissivity of the aquifer can then be estimated using appropriate well-flow equations.

Slug tests stress only a small portion of the aquifer adjacent to the well, and therefore, slug tests are incapable of evaluating hydrogeologic boundary conditions, hydraulic anisotropy, storage coefficients, and pumping characteristics of the well. However, slug tests commonly provide a cost-effective means of gathering point hydraulic conductivities across a large area. Slug tests are commonly considered as a first step in characterising an aquifer because of the relative low cost and effort requirements. Additionally, slug tests do not generate large volumes of groundwater. Therefore, the method is often used to initially characterise water-bearing zones beneath hazardous waste sites, where disposal options of contaminated groundwater may be limited or costly.

Pumping tests are most feasible for relatively high transmissivity zones, such as alluvial sand and gravel aquifers, or extensively fractured aquifers unless low discharge pumps (e.g. Grundfos) are available. In these types of aquifers, a long-term pumping test is the most accurate means of evaluating aquifer properties, and for evaluating other hydrogeologic factors such as boundary conditions, heterogeneity and anisotropy.

Several different types of pumping tests can be conducted to determine aquifer properties, although the fundamental principles of all tests remains similar. The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring draw down as a function of time in the pumping well and/or observation wells or piezometers at known distances from the well. These measurements are then incorporated into an appropriate well-flow equation to calculate the hydraulic characteristics of the aquifer and pumping well.

Numerous different types of pumping tests and well-flow equations exist that may be implemented for nearly all hydrogeologic settings. The overall approach for each test, including capabilities, limitations and assumptions are described below.

Step test involves pumping from a single well at a relatively low flow rate until draw down has stabilised. The pumping rate is then increased to a higher discharge rate until drawdown once again stabilises. This procedure is continued for at least three separate flow rates. Each flow rate is typically 20-40% greater than the previous rate, with a duration of typically 30 minutes to 120 minutes (Kruseman and de Ridder, 1991; Driscoll, 1986) per test.

In general, step tests are relatively short duration tests that are capable of providing general well performance characteristics and aquifer transmissivity and storativity in the vicinity of the pumping well. A step-test provides specific capacity data, and therefore should always be conducted prior to a long-term pumping test if no previous pumping data for the well exist. Step-tests are generally considered less effective for determining hydraulic anisotropy, leakage between layers, boundary conditions, and recharge areas than long-term pumping tests.

Constant discharge pumping test involves pumping from a well at a continuous, known, constant discharge rate over an extended period of time. This type of test typically involves monitoring draw down in several observation wells or piezometers, although the test may also be performed as a single-well test. Long-term, constant discharge pumping tests are the most accurate means of evaluating aquifer hydraulic properties. If properly designed and conducted, these tests can evaluate the following aquifer hydraulic characteristics: hydraulic transmissivity, storativity, hydraulic anisotropy, leakage from overlying or underlying layers, boundary effects, recharge areas, etc. Additionally, well performance characteristics such as well capacity, well yield, and well efficiency may be determined.

Recovery test should generally accompany a constant discharge tests and step tests. A recovery test measures the residual drawdown (s) following the pumping test. The recovery test provides the data required to calculate the transmissivity of the aquifer, thus providing an independent check on the results of the pumping test while costing very little in terms of the total cost of the pumping test (Freeze and Cherry, 1979; Kruseman and de Ridder, 1991). A recovery test is invaluable if the pumping test is performed without the use of piezometers or observation wells to evaluate potential borehole storage effects of the pumping well. Additionally, residual draw-downs are more reliable than draw downs measured during pumping, due to difficulties in the field of maintaining absolutely constant discharge from a pumping well (i.e., all pumps have a level of discharge variability).

3.5 Sampling methodology and protocols

This section discusses specific procedures for collecting soil, groundwater, surface water, sediment, and drain samples. Sample handling, identification, preservation, packaging, and shipping are also discussed. The OIEWG has prepared "*Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water*" (available from the Ministry's web site www.mfe.govt.nz/issues/contam.htm). It contains further detailed information to that presented in this section and will be updated regularly. Refer to it for the latest information.

Sampling involves a number of common elements regardless of whether soil or water is being collected. The main steps in a sampling event are as follows:

- the sampling area is isolated to minimise potential for cross-contamination
- sampling equipment arrives at the site clean and wrapped
- samples are collected in a manner which minimises risks of cross-contamination
- samples are placed in containers and labelled
- samples are placed in cool storage
- quality assurance samples are collected
- samples are transferred with documentation to the laboratory.

3.5.1 Sampling area preparation

The area around the sampling location may be subject to surface contamination or cross-contamination from dust liberated during the investigation. It is necessary to establish an area on which sampling equipment and containers can be placed without risk of contamination. This is generally achieved by placing a clean plastic sheet on the ground, a table or the tailgate of a vehicle.

In addition to keeping an area clean for sample handling, the following sample collection procedures should be observed:

- All sampling equipment should be cleaned prior to obtaining each sample.
- Field personnel should wear clean PVC/latex gloves whilst handling sampling equipment and whilst taking samples.
- A clean pair of gloves should be used for each sample.
- Care should be taken when sampling to avoid any opportunity for excess aeration of the sample.
- Sampling equipment must be operated in a manner which avoids stirring up sediment.
- All organic samples should be well sealed using aluminium foil or Teflon.
- Water samples for VOCs analyses (i.e. hydrocarbons or BTEX) should be filled.according to laboratory specifications. The bottle should be inverted and gently tapped - if any air bubbles are present, the sample must be recollected.
- If free product is present, a sample of water with floating product should be collected for possible fingerprint analysis. Another sample, free of any product can be collected to assess levels of dissolved hydrocarbons. The water sample should be collected by floating off any

bubbles or product sheen. If the water sample has a sheen, this must be noted on the chain-of-custody and in the field book since such samples can only be of indicative value.

- During groundwater sampling the temperature, pH, turbidity, and electrical conductivity of each sample should be recorded.
- Each sample container should be labelled as outlined in Section 3.5.7. Sampling details and other pertinent data should be recorded.
- All samples should be kept under 4°C in iced chilly bins. Samples should be dispatched to the laboratory for analysis on the day of sampling.
- Chain-of-custody documentation should be completed for each sample.

3.5.2 Soil sampling procedures

During sampling, subsurface conditions encountered at every borehole, test pit or auger hole should be logged on field log sheets. Depths should be referred to the ground surface. Unusual or unexpected subsurface conditions such as the presence of perched groundwater or odours should be recorded on the log sheets or in the field log book where relevant. Recorded data for the drilling component should adhere to standard borehole logging.

The borehole/test pit numbering system adopted should conform with that specified in the sampling plan. Every soil sample should be collected, labelled and documented in the manner described in Section 3.5.7.

3.5.2.1 Soil sampling by machine excavator

Where a backhoe is used to recover soil samples the following precautions should apply:

- The backhoe should be in good condition and free of oil or hydraulic fluid leaks.
- The backhoe bucket and boom should be steam cleaned prior to each test pit and at the end of each day's work, ensuring residual grease and oil is removed.
- Following excavation to the target depth, all loose dirt should be removed from the backhoe bucket and a sample representative of the material at the target depth should be recovered using the backhoe.
- A sample should be recovered from the backhoe bucket using a cleaned sample spoon or trowel, taking care to select material that has not contacted the sides of the bucket. The sample should be placed in a clean glass jar with a foil or Teflon-lined cap.
- All holes should be backfilled and reinstated as nearly as possible to original condition.

3.5.2.2 Soil sampling by hand auger

Soil sampling procedures specific to hand auguring are as follows:

- All auger parts should be pre-cleaned and wrapped in aluminium foil until used.
- Care should be taken to select material such that the possibility for cross-contamination is minimised.
- All equipment should be cleaned between each sample point.
- All holes should be backfilled and reinstated as close as possible to original condition.

3.5.2.3 Soil sampling by drilling

Soil sampling procedures specific to drilling are as follows:

- The drill string should be steam cleaned before starting each borehole.
- All sampling equipment should be cleaned before getting each sample.
- Samples should be recovered by driving a split-spoon type sampler into undisturbed material.
- All field staff should change to a clean pair of gloves before handling each sample.
- Where monitoring wells are not required, boreholes should be sealed with cement grout at the completion of the drilling.

3.5.3 Groundwater sampling from monitoring wells

The following measurements should be taken prior to sample collection:

- standing water level
- total depth of the well
- depth to the top of floating product.

Water and product levels should be measured from the lip of the standpipe or well cover. The reference point should be noted and surveyed to a relative datum.

After determination of water levels in all wells on site, sampling can begin. The method of purging a well prior to sampling has received a great deal of attention in the United States. Numerous studies have been performed to determine the need for purging. A report prepared for the Western States Petroleum Association (WSPA) by SECOR International Incorporated (1996) states that "... data analysis indicates that the degree of variability introduced into the sampling process by the absence of purging is no larger than, and in many cases, much smaller than, the variability introduced by the choice of purging method."

If purging is to take place, then two types of purging methods are typically used: micro-purging and macro-purging. In macro-purging, at least three bore volumes of water are removed from the monitoring well. Purging the well removes any stagnant water or water which is not representative of the aquifer. For micro-purging, a low-flow pump is placed at the sampling depth and water is drawn from the well at a specific location.

For each purging method, temperature, electrical conductivity, pH, and turbidity should be monitored. Purging should continue until these parameters stabilise. Records of temperature, electrical conductivity, pH, and turbidity measurements should be maintained. The well should be allowed to recharge to at least 80% before collecting a sample.

Samples should be collected after macro-purging with a suitable sampling device (e.g. a stainless steel or Teflon downhole bailer, dedicated disposable bailer, or a low-flow pump). The low-flow pump is typically used to collect the water sample using the micro-purge method. Additional requirements are as follows:

- A low pump rate should be used for purging to reduce mobilisation of sediment.
- The bailer or pump should be lowered gently to avoid disturbance of any sediment that may still be in the bore and to avoid damage to the bailer or the rope.
- Samples should be recovered from the slotted section of the standpipe.

- Care should be taken when sampling to avoid aerating the sample.
- The sample should be transferred directly from the sample device to the sample containers.
- As the bailer or pump is removed from the well, care should be taken to place the rope or pump leads on a plastic sheet or other means of keeping them clean.

If product is present in the groundwater sample, the analytical results are considered biased and should only be used for indication. These results should not be used in the risk analysis.

3.5.4 Surface water sampling procedures

Observations of surface water flow, substrate, aquatic life, staining, odour and recent weather must be recorded in the field book and referenced to each sampling location. Samples should be recovered from the surface water body at locations designated in the sampling plan. Surface water samples should be recovered from below the water surface to prevent accidental sampling of surface slicks. A suitable sampling device, able to recover samples from a designated depth and prevent ingress of surface water, should be employed. Such devices are readily available. If possible, the sample should be taken directly into the sample container prepared by the laboratory. Surface slicks should be noted and sampled separately.

Care must be taken when sampling to avoid aerating the sample. Additional requirements are as follows:

- Observations such as river gauge levels, colour etc. and particularly how the sample relates to the general stream or drain bed must be recorded in the field book.
- Samples should be collected in an upstream direction to avoid disturbance of sediment which might affect downstream samples.
- Where sample bottles contain a preservative, surface water samples should be collected in a suitable container and transferred to the preserved sample container.
- Each sample collected should be recorded on a sample collection record form.
- Sample containers which have been immersed in water to collect samples shall be placed in clean polyethylene bags to minimise the potential for cross-contamination.

3.5.5 Drain sampling procedures

Water samples may be collected from drains across the site, as designated in the sampling plan, using a stainless steel bailer, stainless steel sampling container or glass jar. Sampling of drains may require field personnel to enter manholes in order to recover the samples. Appropriate confined space procedures should be followed when entering manholes:

- Samples should be collected progressively in an upstream direction to avoid disturbance of sediment which might affect downstream samples.
- The sampling equipment should be lowered gently to avoid disturbance of any sediment.
- Where sample bottles contain preservatives, water samples should be collected in a suitable container and transferred to the preserved container.
- Each sample collected should be recorded on a sample collection record form.

- Sample containers which have been immersed in water to collect samples should be placed in clean polyethylene bags to minimise the potential for cross-contamination.

3.5.6 Sediment sampling procedures

Sediment samples are typically collected from the finest fraction of the stream or lake sediment load, unless sampling objectives suggest other locations. Additional requirements are as follows:

- Observations such as river gauge levels, colour, etc. and particularly how the sample relates to the general stream, lake, or drain bed must be recorded in the field book..
- Sediment samples should be obtained using a grab sampler or other suitable device.
- Sampling should commence at the furthest downstream location working back upstream.

3.5.7 Sample identification, packaging, preservation, shipping, and documentation

This section outlines specific procedures for identifying, packaging, preserving, and shipping soil and water samples.

3.5.7.1 Sample identification

Each sample should either be individually labelled at the time of collection using waterproof, indelible ink or pre-labelled by laboratory personnel. If pre-labelled, pre-preserved sample bottles are provided by the laboratory for specific analyses, other pertinent information should be added to the label at the time of collection. Self-adhesive labels should be securely affixed to the sample container not to sample lid or cap. Sample's identification should be written on the cap in indelible ink in case the label comes off. Using tags or any type of labelling which can be accidentally separated from the sample should be avoided.

Each sample label should include the following information:

- site name
- sample ID code or number (which should also be recorded on the lid)
- name of sample collector
- date and time of collection (this starts the holding time clock)
- depth of sample
- preservatives used (or absence of any preservatives)
- analyses requested.

A single sample may not be sufficient for multiple analyses since different analyses may require different preservatives and/or different sample containers.

3.5.7.2 Sampling packaging and preservation

The analytical methods guideline presents information regarding sample volumes, size and type of sample containers, preservatives, and holding times required. In most cases, preservation includes refrigeration of the sample (4ºC) from the time of sampling to laboratory analyses.

As a general rule of thumb, unless the cohesive-sample soil core method of sampling is used, volatile constituents (for example, BTEX, and TPH) usually require a separate sample container from the sample container used for semi-volatiles and metals analyses. Care must be taken to prevent water-containing samples from freezing because this can cause degassing, fracturing of the sample or separation of a slightly immiscible phase. Preservatives should be prepared in the laboratory using reagent grade chemicals and distilled water and stored in tightly sealed containers, away from sources of contamination. If sample containers are not pre-preserved in the laboratory, aqueous preservatives can be taken to the field in small dropper bottles to facilitate field preservation procedures.

3.5.7.2 Shipping

Samples should be properly labelled, recorded on the chain-of-custody form and shipped to the laboratory as soon as possible (usually daily). Care should be taken to preserve the integrity of the samples in transport by keeping them cool (4°C). This may be accomplished with the use of reusable frozen gels designed to maintain a cool temperature or bags of ice. Letting samples sit in the hot sun or car for several days seriously compromises analytical data. Again, care must be taken to prevent water-containing samples from freezing because this can cause degassing, fracturing of the sample or separation of a slightly immiscible phase.

Samples should be packaged in a proper shipping container to avoid leakage, breakage or contamination. Acceptable packing materials include polyurethane chips, vermiculite, plastic bubble wrap and sawdust. As an extra precaution, volatile sample containers can be doubled-wrapped in plastic bags to prevent cross-contamination. All samples should be accompanied by a sample analysis request/chain-of-custody record.

The forwarding and return addresses, along with phone numbers, should be written legibly in waterproof ink. The receiving laboratory should be notified of the expected date of arrival of the samples. In this way, if the samples are not received in a reasonable length of time, the sender can be notified so that samples lost in transit can be traced expediently. The analytical laboratory should notify the project contact of any samples not received intact.

3.5.7.4 Field documentation

A field log book should be maintained by field personnel. The log book should be used to record general progress, any deviation from the sampling and analysis plan, changed conditions, any health and safety incidents, and any other notable observations. Other notable observations might include the presence of perched groundwater, or odours or significant PID readings.

All sampling areas should be located with reference to the site plan and by measuring distances from permanent features identified on the site plan. All sampling areas should be referenced by a location number. A record of all sampling locations should be kept and recorded on a base map.

A record of samples collected should be kept by the field supervisor. This record should incorporate at least the following information:

- job number
- sampling location number
- sample number
- sample depth
- date.

Each sample should be labelled with the same information, correlating directly with the record of sampling to be kept by the field supervisor.

A chain-of-custody record is required for all samples. Its purpose is to trace sample possession from the time of collection through analyses. The following information should be included in a chain-of-custody record as a minimum:

- sample identification numbers which can be referenced to specific sampling points and times
- name or number of the sample collector
- sample collector's signature
- date and time of collection
- location of site
- sample type
- analyses requested (if chain-of-custody form is also used as Analysis Request form)
- signatures of persons involved in the chain of custody (sampler, transporter, laboratory personnel who accept the sample)
- dates of sample possession (when relinquished, when accepted).

3.6 Data quality objectives

The purpose of data quality objectives (DQOs) is to guide decisions and processes for collecting, analysing and evaluating data that will satisfy the overall programme objectives. General considerations used to establish DQOs are:

- why the environmental datum is needed and how it will be used
- the consequences of an incorrect decision being made as a result of inadequate or invalid environmental data
- level of uncertainty in the results derived from the environmental data that the decision maker is willing to accept.

Additionally, the development of DQOs requires specifying the following:

- sample locations and frequency
- sample collection procedures
- sample handling procedures
- measurement of constituents
- analytical methods used to measure the constituents.

3.6.1 Data categories

There are two data categories, each with specific quality assurance/quality control (QA/QC) elements to ensure data will be of known quality. The categories include screening data and definitive data. Screening data are generated using less precise methods to provide analyte identification with relatively imprecise quantitation and less stringent QA/QC procedures. Definitive data are generated using rigorous analytical methods and QA/QC procedures.

Definitive data generated can be used in the following tasks:

- risk assessment
- site characterisation
- alternative evaluation
- engineering design
- monitoring during implementation.

Screening data are typically used for real-time health and safety monitoring or organic vapour concentrations and measurement of water quality parameters during purging and sampling activities.

3.6.2 Levels of concern and detection limit requirements

The level of concern specifies a concentration range above which some action may need to be taken and therefore, the level of concern is intimately linked with the guidance levels (see Modules 4-6). The selected level of concern directly affects data quality requirements. The sampling and analysis methods used must be accurate at the level of concern. The analytical technique chosen has a detection limit well below the level of concern.

3.6.3 Data quality indicators

Data quality refers to the level of reliability associated with a particular data set. The data quality associated with environmental measurement data is a function of the sampling plan rationale and procedures used to collect the samples, as well as the analytical methods and instrumentation used in making the measurements. Each component has its own potential sources of uncertainty and biases which may affect the overall accuracy and/or precision of measurement.

Sources of uncertainty that can be traced to the sampling component of environmental data collection are poor sampling plan design, inconsistent use of standard operating procedures (SOPs) and incorrect sample handling or storage. The most common sources of uncertainty that can be traced to the analytical component of the total measurement system are problems associated with calibration and instrument contamination. Uncertainty cannot be eliminated entirely from environmental data. The amount of uncertainty that is tolerable depends on the objective of the sampling programme and the intended use of the data collected.

Data quality will be assessed in terms of precision, accuracy, representativeness, completeness, and comparability (PARCC) of the data. The PARCC definitions and QC procedures used to evaluate the PARCC criteria are presented below.

- **Precision.** Precision is the reproducibility of measurements under a given set of conditions. Precision is evaluated by comparing the relative percent differences (RPDs) of field duplicates and laboratory duplicates to acceptance limits.
- **Accuracy.** Accuracy measures laboratory method bias and/or the level of agreement between a measurement and a known true value. Accuracy is assessed by comparing the percent recoveries laboratory control samples against the acceptance limits.
- **Representativeness.** Representativeness is a qualitative parameter used to evaluate whether the data represent the actual environmental conditions during sample collection.

The representativeness evaluation includes review of sample collection, handling methods (holding times, cooler temperatures and temperature blanks) and trip, equipment rinsate and laboratory method blank results.

- **Completeness**. Completeness is defined as a percentage of measurements that are judged acceptable in terms of precision, accuracy, representativeness, and comparability. Completeness is calculated by dividing the number of acceptable sample results by the total number of sample results.
- **Comparability.** Comparability is a qualitative expression of confidence with which one data set can be compared to another. The assessment of comparability includes a review of sample collection and handling methods and laboratory sample preparation, analysis and quantitation procedures.

3.6.4 Field quality control (QC) samples

Field QC samples include field duplicate samples, equipment rinsate blank samples, and field blank samples. Field QC samples assess sample collection techniques and monitor possible cross-contamination between samples and/or equipment. The various types of field QC samples are as follows:

- **Field duplicate samples.** Field duplicate samples are collected from a single sample location in conjunction with field samples and submitted to the laboratory without indication of the association between the two samples (i.e. a 'blind' sample). The field duplicate sample analyses assess the consistency of the sampling technique and the precision of the analytical laboratory. One field duplicate sample is typically collected for every 10-20 field samples.
- **Equipment rinsate blank samples.** Equipment rinsate blank samples are collected after a sampling device has been decontaminated to assess potential cross-contamination between samples as a result of poor decontamination procedures. One sample per day is typically collected.
- **Field blank samples.** Field blank samples are bottles of deionised water prepared in the field and included in each sample cooler containing VOC samples. Field blank samples are used to evaluate sample representativeness by identifying any volatile compounds that may have been introduced into the field samples during sample collection, transportation or storage at the laboratory.

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Appendix 3A
NZ Geomechanics Society terminology for description of soils in the field

1.1 Soil name

For coarse grained soils (>65% sand and gravel) the soil name is based on the particle sizes present. For fine grained soils (>35% silt and clay sizes) it is based on behavioural characteristics.

1.1.1 Particle sizes

boulders		>200 mm	**very coarse gravel**		60-200 mm
gravel	coarse	20-60 mm	**sand**	coarse	0.6-2.0 mm
	medium	6-20 mm		medium	0.2-0.6 mm
	fine	2-6 mm		fine	0.06-0.2 mm
silt		2-60 µm	**clay**		<2 µm

1.1.2 Proportions

	Term	**% of soil mass**	**Example**
Subordinate fraction	(….)y	20-50	sandy
Major fraction	….-….	35-50	sand - gravel
	….	major constituent	gravel
Minor fraction	with trace of	<5	with trace of sand
	with minor	5-12	with minor sand
	with some	12-20	with some sand

1.2. Strength

1.2.1 Fine-grained soils (cohesive)

Term	**Diagnostic features**	**Undrained compressive strength (kPa)**
Very soft	Exudes between fingers when squeezed	<25
Soft	Easily indented by fingers	25-50
Firm	Indented only by strong finger pressure	50-100
Stiff	Indented by thumb pressure	100-200
Very stiff	Indented by thumb nail	200-400
Hard	Difficult to indent by thumbnail	400-1000

1.2.2 Coarse-grained soils

A visual assessment is based on:

Loosely packed	Can be removed from exposure by hand or removed easily by shovel
Tightly packed	Requires pick for removal, either as lumps or as disaggregated material

1.3 Moisture condition

Dry	Soil looks and feels dry: cohesive soils usually hard, powdery or friable while granular soils run freely through hands.
Moist	Soil feels cool, darkened in colour: granular soils tend to cohere while cohesive soils usually weakened by moisture presence, but one gets no free water on hands when remoulding.
Wet	Soil feels cool, darkened in colour: granular soils tend to cohere while cohesive soils usually weakened and free water forms on hands when handling.
Saturated	Soil feels cool, darkened in colour and free water is present in the sample. Fully saturated refers to the case where the soil is below the water table.

1.4 Plasticity

Plasticity of clays and silts is determined from the results of Atterburg limit tests. In the field the characteristics of fine grained soils are identified using dilatancy (reaction to shaking) , dry strength (crushing), and toughness (consistency near the plastic limit) behaviour. The most characteristic test of plasticity in a soil is dilatancy where on rapid shaking water appears and similar shaking gives no reaction for a plastic soil.

1.5 Grading qualifications

The grading of gravels and sands may be qualified in the field as *well graded* (i.e. good representation of all particle sizes from largest to smallest). Poorly graded materials may be further divided into *uniformly graded* (i.e. most particles about the same size) and *gap graded* (i.e. absence of one or more intermediate sizes).

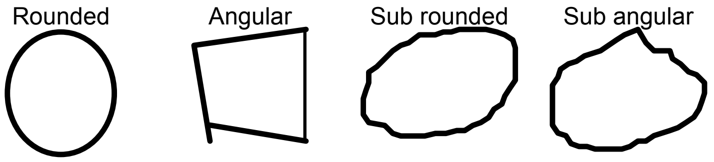
1.6 Weathering

Weathering of soils is more relevant to coarse grained soils and where weathering does not have an influence on the properties of a soil the term may be omitted.

1.7 Bedding

Term	Inclination (from the horizontal)	Term	Bed thickness
Sub horizontal	0-10°	Very thick	>2 m
Gently inclined	10-30°	Thick	600 mm -2 m
Moderately inclined	30-60°	Moderately thick	200-600 mm
Steeply inclined	80-90°	Moderately thin	60-200 mm
Sub vertical	80-90°	Thin	20-60 mm
		Very thin	6-20 mm
		Laminated	2-6 mm
		Thinly laminated	<2 mm

1.8. Particle shape



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

August 1999

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4 Tier 1 soil screening criteria

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):

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

where: CDI = Chronic Daily Intake (a measure of exposure)
SF = Slope Factor (sometimes called Cancer Potency Factor)

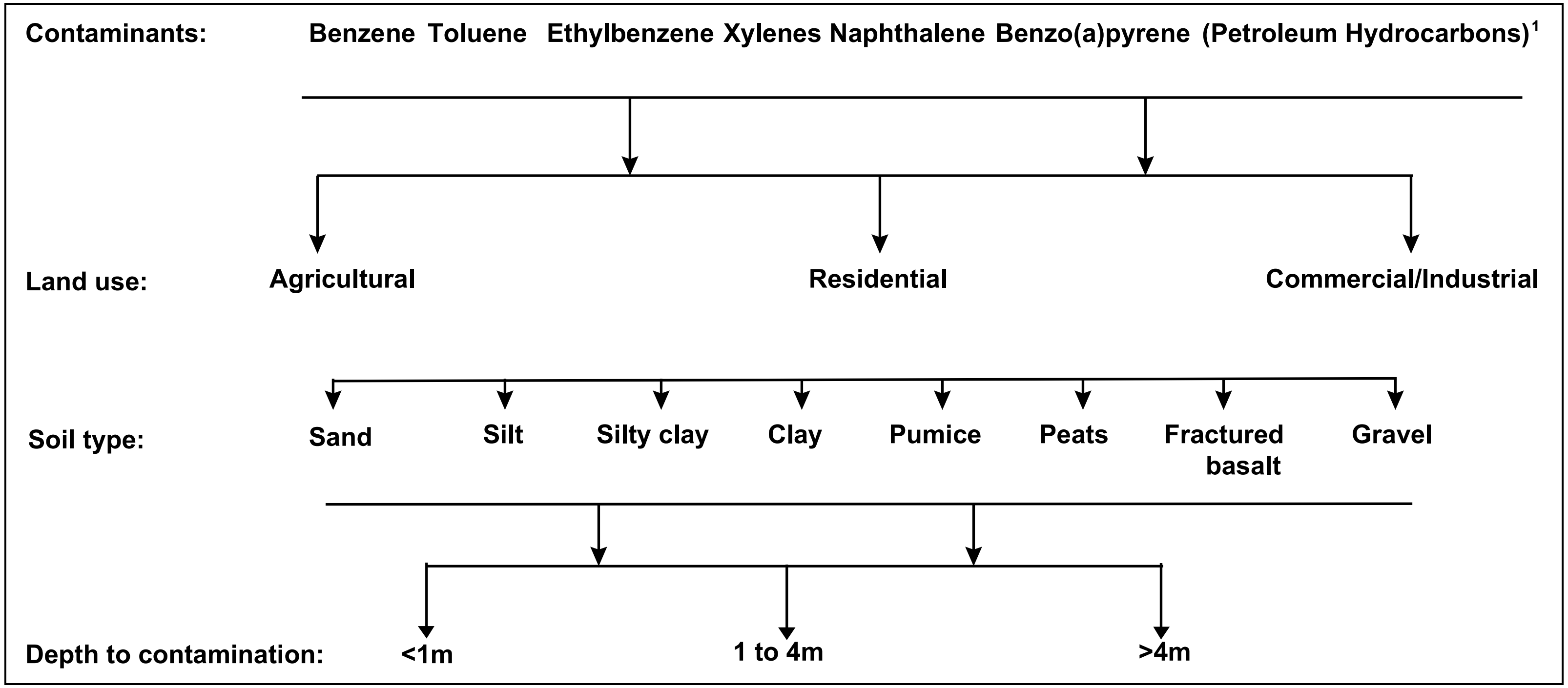
The level of risk that is deemed to be acceptable or tolerable, in a regulatory sense, is an essential judgement in the risk assessment process. While the level of risk deemed to be acceptable is a matter for the community as a whole to decide, the Ministry of Health have adopted an incremental cancer 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):

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

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

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[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:

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[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:

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

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

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[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:

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

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:

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

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

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

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

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[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

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[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.

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[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..

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[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

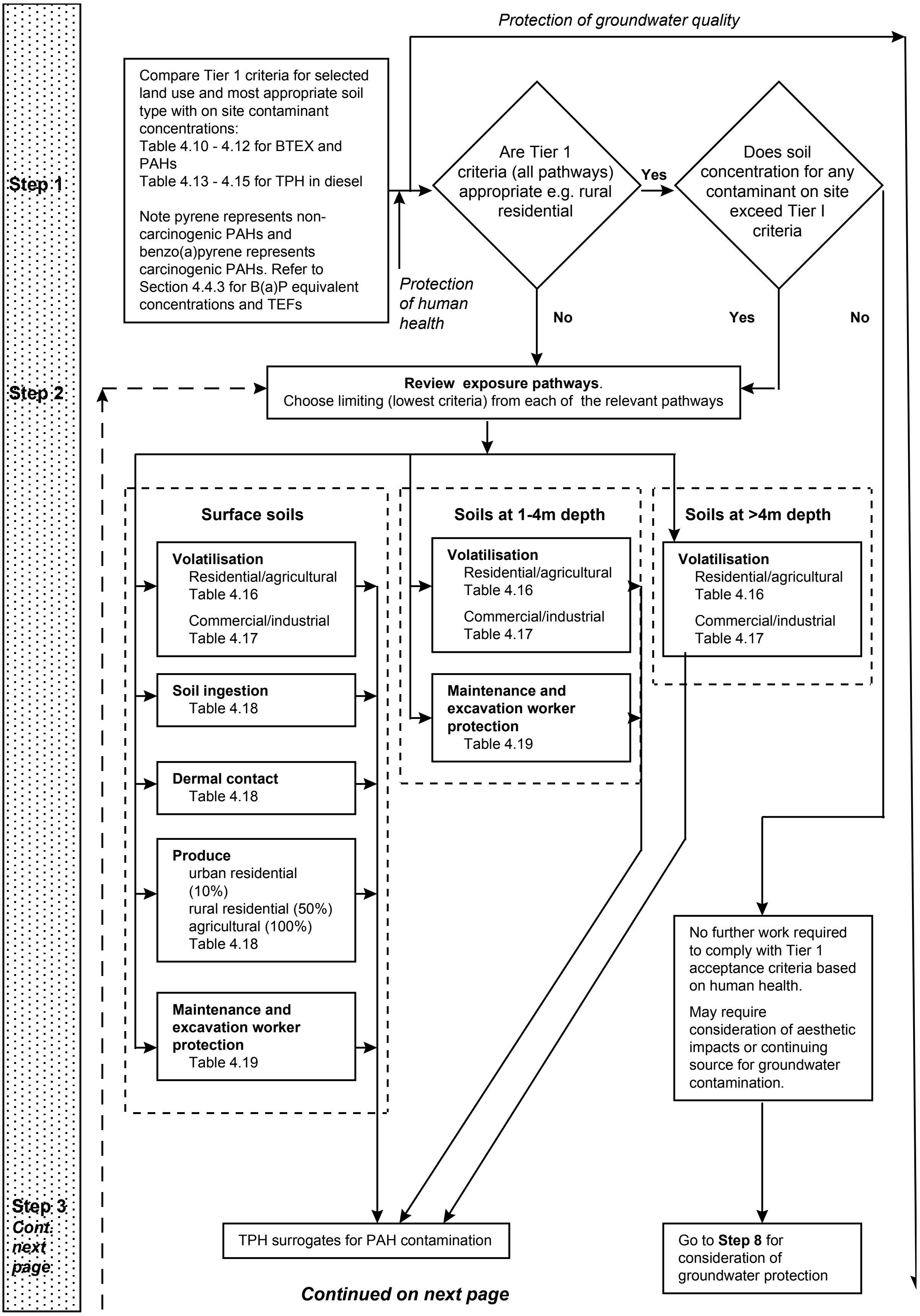

Figure 4.2 (continued) Flow chart for determining Tier 1 soil acceptance criteria

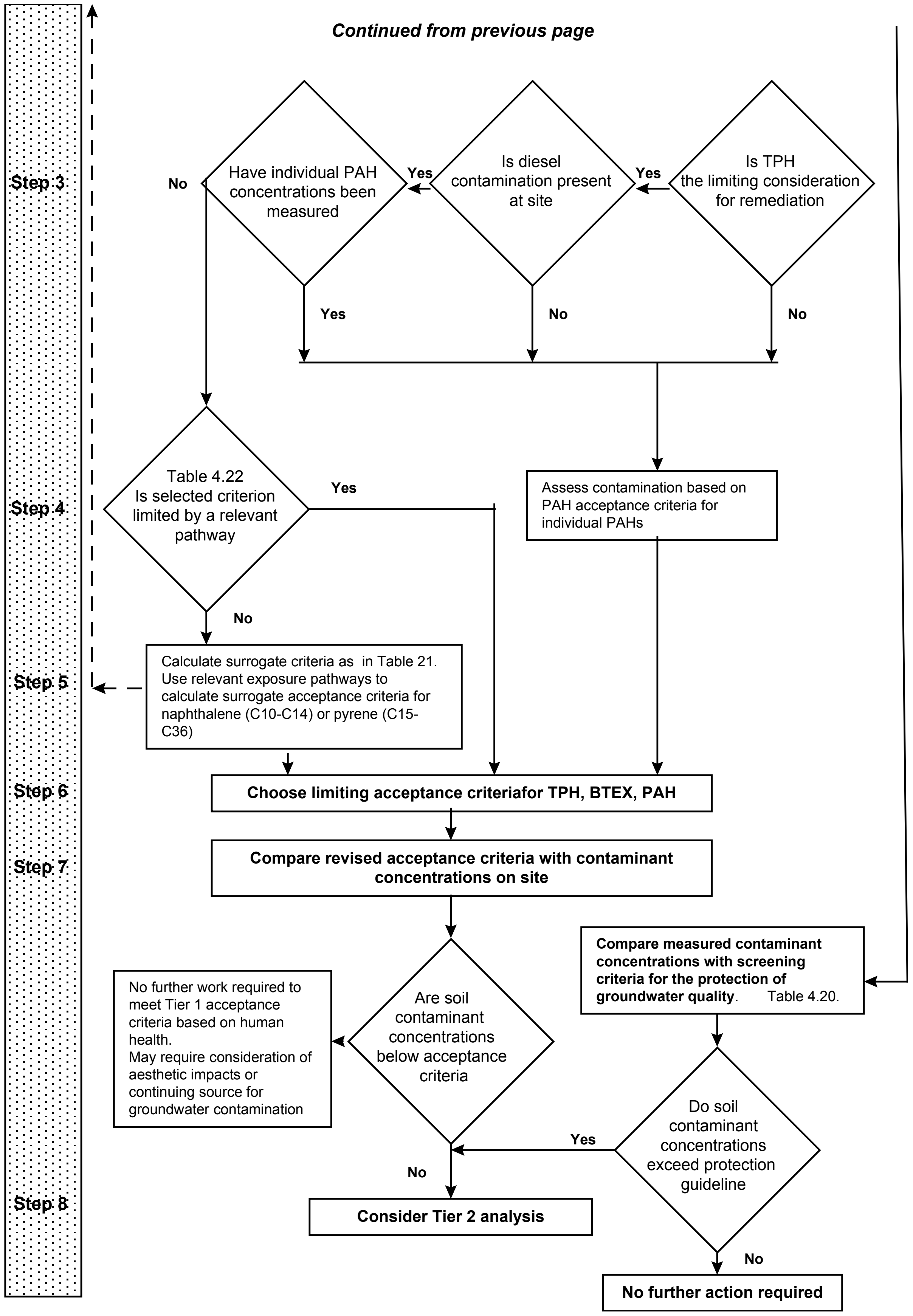

Table 4.10 Tier 1 Soil acceptance criteria *Residential use*(1,3,6) ALL PATHWAYS (all values in mg/kg)

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)		1 m - 4 m		> 4 m	
	Indoor	Outdoor	Indoor	Outdoor	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		Safety factor	TPH screening criteria
		Concentration of PAH species in diesel (%w/w)	Tier 1 Acceptance criteria (mg/kg)		(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)	1 m - 4 m	> 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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USEPA, 1993 - p 18, table 4.6

ANZECC, 1992 - pp 30, 32

USEPA, 1996 - note 1, app 4L

MOH, 1995 - Appl 4L note to Table 4L3.

Appendix 4A
Identification of contaminants of concern

A screening level assessment was undertaken to confirm the selection of contaminants of concern likely to be associated with the release of gasoline into the soil environment. The purpose of this assessment was to:

- confirm the indicator contaminants normally selected as the basis for the assessment of soil and groundwater contamination resulting from a gasoline release are likely to determine the risk to human health
- identify some of the compounds that may be associated with aesthetic impacts such as odour resulting from a gasoline release.

Information on the typical composition of a gasoline was obtained as shown in Table 4A1. For each constituent, or class of constituents, the following information of relevance to the fate of chemicals in the environment, their impact on human health and potential for odour impact, was sought:

- human toxicity (Slope Factor, Reference Dose or Reference Concentration)
- aquatic toxicity
- odour threshold
- solubility
- half-life in soil
- vapour pressure
- organic carbon - water partitioning coefficient
- octanol - water partitioning coefficient.

The information collected is summarised in Table 4A1. Given the screening nature of this assessment, the relative values for each of these parameters is more important than the absolute values. Therefore a rigorous assessment of the appropriateness and validity of information obtained regarding, say, the half life of a chemical in soil was not undertaken. The values listed in Table 4A1 are not used elsewhere in this document.

Information was sought from a range of sources including:

- USEPA Integrated Risk Information System database
- USEPA STF base (soil transport fate database)
- Verschueren K. (1983) *Handbook of Environmental Data on Organic Chemicals*
- American Industrial Hygiene Association (1989) *Odor Thresholds for Chemicals with Established Occupational Health Standards*.

For screening purposes, each chemical was assigned a score between 1 and 5 for the following properties:

- toxicity, expressed in terms of a tolerable dose
- abundance in fresh gasoline
- persistence (related to half-life)
- volatility

- odour index.

The basis for assigning scores to individual chemicals is presented as a note to Table 4A2.

The scores assigned to each chemical for individual properties were then combined to give an overall score reflecting the likely significance in terms of:

- **Human health**

Surface soil score = Abundance x Human Toxicity x Persistence

Depth soil score = Abundance x Toxicity x Persistence x Volatility

- **Aesthetic impact**

Overall score = Abundance x Odour Index x Persistence

The results of the screening level assessment of the chemicals of concern associated with a gasoline release are presented in Table 4A2 and are summarised as follows:

- Benzene, xylene and benzo(a)pyrene were found to be most important with respect to human health impacts associated with surface soils
- Benzene, xylene, isopentane, 2,4-dimethylhexane and n-butane were found to be most important with respect to impact on human health resulting from contaminated soil at depth. In practice the limited persistence of isopentane and n-butane means that they are rarely controlling in the case of the historical spills normally subject to a site assessment
- Xylene, trimethyl benzene and diethyl benzene were found to be most important with respect to aesthetic impacts.

The results of the screening level assessment are generally consistent with the indicator chemicals normally selected for the assessment of petroleum release sites. The indicator chemicals considered further in the derivation Tier 1 soil acceptance criteria are as follows:

- benzene, toluene, ethylbenzene and xylenes
- selected PAHs including naphthalene, pyrene (representative of non-carcinogenic PAHs) and benzo(a)pyrene.

Table 4A1 Summary of selected properties of gasoline constituents

Hydrocarbon group	Representative hydrocarbon	Selected representative hydrocarbon(%m/m)		Human toxicity(1)				Aquatic toxicity(2) (mg/L0)
				Oral		Inhalation		
		Range	Average	Slope factor 1/(mg/kg/d)	RfD (mg/kg/d)	Slope factor 1/(mg/kg/d)	RfD (mg/m^3)	
n-ALKANES		10.8-29.6	20.2			8		
C4	n-Butane	4.8-7.0	5.9			22		
C5	n-Pentane	1.9-4.5	3.2					
C6	n-Hexane	2.0-12.9	7.45		0.06		0.2	
C7	n-Heptane	0.2[-2.3	1.25					
C8	n-Octane	1.3	1.3					
C9	n-Nonane	0.4-0.8	0.6		0.6			
C10-14	n-Decane	0.2-0.8	0.5					
BRANCHED ALKANES		18.8-59.5	39.15					
C4	Isobutane	0.7-2.2	1.45					
C5	Isopentane	8.6-17.3	12.95					
C6	2-Methylpentane	4.6-9.7	7.15					
C7	2-Methylhexane	1.4-8.3	4.85					
C8	2,4-Dimethylhexane	1.8-16.7	9.25					
C9	2,4,4-Trimethylhexane	1.2-2.7	1.95					
C10-14	2,2,5,5-Tetramethylhexane	0.5-2.6	1.55					
CYCLOALKANES		3.2-13.7	8.45					
C6	Cyclohexane	0.2	0.2					
C7	Methylcyclohexane	1.0-3.9	2.45				3	
C8	1,2,4-Trimethylcyclopentane	0.2-1.4	0.8					
C9	1,1,3-Trimethylcyclohexane	9.2-0.7	0.45					
Others			4.55					
ALKENES		5.5-13.5	9.5					
C4	Butene	0.9	0.9					
	(alpha butylene)		2.3					
	(beta butylene)		1.3					
C5	1-Pentene	1.3-3.3	5					
C6	Hexene	0.8-1.8						
Others		2.5-7.5						

Table 4A1 (CONTINUED) Summary of selected properties of gasoline constituents

Hydrocarbon group	Representative hydrocarbon	Selected representative hydrocarbon(%m/m)		Human toxicity(1)				Aquatic toxicity(2) (mg/L0)
				Oral		Inhalation		
		Range	Average	Slope factor 1/(mg/kg/d)	RfD (mg/kg/d)	Slope factor 1/(mg/kg/d)	RfD (mg/m^3)	
MON0-AROMATICS		19.3-40.9	30.1					
	Benzene	0.9-4.4	2.65	0.029				0.3
	Toluene	4.0-6.5	5.25		0.2		0.4	0.3
	Mixed xylenes	5.6-6.8	7.2		2			
	(o-xylene)				2			
	(m-xylene)				2			
	(p-xylene)							
	Ethylbenzene	1.2-1.4	1.3		0.01		1	
C3-benzenes	1,3,5-Trimethybenzene	3.2-11.3	7.25					
C4-benzenes	1,2-Diethylbenzene	2.1-2.6	2.35					
Others		`.6-5.2	3.4					
POLY-AROMATICS								
	Benzo(a)pyrene			7.3				
	Fluorene							
	Naphthalene	0.7	0.7					
	Total PAH							0.003
CARBOXYLIC ACIDS								
	Benzoic acid				40			
UNKNOWNS		0.6-13.8	10.2					

Table 4A1 (CONTINUED) Summary of selected properties of gasoline constituents

Hydrocarbon group	Representative hydrocarbon	Geometric mean air odour threshold (ppm) (3)		Odour index(4)	Solubility (mg/L)		Persistence 1/2 life in soil(6)	Vapour pressure(5)		Koc(5)	Kow(5)
		Detection	Recognition		Water	Temp °C	days	(mmHg)	Temp °C		
n-ALKANES											
C4	n-Butane			480	61	20		1823	25		776.2
C5	n-Pentane			570	30	15		430	20		
C6	n-Hexane				9.5	20		120	20		7943
C7	n-Heptane	230	330	200	3	20		35	20		45710
C8	n-Octane	150	240	100	0.66	20		11	20		
C9	n-Nonane			9800				3.22	20		
C10-14	n-Decane							2.7	20		
BRANCHED ALKANES											
C4	Isobutane			$3.00x10^{6}$	49	20		1520	7.5		
C5	Isopentane				48	20					169.8
C6	2-Methylpentane				14	23		400	42		588.8
C7	2-Methylhexane				380	23					1995
C8	2,4-Dimethylhexane										
C9	2,4,4-Trimethylhexane										
C10-14	2,2,5,5-Tetramethylhexane	780									
CYCLOALKANES											
C6	Cyclohexane			$2.03x10^{5}$	55	20		77	20	482	2754
C7	Methylcyclohexane				45	15		144	20		724.4
C8	1,2,4-Trimethylcyclopentane				14	20					
C9	1,1,3-Tri methylcyclohexane										
Others											
ALKENES											
C4	Butene										
	(alpha butylene)			$4.35x10^{7}$				760	-6.3		
	(beta butylene)			$3.33x10^{6}$							
C5	1-Pentene			$3.76x10^{8}$	50	25		100	-18		
C6	Hexene				50	20		186	25		177.8
Others											

Table 4A1 (CONTINUED) Summary of selected properties of gasoline constituents

Hydrocarbon group	Representative hydrocarbon	Geometric mean air odour threshold (ppm) $^{(3)}$		Odour index$^{(4)}$	Solubility (mg/L)		Persistence 1/2 life in soil$^{(6)}$	Vapour pressure$^{(5)}$		Koc$^{(5)}$	Kow$^{(5)}$
		Detection	Recognition		Water	Temp °C	days	(mm Hg)	Temp °C		
MON0-AROMATICS											
	Benzene	61	97	300	1780	20	23	76	20	31	134.9
	Toluene	1.6		16609	515	20	5.6	22	20	95	537
	Mixed xylenes										
	(o-xylene)	5.4		300	175	20	32	5	20	129	1318
	(m-xylene)	0.62		2100	161	25	15	6	20	166	1580
	(p-xylene)	2.1		18200	198	25	17	6.5	20	260	1318
	Ethylbenzene	2.2			152	20				250	1413
C3-benzenes											
C4-benzenes											
Others											
POLY-AROMATICS											
	Benzo(a)pyrene										
	Fluorene				1.9						
	Naphthalene	0.038		2400	30	25	0.12	1	53		
	Total PAH										
CARBOXYLIC ACIDS											
	Benzoic acid	0.62			2700	18		0.0045	25	1881.9	74

Notes
1. Based on USEPA IRIS AND MDEP, 1994
2. ANZECC Guidelines 1994
3. Based on American Industrial Hygiene Association odour thresholds
4. Verschueren K 1983, Handbook of Environmental Data on Organic Chemicals
5. STFBASE - values are te first reference half-life in the database
6. Verschuerne, 1983

Table 4A2 Preliminary ranking of contaminants of concern in gasoline

Hydrocarbon group	Representative hydrocarbon	Relative concern (Score 1 to 5)							
		Abundance	Human toxicity	Odour index	Volatility	Persistence	Health		Aesthetic
							Surface	Depth	
n-ALKANES									
C4	n-Butane	4	2	1	5	1	8	40	4
C5	n-Pentane	3	2	2	4	1	6	24	6
C6	n-Hexane	4	2	1	4	1	8	32	4
C7	n-Heptane	3	2	1	3	1	6	18	3
C8	n-Octane	3	2	1	3	1	6	18	3
C9	n-Nonane	2	1	3	2	2	4	8	12
C10-14	n-Decane	2	1	3	2	2	4	8	12
BRANCHED ALKANES									
C4	Isobutane	3	2	5	5	1	6	30	15
C5	Isopentane	5	2	4	5	1	10	50	20
C6	2-Methylpentane	4	2	4	4	1	8	32	16
C7	2-Methylhexane	3	2	4	4	1	6	24	12
C8	2,4-Dimethylhexane	4	2	4	3	2	16	48	32
C9	2,4,4-Trimethylhexane	3	1	4	3	2	6	18	24
C10-14	2,2,5,5-Tetramethylhexane	3	1	4	2	2	6	12	24
CYCLOALKANES									
C6	Cyclohexane	2	2	4	3	1	4	12	8
C7	Methylcyclohexane	3	2	4	3	1	6	18	12
C8	1,2,4-Trimethylcyclopentane	2	1	4	2	2	4	8	16
C9	1,1,3-Tri methylcyclohexane	2	1	4	2	2	4	8	16
Others									
ALKENES									
C4	Butene (alpha butylene) (beta butylene)	2	2	5	5	1	4	20	10
C5	1-Pentene	3	2	5	4	1	6	24	15
C6	Hexene	3	2	5	4	1	6	24	15
Others									

Table 4A2 (CONTINUED) Preliminary ranking of contaminants of concern in gasoline

Hydrocarbon group	Representative hydrocarbon	Relative concern (Score 1 to 5)							
		Abundance	Human toxicity	Odour index	Volatility	Persistence	Health		Aesthetic
							Surface	Depth	
MON0-AROMATICS									
	Benzene	3	4	1	3	2	24	72	6
	Toluene	4	1	3	3	2	8	24	24
	Mixed xylenes	4	2	2	2	3	24	48	36
	(o-xylene)								
	(m-xylene)								
	(p-xylene)								
	Ethylbenzene	3	2	2	2	3	18	36	27
C3-benzenes		4	1	2	2	4	16	32	48
C4-benzenes		3	1	2	2	4	12	24	36
Others									
POLY-AROMATICS									
	Benzo(a)pyrene	1	5	1	1	5	25	25	5
	Fluorene	2	2	1	1	4	16	16	8
	Naphthalene	2	2	2	2	4	16	32	16
	Total PAH								
CARBOXYLIC ACIDS									
	Benzoic acid								
Prisline			1						
Pytane			1						
Waxes			1						

Notes

Determination of relative concern rankings

Dose (mg/kg/d)	Rank	Abundance	Rank	Persistence	Rank	Volatility	Rank	Odour index	Rank
10^{-4} - 10^{-5}	5	10-15%	5	B(a)P	5	>1000	5	<0.5	5
10^{-3} - 10^{-4}	4	5-10%	4	Naphthalene	4	>100	4	>0.5	4
10^{-2} - 10^{-3}	3	1-5%	3	EX	3	>10	3	>5	3
10^{-1} - 10^{-2}	2	0.1-1%	2	BT	2	>1	2	>50	2
10^{0}- 10^{-1}	1	<0.1%	1	Light alkanes	1	>0.1	1	>500	1

Surface Health rank = Abundance*Human toxicity*Persistence
Depth Health rank = Abundance*Human toxicity*Persistence*Volatility
Aesthetic rank = Abundance*Odour Index*Persiste

Appendix 4B
Basis for total petroleum hydrocarbon (TPH) criteria protective of human health

Hydrocarbon fuels of interest in the context of petroleum contaminated sites are generally complex mixtures of compounds, including alkanes, alkenes and a range of aromatic compounds. Analysis of soil and groundwater samples for total petroleum hydrocarbons (TPH) parameter measures the total concentration of all petroleum related hydrocarbons, expressing the results in terms of the concentration of hydrocarbon compounds within various carbon ranges, e.g. C6 to C9. The TPH parameter is a useful indicator of hydrocarbon contamination, but it is of limited use in the assessment of health risk, but as it refers to the concentration of a complex mixture of compounds which do not exhibit toxicological or fate and transport properties.

The health risk associated with exposure to petroleum hydrocarbons may be considered to consist of the risk associated with a number of well defined compounds of known and significant toxicity (e.g. benzene and other monocyclic aromatic hydrocarbons, and PAHs, such as benzo(a)pyrene) and a much larger number of less well defined, generally less toxic compounds.

Acknowledging the variability in the criteria nominated for TPH in the United States, the TPH Criteria Working Group (TPHCWG) was established to develop a technically defensible approach to the development of soil clean-up levels for TPH that are protective of human health. The TPHCWG includes representatives from academia, industry (e.g. Shell, Exxon, Chevron, API, Association of American Railroads) and government (e.g. USEPA and some state regulators, Department of Defense).

The TPHCWG have developed an approach for the derivation of health based soil clean-up levels based on normal procedures for the derivation of such values. In order to facilitate this TPHCWG have assigned representative toxicological and fate and transport properties to each of the fractions. The representative properties give consideration to the range of properties exhibited by the chemicals comprising the fraction considered.

The work of the TPHCWG is reaching a final draft stage. Volume 3 *Selection of Representative TPH Fractions Based on Fate and Transport Considerations* was released as a final draft in February 1997. Volume 4, which will address the representative toxicological issues is due to be released as a final draft shortly.

In 1994, the Massachusetts Department of Environmental Protection (MDEP) adopted a similar approach in *Interim Final Petroleum Report: Development of Health-based Alternative to the Total Petroleum Hydrocarbon (TPH) Parameter*. The MDEP considered the information available regarding the toxicity and fate and transport of whole products (e.g. unleaded gasoline) and individual key components (e.g. benzene). The MDEP adopted an approach based on developing specific acceptance criteria for the contaminants of primary concern (e.g. benzene, benzo(a)pyrene) and the development of acceptance criteria based on indicator chemicals for each of the TPH fractions considered. A key difference between the MDEP and TPHCWG approaches is that the MDEP assigned a surrogate chemical to each of the fractions considered and then assessed each fraction as it if were comprised entirely of the surrogate compound, e.g. the C6 to C9 fraction was assessed as if it was all n-hexane. In practice, this approach is conservative as the C7 to C9 compounds are less toxic than n-hexane. The TPHCWG approach therefore has the advantage of considering the properties of each of the range of chemicals included in each fraction.

The TPHCWG split the range of petroleum hydrocarbons into six fractions, considering separately the aromatic and aliphatic components of each as follows:

- C6 to C8 (or C7 to C8 for aromatics)
- C9 to C11
- C11 to C12
- C13 to C16
- C17 to C21
- C22 to C34

The distinction between aromatic and aliphatic compounds in the TPH fractions has been dropped for the purposes of these guidelines as the aromatic component will be addressed separately by direct measurement of BTEX and PAH concentrations, and because the analytical technique proposed for New Zealand will not distinguish between aromatics and aliphatics. Therefore the criteria developed for New Zealand using this approach apply principally to the aliphatic component.

In considering toxicological properties the TPHCWG considered only three fractions, as follows (due to the inability of the toxicological data to achieve a greater level of resolution):

- C6 to C8
- C9 to C16
- C17 to C34

In integrating this approach proposed by the TPHCWG and the standard analytical method technique being developed on behalf of the OIEWG for use in New Zealand, Tier 1 soil and groundwater acceptance criteria have been developed on the basis of the following fractions:

- C7 to C9
- C10 to C14
- C15 to C36

Due to minor differences between the fractions selected for use in New Zealand and those nominated by the TPHCWG, some minor changes have been made to the toxicological and fate and transport properties adopted, based on a weighted averaging approach.

The toxicological and fate and transport properties assumed for each of the fractions are summarised in Tables 4B1 and 4B2.

Table 4B1 Adopted toxicological properties for TPH

Fraction	C7 - C9	C10 - C14	C15 - C36
Oral reference dose (mg/kg/d)	5.0	0.1	1.5
Inhalation reference Dose (mg/kg/d)	5.0	0.3	1.5

Table 4B2 Adopted fate and transport properties for TPH

Fraction	C7 - C9	C10 - C14	C15 - C36
Molecular weight (g/mol)	120	185	245
Solubility (mg/L)	3.3	4.3×10^{-3}	2.3×10^{-5}
Vapour pressure (atm)	2.2×10^{-2}	1.7×10^{-4}	6.5×10^{-6}
Henry Coefficient (c/c)	120	160	135
log Koc	4.0	6.1	8.7
log Kow	5.2	7.6	9.3
Dair (cm^2/s)	6.0×10^{-2}	4.2×10^{-2}	3.3×10^{-2}
Dwat (cm^2/s)	7.1×10^{-6}	4.8×10^{-6}	3.8×10^{-6}

Appendix 4C
Exposure equations

A generalised equation for estimating exposure associated with contaminated soil is presented in Section 4. Specific forms of the general equation are presented in this appendix for the following exposure routes:

- ingestion of soil
- inhalation of volatiles
- dermal absorption
- consumption of home grown produce.

Ingestion of Contaminated Soil

The Chronic Daily Intake (CDI) may be determined by the following expression:

$$\mathbf{CDI = \frac{C \times CF \times IR_{adj} \times EF \times MF}{AT}} \qquad \mathbf{(C1)}$$

where:

CDI = chronic daily intake (mg/kg/d)

C = concentration of contaminant in the soil (mg/kg)

CF = conversion factor=10^{-6} kg/mg

EF = exposure frequency (d/yr)

AT = averaging time (d)

= (ED x 365) days for non-carcinogens by convention or (70 years x 365) days for carcinogens, representing lifetime exposure, by convention (USEPA, 1989a)

MF = matrix factor, accounts for reduced bioavailability of contaminant due to binding to the soil matrix. In the absence of necessary information, MF usually taken as 1.0. (USEPA, 1989a)

IR_{adj} = age adjusted ingestion rate

$$\mathbf{= S \; \frac{ED_i \times IR_i}{BWi}} \qquad \mathbf{(C\ 2)}$$

where:

ED_i = exposure duration (yr) for age group i

IR_i = ingestion rate (mg/d) for age group i

BW_i = body weight (kg) for age group i

The CDI determined using equation C1 is a weighted average, taking account of variation in body weight and ingestion rate with age.

Inhalation of Volatile Contaminants

The Chronic Daily Intake (CDI) by inhalation of volatile may be determined by the following expression:

$$\mathbf{CDI} = \frac{\mathbf{IR \times C \times VF \times EF \times ED}}{\mathbf{AT \times BW}} \qquad \mathbf{(C3)}$$

CDI = chronic daily intake (mg/kg/d)

where:

C = concentration of contaminant in soil (mg/kg)

VF = volatilisation factor (kg/m^3)

EF = exposure frequency (d/yr)

AT = averaging time (d)

= (ED x 365) days for non-carcinogens by convention or (70 years x 365) days for carcinogens, a lifetime by convention

ED = exposure duration (yr)

IR = inhalation rate (m^3/d)

BW = body weight (kg)

Refer to Appendix 4D for the results of modelling of the emission of volatile components.

Note: for the inhalation pathway an age adjusted inhalation rate is not required because weight standardised inhalation rates for adults and children are similar (child: 3.8 m^3/d/15 kg=0.257, adult: 20 m^3/d / 70 kg = 0.286, body weight ratio: 15 kg/70 kg = 0.214). For other pathways an age adjustment factor is necessary due to larger differences between these values.

Dermal Absorption from Contaminated Soil

The Chronic Daily Intake (CDI) for dermal absorption from contaminated soil may be determined using the following expression:

$$\mathbf{CDI} = \frac{\mathbf{C \times AH_{adj} \times AR \times AF \times EF \times CF}}{\mathbf{AT}} \qquad \mathbf{(C\ 4)}$$

where:

CDI = chronic daily intake (mg/kg/d)

C = concentration of contaminant in the soil (mg/kg)

AR = area of exposed skin (face, neck, forearms, hands) (cm^2/d)

AF = absorption factor (unitless)

EF = exposure frequency (d/yr)

CF = conversion factor (10^{-6} kg/mg)

AT = averaging time (d)

= (ED x 365) days for non-carcinogens by convention or (70 years x 365) days for carcinogens, a lifetime by convention

AH_{adj} = age adjusted soil adherence

$$= \mathbf{S} \; \frac{\mathbf{AH_i \text{ x } ED_i}}{\mathbf{BW}} \qquad \mathbf{(C\ 5)}$$

where:

AH_i = soil adherence (mg/cm^2) for age group i'

ED_i = exposure duration (yr) for age group i

BW_i = body weight (kg) for age group i

The CDI determined in equation C4 is a weighted average, taking into account variation in body weight, skin area and exposure patterns with age.

Ingestion of Produce

The Chronic Daily Intake (CDI) for ingestion of produce may be estimated using the following expression:

$$\mathbf{CDI} = \frac{\mathbf{C \text{ x } PUF \text{ x } IP_{adj} \text{ x } EF \text{ x } Pg}}{\mathbf{AT}} \qquad \mathbf{(C6)}$$

where

CDI = chronic daily intake (mg/kg/d)

C = concentration of contaminant in soil (mg/kg)

PUF = product uptake factor (unitless)

EF = exposure frequency (d/yr)

AT = averaging time (d)

= (ED x 365) days for non-carcinogens by convention or (70 yrs x 365) days for carcinogens by convention

Pg = proportion of produce grown on-site

IP_{adj} = age adjusted ingestion rate for produce

$$= \mathbf{S} \; \frac{\mathbf{IP_i \text{ x } EDi}}{\mathbf{BW_i}} \qquad \mathbf{(C\ 7)}$$

where:

IP_i = ingestion rate for produce (kg/d) for age group i

ED_i = exposure duration (yrs) for age group i

BW_i = body weight (kg) for age group i

The CDI estimated in equation C6 is a weighted average taking into account variation in body weight and produce consumption with age.

Appendix 4D
Volatilisation modelling

1.1 Overview

Modelling the migration of volatiles from contaminated soil and groundwater into outdoor and indoor air is an important component in deriving Tier 1 Acceptance Criteria for soil and groundwater.

For the purposes of this module it is necessary to predict contaminant concentrations in air within the breathing zone of the nominated receptors for the following scenarios;

- Soil to indoor air
- Soil to outdoor air
- Groundwater to indoor air
- Groundwater to outdoor air.

Some of the key mechanisms and processes considered in modelling the transport of volatile components are outlined as follows:

- **Diffusion through soil air (and, to a lesser extent, soil water)**

Diffusion has been assumed to be the dominant means of transport through the soil column.

- **Advective transport through the soil column**

  Advective transport has been shown to be important, particularly for the intrusion of vapours into basement areas where heating or other processes establish a pressure differential between the soil and the building. Advective transport is likely to be most important where contaminated soils are located within 1 metre of the building foundations. Advective transport has been considered in modelling emissions from surface soils (<1 metre) to indoor air.

- **Diffusion and advective transport through building foundations**

  As discussed above, advective transport is assumed to be negligible except where contaminated soils are located within 1 metre of the building foundation. Diffusion through the building foundations can be a dominant resistance component in many scenarios. For the purposes of modelling, slab on ground construction has been assumed for both commercial and residential buildings. Preliminary estimates indicate that contaminant concentration in indoor air in houses constructed on stumps with sub-floor ventilation, are lower than those for slab on ground construction, i.e. use of the slab on ground construction is conservative.

- **Depletion of contaminant source with time through volatilisation, leaching and biodegradation**

  Biodegradation of the contaminant source has been conservatively neglected due to a lack of reliable quantitative data, however the Jury based model, used to predict emission from contaminated soil, can incorporate first order biodegradation of contaminants. Source depletion through volatilisation has been considered, however losses due to leaching have been set to zero. This represents a conservative assumption in the case of diffusion to outdoor air, however leaching is expected to be negligible beneath buildings or paved areas.

A constant source has been assumed in modelling volatilisation from groundwater to indoor or outdoor air.

- **Biodegradation of the vapour plume**

  Biodegradation of the vapour plume has been conservatively neglected at this stage due to the lack of reliable quantitative information. Current research in the United States may provide information allowing inclusion of this process in the future.

- **Dilution and dispersion of contaminants in the receiving air environment**

  Simple box dilution model, assuming contaminants are fully mixed within the box, have been assumed for both indoor and outdoor air.

- **Diffusion through the air boundary layer in transport to outdoor air**

  The volatilisation of some contaminants from surface soils to outdoor air can be influenced by the resistance to transport through the air surface boundary layer. The boundary layer resistance has been conservatively neglected in deriving Tier 1 criteria for soils. This approach is consistent with that used in RBCA[1], however, the boundary layer resistance is readily incorporated in the Jury based models. The air boundary layer resistance is expected to be negligible compared to the soil column resistance for all but the very surface layers of soil.

Each of the volatilisation models used may be considered to be comprised of the following units or modules:

- Equilibrium partitioning

  Predicting soil gas concentrations at the source, based on measured soil or groundwater concentrations

- Diffusion transport

  Predicting the flux of contaminants through the soil column and concrete slab foundation (if appropriate) based on gas and liquid phase diffusion and advective transport (where appropriate) given the soil gas concentration at the source layer (and liquid phase convection in the case of the Jury model);

- Dilution

  Predicting the indoor or outdoor air concentrations resulting from a given flux, based on simple box models.

1.2 Volatilisation factor

The Volatilisation Factor is used to relate the indoor and outdoor air concentrations to the measured soil concentrations. Some volatilisation models are configured to return a Volatilisation Factor. The Volatilisation Factor is defined as follows:

$$VF = \frac{C_{AIR}}{C_{SOIL}} \quad \textbf{for soil contamination} \qquad \text{(D1)}$$

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[1] ASTM (1995) “Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites”, Designation: E 1739-95

$$VF = \frac{C_{AIR}}{C_{GW}} \quad \textbf{for groundwater contamination} \qquad \text{(D2)}$$

where:

VF = Volatilisation factor for soil or groundwater

C_{AIR} = Concentration in the air for indoors or outdoors (mg/m^3)

C_{SOIL} = Concentration of contaminant in soil (mg/kg)

C_{GW} = Concentration of contaminant in groundwater (mg/L)

1.3 Soil volatilisation model

1.3.1 Summary

Two models have been considered as the basis for the modelling the emission of volatile contaminants from soil. The two models are summarised as follows:

- **Modified Jury behaviour assessment model (BAM)**

  Jury et al (1983) 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 boundary condition for the governing differential equation describing the boundary layer resistance, for one incorporating the resistance to transport through the overlying soil, in the case of sub-surface soils, and transport through the building foundations for indoor air. This does not alter the form of the Jury solution. A disadvantage of the Jury model is the complexity of the equations and the inability to account for advective transport in the vapour phase.

- **Modified 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 used in the RBCA protocol. 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), and allow use of the same model to assess transport to outdoor air. The modified Johnson and Ettinger model is mathematically simpler than the Jury model but incorporates a simplification in the conceptual model and therefore the criteria developed using the modified Johnson and Ettinger model are lower than those developed using the Jury model by a factor of less than 2.

The Tier 1 soil acceptance criteria have been determined using the Jury model where diffusion is limiting. Where advective transport is important (soils <1 metre) the Johnson and Ettinger model has been used. In practice consideration of advective transport results in more rapid depletion of the contaminated layer with a higher peak indoor air concentration. The long term (20-30 years) average concentration in indoor or outdoor air does not change significantly as in most cases the soil layer fully depletes even when diffusion only transport is considered.

The Johnson and Ettinger model has been used to estimate volatile emissions from groundwater.

A limitation of the Jury model is the assumption of linear, single component phase partitioning. This is the most common phase partitioning approach used, however it overestimates the concentration in the vapour phase where separate phase hydrocarbons begin to form, thus overestimating the concentration in indoor or outdoor air. The Johnson and Ettinger model is not necessarily subject to the same limitation as it uses as a starting point the soil gas concentration. However, the Johnson and Ettinger model must be used in conjunction with a phase partitioning relationship and of these the linear relationship discussed above is most common[2]. The Johnson and Ettinger model can be used with alternative phase partitioning relationships if necessary.

The Jury model (Jury et al, 1983) is based on a solution to the following differential equation (mass balance):

$$\frac{\partial C_T}{\partial t} = D_E\left(\frac{\partial^2 C_T}{\partial z^2}\right) - V_E\left(\frac{\partial C_T}{\partial z}\right) - \mu C_T \qquad \text{(D3)}$$

The Jury model is configured to account for:

- volatilisation from a uniformly contaminated layer of soil, starting at the surface and extending to a depth of L
- diffusion of contaminants through the soil
- transport of contaminants through the surface boundary layer (a boundary condition for solution of the differential equation)
- advective transport of contaminants in soil moisture (either upward or downward).

In order to generalise the Jury model to model the emission of volatiles from a uniformly contaminated layer of soil some depth below the surface and to account for transport to indoor air, the boundary layer resistance term (He) in the solution to the Jury model was redefined to reflect the resistance to transport provided by either;

- overlying “clean” soil in the case of transport to outdoor air, assuming the resistance provided by the layer of soil exceeds that provided by the air boundary layer
- overlying “clean” soil and the concrete slab foundation for a building in the case of transport to indoor air.

Given that in each case the resistance term (H_e) can be defined in terms of a constant or combination of constants (i.e. independent of time and depth), the form of the Jury solution remains unchanged. This approach incorporates a simplifying assumption in that the overlying soil is treated as a simple resistance rather than as a continuation of the contaminated media. This approach neglects the impact of attenuation in the overlying soils but does facilitate use of the simpler solution to the differential equation.

The resistance terms describing the impact of the overlying soil layers and the concrete slab foundation are based on Johnson and Ettinger (1991) as used in RBCA.

The Johnson and Ettinger (1991) depleting source model is based on a simplifying assumption of sequential removal of contaminants from the upper surface of the contaminated layer, such that the, say, the initial step change in soil concentration assumed in the case of a buried layer of contaminated

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[2] A linear relationship is most commonly assumed because it is simple and mathematically convenient rather than because it is the best approach under all circumstances.

soil is retain throughout, with only the depth to the upper surface of the contamination and the thickness of the contaminated layer varying. This simplification results in a less complex solution to the differential equation, however the resultant model slightly overestimates the flux of contaminants relative to the Jury model predictions.

The equations for both the modified Jury and modified Johnson models are presented in Section 3.5.

1.3.2 Equilibrium model

A simple three phase linear partitioning model has been adopted, based on the assumption that at any point time within the system, an equilibrium is established between contaminant concentrations within each of the phases; adsorbed, dissolved and soil vapour. Adsorption of contaminants is assumed to be governed by a linear organic carbon relationship, which is found to hold for most moist soils. The vapour/dissolved phase equilibrium is assumed to be governed by Henry's Law. This approach is consistent with that used by most volatilisation models and is expected to overestimate volatilisation when separate phase hydrocarbons form.

1.3.3 Soil to indoor air

Transport of contaminants from soil to indoor air is modelled on the assumption of diffusive transport, based on the Millington-Quirk model to account for the tortuosity of the diffusion path (refer equations D10 and D11). The Millington-Quirk model is adopted in the derivation of both the Jury and Johnson and Ettinger models. The Millington-Quirk model is used to determine an effective diffusivity governing the movement of contaminants in the sub-surface.

Diffusion through concrete foundations is assumed to occur via cracks in the slab. The movement of volatiles through concrete slabs is not well understood, however the approach adopted by Johnson and Ettinger (1991) has been used in this instance. Transport through the concrete slab is assumed to occur by diffusion through cracks, which are themselves partially filled with particulate matter. Diffusion through the cracks is modelled in a manner consistent with diffusion through soils, with the exception that the diffusion area is adjusted to account for the area of the crack.

1.3.4 Soil to outdoor air

Transport of contaminants from soil into outdoor air is again assumed to occur as a result of diffusion. In this case advective transport in both the gas and liquid phase have been neglected.

Diffusive transport is modelled using the Millington-Quirk model as outlined above. Any air boundary layer resistance is assumed to be negligible compared to the resistance to diffusion through the soil column.

1.3.5 Equations

Refer Jury et al, 1983

For all modelling equations, definitions of parameters used and adopted values are presented in Section 8.

Equilibrium

C_T = Total Concentration of Contaminant (M/L^3)

$= R_S C_S = R_L C_L = R_G C_G$ (D4)

$= r_S C_S + qC_L + aC_G$ (D5)

r_S = Bulk density of soil (M/L^3)

q = Water volume fraction

a = Air volume fraction

C_S = Concentration of contaminant in the solid phase (M/M)

C_L = Concentration of contaminant in the liquid phase (M/L^3)

C_G = Concentration of contaminant in the vapour phase (M/L^3)

$$R_S = \rho_S + \frac{\theta}{K_D} + \frac{aK_H}{K_D}$$

= Solid phase equilibrium partitioning parameter (unitless, refer D4) (D6)

$R_L = r_s K_D + q + aK_H$ (D7)

= Liquid phase equilibrium partitioning parameters (unitless, refer D4)

$$R_G = \frac{\rho_S \mathrm{K_D}}{\mathrm{K_H}} + \frac{\theta}{\mathrm{K_H}} + \mathrm{a} \qquad \text{(D8)}$$

= Gas phase equilibrium partitioning parameter (unitless, refer D4)

K_H = Henry's Constant (unitless) (D9)

$K_D = F_{OC} * K_{OC}$

F_{OC} = Fraction of Organic Carbon

K_{OC} = Organic Carbon Adsorption Coefficient

Diffusive Transport

D_E = Retarded Diffusion Coefficient based on total soil concentration (L^2/t) (D10)

$$= \frac{D_G}{R_G} + \frac{D_L}{R_L}$$

$$D_G = D_G^{air}\left(\frac{a^{10/3}}{\phi^2}\right) \qquad \text{(D11)}$$

$$D_L = D_L^{wat}\left(\frac{\theta^{10/3}}{\phi^2}\right) \qquad \text{(D12)}$$

f = Total porosity = a + q

Z = Distance from top of contamination layer (down is +ve)

t = Time

Co = Initial C_T (t = 0)

H_E = Boundary Condition term

$$= \frac{1}{R_G\left(\frac{L_S}{D_S^{eff}} + \frac{L_{crack}}{D_{crack}\eta}\right)} \quad \text{for indoor air calculation (concrete slab).} \qquad \text{(D13)}$$

$$= \frac{1}{R_G\left(\frac{L_S}{D_S^{eff}}\right)}$$ for outdoor air calculation (no concrete slab). (D14)

L_S = depth of soil above contamination layer (L)

D_S^{eff} = effective diffusion coefficient of overlay soil (L^2/t)

L_{crack} = thickness of foundation or concrete paving (L)

D_{crack} = effective diffusion coefficient of soil in foundation cracks (L^2/t)

h = area of cracks / area of foundation

V_E = effective solute advective velocity (L/t) (D15)

$$= \frac{J_W}{R_L}$$

J_W = water flux (M/L^2t)

L = Contamination Layer Thickness (L)

m = Degradation Rate (1/t)

J_S = Contamination Flux (M/L^2t)

Diffusive Flux

$$J_S(Z,t) = \frac{1}{2}\,\mathrm{CoH_E.exp(-mt).erfc}\left(\frac{Z - V_E t}{\sqrt{4D_E t}}\right)$$

$$-\frac{1}{2}\,\mathrm{CoH_E.exp(-mt).erfc}\left(\frac{Z - L - V_E t}{\sqrt{4D_E t}}\right)$$

$$+\frac{1}{2}\,\mathrm{Co(H_E{+}V_E).exp}\left(\frac{V_E Z}{D_E} - \mu t\right)\mathrm{erfc}\left(\frac{Z + V_E t}{\sqrt{4D_E t}}\right)$$

$$-\frac{1}{2}\,\mathrm{Co(H_E{+}V_E).exp}\left(\frac{V_E Z}{D_E} - \mu t\right)\mathrm{erfc}\left(\frac{Z + L + V_E t}{\sqrt{4D_E t}}\right)$$

$$+\frac{1}{2}\,\mathrm{Co(2H_E{+}V_E).exp}\left(\frac{H_E(H_E + V_E)t + (H_E + V_E)Z + H_E L}{D_E} - \mu t\right)$$

$$*\ \mathrm{erfc}\left(\frac{Z + L + (2H_E + V_E)t}{\sqrt{4D_E t}}\right)$$

$$-\frac{1}{2}\,\mathrm{Co(2H_E{+}V_E).exp}\left(\frac{H_E(H_E + V_E)t + (H_E + V_E)Z}{D_E} - \mu t\right)\mathrm{erfc}\left(\frac{Z + (2H_E + V_E)t}{\sqrt{4D_E t}}\right)$$

(D16)

<u>Surface Soil to Outdoor Air</u> (Special Case)

$$\mathrm{VF_{ss}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{2\mathrm{W}\rho_{\mathrm{s}}}{\mathrm{U_{air}}\delta_{\mathrm{air}}}\sqrt{\frac{\mathrm{D_s^{eff}H}}{\pi(\sigma_{\mathrm{ws}}+\mathrm{k_s}\rho_{\mathrm{s}}+\mathrm{H}\sigma_{\mathrm{as}})\tau}}\times10^3\ \frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}} \tag{D17}$$

or

$$\mathrm{VF_{ss}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\mathrm{W}\rho_{\mathrm{s}}\mathrm{d}}{\mathrm{U_{air}}\delta_{\mathrm{air}}\tau}\times10^3\ \frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}} \qquad \text{whichever is less.} \tag{D18}$$

1.3.6 Surface soils

The volatilisation models presented to date are based on the assumption of diffusive transport only, i.e. no advective transport. However a pressure differential between indoor air and outdoor air (and hence soil gas) can be established by heating and other processes. Such pressure differences can induce advective transport of contaminants through soil and into indoor air. This is expected to be an important mechanism for surface soils (i.e. depths <1 metre).

The original Johnson and Ettinger model accounted for advective transfer. The ASTM RBCA guidance presents a simplified version of the equation which includes an assumption of no advective transport. The original diffusion/advective transport, depleting source form of the Johnson and Ettinger model has been used to estimate a volatilisation factor for surface soils to indoor air.

Theoretical work on surficial contaminated soils (Ferguson et al, 1995) suggest that pressure-driven flow is likely to dominate in winter. A pressure difference of 3.5 Pa, between indoor and outdoor air, in winter was used, which is consistent with UK measurements (made by the Building Research Establishment). This is also the default value used by Nazaroff et al (1985) for single-storey North American houses with basements.

The Johnson and Ettinger equations are composed of two parts: a depleting layer equation and a mass balance. When the volatilisation factor based on transport from the depleting layer becomes greater than the volatilisation factor based on a simple mass balance, then it is assumed that the contaminated layer is fully depleted.

Mass depleting equation:

$$\mathrm{VF_{sesp}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\rho_{\mathrm{s}}}{\tau\mathrm{ER.L_B}}\left[\sqrt{\gamma^2+2\psi\tau}-\gamma\right]\times10^3\ \frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}} \tag{D19}$$

where: $$\gamma=\frac{\mathrm{D_S^{eff}A_B}}{\mathrm{Q_{soil}}}\left[1-\exp\left(\frac{-\mathrm{Q_{soil.}L_{crack}}}{\mathrm{D_{crack.}A_B}\eta}\right)\right] \tag{D20}$$

$$\psi=\frac{\mathrm{D_s^{eff}H}}{\left[\sigma_{\mathrm{ws}}+\mathrm{k_s}\rho_{\mathrm{s}}+\mathrm{H}\sigma_{\mathrm{as}}\right]} \tag{D21}$$

or mass balance for depleted layer (which ever is less).

$$\mathrm{VF_{sesp}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\rho_s\Delta\mathrm{H_c}}{\tau\mathrm{ER.L_B}}\times10^3\ \frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}} \tag{D22}$$

Most of the parameters used above are defined in Section 8. Other parameters used include:

- A_B: surface area
- Q_{soil}: advective emission rate.

The surface area of the building foundation area has been set at 200 m^2 for residential buildings and 400 m^2 for commercial buildings. The dimensions of the buildings are important when considering pressure induced transfer. The assumed dimensions of the residential and commercial buildings are 16.67 m x 12 m and 20 m x 20 m respectively.

Q_{soil} has been estimated by Nazaroff by the following equations:

$$Q_{soil} = \frac{2\pi \Delta P k_v X_{crack}}{\mu_v \ln\left(2Z_{crack} / r_{crack}\right)} \qquad \text{(D23)}$$

and $$r_{crack} = \frac{\eta A_B}{X_{crack}} \qquad \text{(D24)}$$

where:

DP=Pressure difference (35 g/cm.s^2)

k_v=permeability of soil (cm^2)

X_{crack}=perimeter of floor area (cm)

m_v=vapour phase viscosity (1.8 x 10^{-4} g/cm.s)

Z_{crack}=depth to contamination (foundation thickness) (cm)

h=areal fraction of cracks in foundation (0.01)

A_B=Total area of infiltration (cm^2)

r_{crack}=radius of crack in foundation (cm)

1.4 Groundwater volatilisation model

1.4.1 Overview

Transport of volatile contaminants from contaminated groundwater to indoor or outdoor air may be modelled using a pseudo steady state approach provided the groundwater concentration remains constant with time. Assumption of pseudo steady state conditions greatly simplifies the governing differential equations and the resultant expressions for contaminant flux at the soil surface.

For the purposes of deriving Tier 1 Groundwater Acceptance Criteria pseudo steady state conditions are assumed to hold and therefore the solutions to the steady state model presented in the RBCA protocol, based on Johnson and Ettinger (1991), have been adopted.

Assumption of constant contaminant concentrations in groundwater requires that contaminants lost through volatilisation and other mechanisms (e.g. biodegradation) are replaced by the ongoing contamination of groundwater by a source e.g. contaminated soil. More detailed, site-specific modelling is required to account for variations in groundwater concentrations with time.

Where volatilisation from soil has been modelled on the basis of uniform soil conditions or properties, the adopted model for volatilisation from groundwater accounts for the increased moisture content and reduced air filled porosity associated with the capillary zone immediately above the groundwater.

1.4.2 Groundwater to indoor air

The volatilisation of contaminants from groundwater to outdoor air, as described by the Volatilisation Factor, may be estimated using the following expression:

(Refer - Johnson and Ettinger, 1991)

$$VF_{wesp}\left[\frac{(mg/m^3-air)}{(mg/L-H_2O)}\right]=\frac{H\left[\dfrac{D_{ws}^{eff}/L_{GW}}{ER.L_B}\right]}{1+\left[\dfrac{D_{ws}^{eff}/L_{GW}}{ER.L_B}\right]+\left[\dfrac{D_{ws}^{eff}/L_{GW}}{(D_{crack}^{eff}/L_{crack})\eta}\right]}\times 10^3\,\frac{L}{m^3}$$

(D25)

1.4.3 Groundwater to outdoor air

The volatilisation of contaminants from groundwater to outdoor air, as described by the Volatilisation Factor may be estimated using the following expression:

(Refer - USEPA, 1988)

$$VF_{amb}\left[\frac{(mg/m^3-air)}{(mg/L-H_2O)}\right]=\frac{H}{1+\left[\dfrac{U_{air}\delta_{air}L_{GW}}{WD_{ws}^{eff}}\right]}\times 10^3\,\frac{L}{m^3}$$

(D26)

1.4.4 Effective diffusion coefficients

The effective diffusion coefficients, or the effective diffusivity, of the soil profile including the capillary zone, must be determined for use in the equations presented above for volatilisation from groundwater.

(Refer - Johnson and Ettinger, 1991)

$$D_s^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\sigma_{as}^{3.33}}{\sigma_T^2}+D^{wat}\frac{1}{H}\frac{\sigma_{ws}^{3.33}}{\sigma_T^2}$$

Effective diffusion coefficient through soil

(D27)

$$D_{cap}^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\sigma_{acap}^{3.33}}{\sigma_T^2}+D^{wat}\frac{1}{H}\frac{\sigma_{wcap}^{3.33}}{\sigma_T^2}$$

Effective diffusion coefficient through capillary fringe

(D28)

$$D_{ws}^{eff}\left[\frac{cm^2}{s}\right]=(h_{cap}+h_v)\left[\frac{h_{cap}}{D_{cap}^{eff}}+\frac{h_v}{D_s^{eff}}\right]^{-1}$$

Effective diffusion coefficient between groundwater and soil surface (D29)

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\sigma_{acrack}^{3.33}}{\sigma_{Tcrack}^2}+D^{wat}\frac{1}{H}\frac{\sigma_{wcrack}^{3.33}}{\sigma_{Tcrack}^2}$$

Effective diffusion coefficient through foundation cracks (D30)

1.5 Outdoor air dilution model

The modified Jury model for volatilisation from contaminated soil can be used to estimate the flux of contaminants to indoor or outdoor air. It is necessary to link estimates of the flux with a dilution model to give the indoor and outdoor air concentrations. A simple box model was used for both indoor and outdoor air concentrations, as follows:

$$C_{OUTDOOR} = \frac{J \times W}{U_{air} \times \delta_{air}} \tag{D31}$$

where: J = Flux of Contaminant into Outdoor Air

W = Width of site (parallel to wind direction)

U_{air} = Wind Speed

d_{air} = Ambient air mixing zone height

$$C_{INDOOR} = \frac{J}{ER \times L_B} \tag{D32}$$

where: J = Flux of contaminant into building

ER = Air exchange rate of building

L_B = Enclosed space volume / Infiltration area ratio

The expressions presented in Section 5 for the volatilisation factors, describing the volatilisation of contaminants from groundwater, already incorporate the simple box models presented above.

1.6 Average concentration

Exposure estimates used in risk assessment for chronic (including carcinogenic) health effects are based on an estimate of the long term average indoor and outdoor air concentrations. The modified Jury model predicts contaminant fluxes (and therefore air concentrations) that vary with time. For the modified Jury model the flux is calculated as shown in Section 3.5 with the appropriate dilution factor (Eq. D31, D32) applied to calculate the instantaneous concentration of the air. The average concentration is calculated as follows:

$$\overline{C_{AIR}} = \frac{\int_0^{\tau} C_{AIR} dt}{\tau} \tag{D33}$$

where t = averaging time

= Exposure duration for carcinogenic contaminants (e.g. 20 years for commercial use, 30 years for residential use)

= 7 years for Non-Carcinogenic Contaminants (refer to Module 4).

The averaging time, t, is also used in the volatilisation factor calculation for volatilisation of contaminants from surface soils to ambient air. Due to the form of the Jury solution (D16) a numerical procedure (Simpson’s Rule) for integrations and averaging has been used.

1.7 Modified Johnson and Ettinger model

1.7.1 Overview

A modified version of the Johnson and Ettinger (1991) model may also be used to estimate the volatilisation of contaminants from soil. Modifications to the Johnson and Ettinger model considered included neglecting advective transport of vapours, assumption of no basement and configuring model for transport to outdoor, as well as indoor, air. The modified version of Johnson and Ettinger model, including the dilution component is presented in the following sections.

The modified Johnson and Ettinger model is presented here for information and comparison with the modified Jury model. It represents a simpler calculation procedure which results in slightly more conservative (stringent) acceptance criteria.

1.7.2 Soil to indoor air

Mass-depleting Equation:

$$\mathrm{VF_{sesp}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\rho_s \mathrm{L_T^o}}{\tau \mathrm{ER.L_B}}\left[\sqrt{\beta^2+2\chi\tau}-\beta\right]\times 10^3\,\frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}} \tag{D34}$$

where: $$\beta=\frac{\mathrm{D_s^{eff}L_{crack}}}{\mathrm{D_{crack}}\eta \mathrm{L_T^o}}+1 \tag{D35}$$

$$\chi=\frac{\mathrm{D_s^{eff}H}}{(\mathrm{L_T^o})^2\left[\sigma_{ws}+\mathrm{k_s}\rho_s+\mathrm{H}\sigma_{as}\right]} \tag{D36}$$

or mass balance for depleted layer (which ever is less).

$$\mathrm{VF_{sesp}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\rho_s\Delta \mathrm{H_c}}{\tau \mathrm{ER.L_B}}\times 10^3\,\frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}} \tag{D37}$$

1.7.3 Soil to outdoor air

For transport from soil to outdoor air L_{crack} is assumed to equal 0 (therefore $\beta = 1$) and the dilution component of the expression is replaced with that appropriate to dilution in outdoor air.

$$\mathrm{VF_{samb}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\mathrm{W}\rho_s}{\mathrm{U_{air}}\delta_{air}\tau}\left[\sqrt{(\mathrm{L_T^o})^2+\frac{2\mathrm{D_s^{eff}}\tau \mathrm{H}}{\left[\sigma_{ws}+\mathrm{k_s}\rho_s+\mathrm{H}\sigma_{as}\right]}}-\mathrm{L_T^o}\right]\times 10^3\,\frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}}$$

(D38)

or

$$\mathrm{VF_{samb}}\left[\frac{(\mathrm{mg/m^3-air})}{(\mathrm{mg/kg-soil})}\right]=\frac{\mathrm{W}\rho_s \mathrm{d}}{\mathrm{U_{air}}\delta_{air}\tau}\times 10^3\,\frac{\mathrm{cm^3.kg}}{\mathrm{m^3.g}}$$

whichever is less. (D39)

1.8 Model parameters

The key input parameters for volatilisation from both soil and groundwater to indoor and outdoor air are presented in Tables 4Da and 4Db.

Table 4Da Summary of model parameters

Parameter	Definition	Adopted Value
r_s	bulk density of soil	soil specific
q_{as}, a	air porosity of soil	soil specific
q_{ws}, q	water porosity of soil	soil specific
q_T, f	total porosity	soil specific
q_{acap}	air porosity of soil in capillary fringe	soil specific
q_{wcap}	water porosity of soil in capillary fringe	soil specific
q_{acrack}	air porosity of soil in foundation cracks	soil specific
q_{wcrack}	water porosity of soil in foundation cracks	soil specific
W	width of source area parallel to wind direction (cm)	1500
U_{air}	wind speed above ground surface (cm/s)	225
d_{air}	ambient air mixing zone height (cm)	150
D_s^{eff}, D_E	diffusion coefficient in soil (cm^2/s)	chem/soil specific
H, K_H	Henry's constant (cm^3H_2O/cm^3air)	chemical specific
k_s, K_D	soil-water sorption coefficient (foc x K_{oc})	chem/soil specific
Foc	fraction organic carbon	soil specific
Koc	organic carbon adsorption coefficient	chemical specific
D^{wat}	diffusion coefficient in water (cm^2/s)	chemical specific
D^{air}	diffusion coefficient in air (cm^2/s)	chemical specific
d, ΔH	layer thickness of contaminated soil (cm)	200
h_v	thickness of vadose zone (cm) - (L_{GW} - h_{cap})	depth & soil spec.
h_{cap}	thickness of capillary fringe (cm)	soil specific
ER	enclosed space air exchange rate (s^{-1}) residential	0.00056
	commercial/industrial	0.00056
L_B	enclosed space volume/infiltration area ratio (cm) residential	200
	commercial/industrial	300
L_{crack}	enclosed space foundation or wall thickness (cm)	20
h	areal fraction of cracks in foundation/walls ($cm^2_{cracks}/cm^2_{total\ A}$)	0.01
L_{GW}	depth to ground water (cm)	200 / 400 / 800
t	averaging time period (s) Non-carcinogenic (7 yr)	220,752,000
	Carcinogenic - commercial (20 yr)	630,720,000
	Carcinogenic - residential (30 yr)	946,080,000
L_S, L_T^o	initial separation of building slab & soil (cm)	0 / 100 / 400
Z	distance from top of contamination layer	0 (top)
V_E	effective solute advective velocity (cm/s)	0
m	degradation rate (1/s)	0
H_E	boundary condition term	site,soil,chem spec.
μ_v	Vapour viscosity (g/cm.s)	1.8×10^{-4}
ΔP	Pressure difference of indoor air and soil ($g/cm.s^2$)	35
Co	initial concentration (mg/cm^3) - arbitrary number	1

Table 4Db Soil properties for volatilisation modelling

Soil Type	Example	Air Filled Porosity (unitless)	Water Filled Porosity (unitless)	Total Porosity (unitless)	Organic Carbon Content (%)	Bulk Density (tonne/m^3)	AirPermeability (cm^2)	Capillary Fringe Thickness (m)
Sand, sandy loam, silty sand	Recent (R), yellow brown sands (YBS)	0.26	0.12	0.38	0.3	1.9	1×10^{-8}	0.05
Silts, sandy silts, silty loams, clayey sand	Yellow grey earths (YG), yellow brown earth (YB)	0.18	0.27	0.45	0.3	1.9	1×10^{-9}	0.3
Silty clay, clay loam, sandy clay		0.06	0.44	0.5	0.3	1.8	7×10^{-10}	0.8
Clay		0.02	0.48	0.5	0.3	1.8	6×10^{-11}	1
Pumice	Pumice sands (YBP)	0.2	0.35	0.55	0.5	1.7	4×10^{-8}	0.5
Peats and other highly organic soils		0.23	0.23	0.46	12	1.6	1×10^{-9}	0.3
Fractured basalts		0.08	0.03	0.11	<0.1	2.4	1×10^{-9}	0.05
Gravel		0.25	0.03	0.28	<0.1	2	1×10^{-5}	0.05

1.9 Discussion of results

The results of the volatilisation modelling of diffusive transport from soil to indoor and outdoor air (Jury model) are presented in Tables 4D1 a-f and 4D2 a-f. The results of modelling advective transport are presented in Tables 4D3 a-f and 4D4 a-f.

A review of the results from the Jury model indicates slightly higher criteria are nominated for the sand soil type compared to the silty sand soil type for the indoor air pathway. The reason for this apparent discrepancy is as follows:

- the Jury model allows for diffusion both upward and downward
- for all soil types except sand the resistance to downward migration (assuming a uniform soil type of infinite depth) is greater than that for upward migration (i.e. through a layer of soil and a concrete building foundation). On this basis the mass of contaminant migrating downward is relatively minor.
- sand has a low resistance to migration through the soil. Large resistance from the concrete foundation produces a greater resistance upwards than that downwards. Therefore, a significant quantity of contaminant migrates downward, rather than upward and into the building (hence criteria for this soil type are higher).

In practice groundwater or other features would limit the downward diffusion of contaminants (i.e. the assumption of a uniform soil of infinite depth does not hold) and therefore where the calculated criteria for sand are higher than those for silty sand, the values for silty sand have been adopted for sand in Tables 4.10 to 4.15 of Module 4.

All of the acceptance criteria derived for soils are based on an initial thickness of the contaminated layer of 2 metres. This is expected to be a reasonable value reflecting a conservative estimate of that typically remaining at many sites. Where a thicker contaminated zone remains on-site in most cases it is only likely to be two to three times the thickness selected and therefore at worst the nominated criteria could be in error by a similar factor.

1.10 References

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Millington J.J and Quirk J.P. 1961. **Permeability of Porous Solid.** Trans. Faraday Soc., 57. 1200-1207

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Table 4D1a Preliminary Health Risk Based Acceptance Criteria - Soil - *Residential and Agricultural Site Use* SAND SOIL Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1 m	>4 m	Surface	>1 m	>4 m
Alkanes										
C_7 - C_9		5		5	6.20E-03	6.01E-03	5.51E-03	7.65E-05	6.94E-05	5.92E-05
C_{10} - C_{14}		0.3		0.3	5.21E-04	4.98E-04	4.38E-04	5.47E-05	2.62E-05	1.08E-05
C_{15} - C_{36}		1.5		1.5	8.62E-07	9.85E-07	8.62E-07	2.24E-06	9.85E-08	2.53E-08
MAHs										
benzene	0.029		3.45E-04		1.71E-03	1.66E-03	1.53E-03	1.79E-05	1.66E-05	1.47E-05
toluene		0.11		0.11	2.67E-03	2.56E-03	2.29E-03	7.65E-05	5.78E-05	3.88E-05
ethylbenzene		0.029		0.029	1.41E-03	1.35E-03	1.20E-03	7.65E-05	4.58E-05	2.49E-05
xylene		0.09		0.09	2.87E-03	2.76E-03	2.47E-03	7.65E-05	5.90E-05	4.06E-05
Aromatics										
naphthalene		0.004		0.004	2.92E-04	2.78E-04	2.44E-04	3.89E-05	1.72E-05	6.34E-06
pyrene		0.03		0.03	3.40E-08	3.24E-08	2.84E-08	4.06E-07	3.34E-09	8.39E-10
Benzo(a)pyrene	7.3		1.37E-06		4.31E-10	4.11E-10	3.60E-10	2.21E-08	1.31E-11	3.28E-12

Risk Based Screening Level (mg/kg)												
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1 m	>4 m	Surface	>1 m	>4 m	Surface	>1 m	>4 m	Surface	>1 m	>4 m
C_7 - C_9							2.39E+05	2.63E+05	3.08E+05	3.92E+03	4.05E+03	4.42E+03
C_{10} - C_{14}							2.00E+04	4.18E+04	1.02E+05	2.80E+03	2.93E+03	3.33E+03
C_{15} - C_{36}							2.45E+06	5.56E+07	2.16E+08	8.47E+06	7.41E+06	8.47E+06
MAHs												
benzene	1.65E+02	1.77E+02	2.00E+02	2.29E+00	2.36E+00	2.55E+00						
toluene							5.25E+03	6.94E+03	1.03E+04	2.00E+02	2.09E+02	2.34E+02
ethylbenzene							1.38E+03	2.31E+03	4.26E+03	1.00E+02	1.04E+02	1.18E+02
xylene							4.29E+03	5.56E+03	8.10E+03	1.52E+02	1.59E+02	1.78E+02
Aromatics												
naphthalene							3.75E+02	8.47E+02	2.30E+03	6.67E+01	7.00E+01	7.97E+01
pyrene							2.70E+05	3.28E+07	1.31E+08	4.29E+06	4.51E+06	5.15E+06
benzo (a) pyrene	5.29E+02	8.90E+05	3.56E+06	3.61E+04	3.79E+04	4.33E+04						

Table 4D1b Preliminary Health Risk Based Acceptance Criteria - Soil *Residential and Agricultural Site Use* SILT SOIL Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	8.92E-03	8.13E-03	6.39E-03	7.65E-05	6.18E-05	4.49E-05
C_{10} - C_{14}		0.3		0.3	5.59E-04	4.60E-04	3.00E-04	2.51E-05	8.78E-06	2.88E-06
C_{15} - C_{36}		1.5		1.5	5.29E-07	8.33E-07	5.29E-07	1.02E-06	2.10E-08	5.33E-09
MAHs										
benzene	0.029		3.45E-04		2.19E-03	2.01E-03	1.60E-03	1.79E-05	1.47E-05	1.10E-05
toluene		0.11		0.11	3.74E-03	3.20E-03	2.23E-03	7.65E-05	3.90E-05	1.91E-05
ethylbenzene		0.029		0.029	1.84E-03	1.54E-03	1.03E-03	4.99E-05	2.36E-05	9.41E-06
xylene		0.09		0.09	4.03E-03	3.46E-03	2.42E-03	7.65E-05	4.08E-05	2.05E-05
Aromatics										
naphthalene		0.004		0.004	2.86E-04	2.35E-04	1.52E-04	1.77E-05	4.87E-06	1.49E-06
pyrene		0.03		0.03	3.40E-08	3.18E-08	2.67E-08	3.46E-07	2.42E-09	6.09E-10
benzo (a) pyrene	7.3		1.37E-06		4.31E-10	4.25E-10	4.07E-10	4.07E-08	1.38E-10	3.47E-11

Risk Based Screening Level (mg/kg)												
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							2.39E+05	2.95E+05	4.07E+05	2.73E+03	2.99E+03	3.81E+03
C_{10} - C_{14}							4.37E+04	1.25E+05	3.81E+05	2.61E+03	3.18E+03	4.87E+03
C_{15} - C_{36}							5.34E+06	2.60E+08	1.03E+09	1.38E+07	8.76E+06	1.38E+07
MAHs												
benzene	1.65E+02	1.99E+02	2.66E+02	1.79E+00	1.95E+00	2.44E+00						
toluene							5.25E+03	1.03E+04	2.10E+04	1.43E+02	1.67E+02	2.40E+02
ethylbenzene							2.12E+03	4.48E+03	1.12E+04	7.68E+01	9.19E+01	1.37E+02
xylene							4.29E+03	8.05E+03	1.60E+04	1.09E+02	1.27E+02	1.81E+02
Aromatics												
naphthalene							8.23E+02	3.00E+03	9.80E+03	6.79E+01	8.29E+01	1.28E+02
pyrene							3.17E+05	4.52E+07	1.80E+08	4.29E+06	4.59E+06	5.48E+06
benzo (a) pyrene	2.87E+02	8.43E+04	3.37E+05	3.61E+04	3.66E+04	3.82E+04						

Table 4D1c Preliminary Health Risk Based Acceptance Criteria - Soil *Residential and Agricultural Site Use* SILTY CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	6.65E-03	3.32E-03	1.27E-03	3.84E-05	1.72E-05	6.40E-06
C_{10} - C_{14}		0.3		0.3	3.48E-04	4.70E-05	1.30E-05	3.53E-06	2.51E-07	6.57E-08
C_{15} - C_{36}		1.5		1.5	2.21E-08	8.28E-08	2.21E-08	1.44E-07	4.45E-10	1.11E-10
MAHs										
benzene	0.029		3.45E-04		1.61E-03	8.48E-04	3.36E-04	9.70E-06	4.46E-06	1.70E-06
toluene		0.11		0.11	2.00E-03	5.64E-04	1.76E-04	1.33E-05	3.04E-06	8.95E-07
ethylbenzene		0.029		0.029	9.34E-04	1.76E-04	5.09E-05	7.80E-06	9.37E-07	2.57E-07
xylene		0.09		0.09	2.14E-03	6.22E-04	1.96E-04	1.40E-05	3.35E-06	9.93E-07
Aromatics										
naphthalene		0.004		0.004	2.30E-04	5.91E-05	1.83E-05	4.27E-06	3.64E-07	9.62E-08
pyrene		0.03		0.03	3.40E-08	3.32E-08	3.11E-08	5.82E-07	7.23E-09	1.82E-09
benzo (a) pyrene	7.3		1.37E-06		4.31E-10	4.30E-10	4.25E-10	7.86E-08	5.69E-10	1.43E-10

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							4.75E+05	1.06E+06	2.85E+06	3.66E+03	7.33E+03	1.91E+04
C_{10} - C_{14}							3.10E+05	4.36E+06	1.67E+07	4.20E+03	3.11E+04	1.12E+05
C_{15} - C_{36}							3.80E+07	1.23E+10	4.92E+10	3.31E+08	8.81E+07	3.31E+08
MAHs												
benzene	3.03E+02	6.59E+02	1.73E+03	2.43E+00	4.62E+00	1.17E+01						
toluene							3.02E+04	1.32E+05	4.49E+05	2.68E+02	9.49E+02	3.03E+03
ethylbenzene							1.36E+04	1.13E+05	4.13E+05	1.51E+02	8.02E+02	2.77E+03
xylene							2.34E+04	9.82E+04	3.31E+05	2.05E+02	7.05E+02	2.24E+03
Aromatics												
naphthalene							3.42E+03	4.01E+04	1.52E+05	8.46E+01	3.29E+02	1.06E+03
pyrene							1.88E+05	1.51E+07	6.01E+07	4.30E+06	4.40E+06	4.69E+06
benzo (a) pyrene	1.48E+02	2.05E+04	8.16E+04	3.61E+04	3.62E+04	3.66E+04						

Table 4D1d Preliminary Health Risk Based Acceptance Criteria - Soil *Residential and Agricultural Site Use* CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30 yr			
Target Risk:	0.00001	Exposure Dur:	30 yr			
Target HI:	1	Body Weight:	70 kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/kg$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	1.31E-03	1.65E-04	4.49E-05	6.54E-06	8.15E-07	2.22E-07
C_{10} - C_{14}		0.3		0.3	1.00E-04	1.41E-06	3.56E-07	5.75E-07	6.99E-09	1.76E-09
C_{15} - C_{36}		1.5		1.5	5.98E-10	2.39E-09	5.98E-10	2.35E-08	1.18E-11	2.96E-12
MAHs										
benzene	0.029		3.45E-04		1.14E-03	4.44E-04	1.52E-04	6.08E-06	2.27E-06	7.58E-07
toluene		0.11		0.11	1.31E-03	2.23E-04	6.31E-05	7.77E-06	1.14E-06	3.15E-07
ethylbenzene		0.029		0.029	3.09E-04	1.23E-05	3.17E-06	4.27E-06	6.12E-08	1.57E-08
xylene		0.09		0.09	1.38E-03	2.39E-04	6.79E-05	8.06E-06	1.22E-06	3.38E-07
Aromatics										
naphthalene		0.004		0.004	2.26E-04	5.45E-05	1.66E-05	4.05E-06	3.29E-07	8.68E-08
pyrene		0.03		0.03	3.40E-08	3.34E-08	3.18E-08	6.72E-07	9.63E-09	2.43E-09
benzo (a) pyrene	7.3		1.37E-06		4.31E-10	4.30E-10	4.27E-10	9.09E-08	7.60E-10	1.91E-10

Contaminant	Risk Based Screening Level (mg/kg) Carcinogenic Outdoors			Carcinogenic Indoors			Non-carcinogenic Outdoors			Non-carcinogenic Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							2.79E+06	2.24E+07	8.22E+07	1.86E+04	1.48E+05	5.42E+05
C_{10} - C_{14}							1.91E+06	1.57E+08	6.22E+08	1.46E+04	1.03E+06	4.10E+06
C_{15} - C_{36}							2.33E+08	4.63E+11	1.85E+12	1.22E+10	3.06E+09	1.22E+10
MAHs												
benzene	4.83E+02	1.30E+03	3.87E+03	3.45E+00	8.82E+00	2.58E+01						
toluene							5.17E+04	3.53E+05	1.28E+06	4.09E+02	2.40E+03	8.48E+03
ethylbenzene							2.48E+04	1.73E+06	6.76E+06	4.56E+02	1.14E+04	4.45E+04
xylene							4.08E+04	2.69E+05	9.71E+05	3.18E+02	1.83E+03	6.45E+03
Aromatics												
naphthalene							3.61E+03	4.44E+04	1.68E+05	8.60E+01	3.57E+02	1.17E+03
pyrene							1.63E+05	1.14E+07	4.51E+07	4.30E+06	4.37E+06	4.59E+06
benzo (a) pyrene	1.28E+02	1.53E+04	6.11E+04	3.61E+04	3.62E+04	3.65E+04						

Table 4D1e Preliminary Health Risk Based Acceptance Criteria - Soil *Residential and Agricultural Site Use* PUMICE Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30 yr		
Target Risk:	0.00001	Exposure Dur:	30 yr		
Target HI:	1	Body Weight:	70 kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/kg$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	7.32E-03	6.58E-03	5.02E-03	6.85E-05	5.27E-05	3.61E-05
C_{10} - C_{14}		0.3		0.3	3.42E-04	2.78E-04	1.78E-04	1.79E-05	5.38E-06	1.68E-06
C_{15} - C_{36}		1.5		1.5	3.09E-07	4.95E-07	3.09E-07	7.32E-07	1.20E-08	3.04E-09
MAHs										
benzene	0.029		3.45E-04		1.81E-03	1.63E-03	1.26E-03	1.60E-05	1.26E-05	8.91E-06
toluene		0.11		0.11	2.69E-03	2.26E-03	1.54E-03	6.18E-05	2.94E-05	1.33E-05
ethylbenzene		0.029		0.029	1.21E-03	9.94E-04	6.52E-04	3.58E-05	1.60E-05	5.93E-06
xylene		0.09		0.09	2.93E-03	2.47E-03	1.69E-03	6.62E-05	3.12E-05	1.44E-05
Aromatics										
naphthalene		0.004		0.004	1.75E-04	1.42E-04	9.05E-05	1.27E-05	2.96E-06	8.73E-07
pyrene		0.03		0.03	2.04E-08	1.95E-08	1.71E-08	3.01E-07	2.06E-09	5.17E-10
benzo (a) pyrene	7.3		1.37E-06		2.59E-10	2.56E-10	2.49E-10	3.72E-08	1.32E-10	3.31E-11

Contaminant	Risk Based Screening Level (mg/kg)											
	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							2.67E+05	3.46E+05	5.06E+05	3.32E+03	3.70E+03	4.85E+03
C_{10} - C_{14}							6.11E+04	2.04E+05	6.51E+05	4.27E+03	5.26E+03	8.21E+03
C_{15} - C_{36}							7.48E+06	4.54E+08	1.80E+09	2.36E+07	1.47E+07	2.36E+07
MAHs												
benzene	1.84E+02	2.33E+02	3.29E+02	2.17E+00	2.40E+00	3.10E+00						
toluene							6.49E+03	1.36E+04	3.03E+04	1.99E+02	2.36E+02	3.49E+02
ethylbenzene							2.95E+03	6.62E+03	1.79E+04	1.17E+02	1.42E+02	2.17E+02
xylene							4.96E+03	1.05E+04	2.28E+04	1.50E+02	1.77E+02	2.60E+02
Aromatics												
naphthalene							1.15E+03	4.94E+03	1.67E+04	1.11E+02	1.37E+02	2.15E+02
pyrene							3.64E+05	5.32E+07	2.12E+08	7.16E+06	7.50E+06	8.55E+06
benzo (a) pyrene	3.13E+02	8.84E+04	3.53E+05	6.01E+04	6.07E+04	6.23E+04						

Table 4D1f Preliminary Health Risk Based Acceptance Criteria - Soil *Residential and Agricultural Site Use* PEATS and HIGH ORGANIC Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30 yr			
Target Risk:	0.00001	Exposure Dur:	30 yr			
Target HI:	1	Body Weight:	70 kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	1.41E-03	1.29E-03	1.02E-03	6.18E-05	2.92E-05	1.35E-05
C_{10} - C_{14}		0.3		0.3	1.54E-05	1.39E-05	1.07E-05	5.36E-06	6.26E-07	1.69E-07
C_{15} - C_{36}		1.5		1.5	1.80E-08	2.33E-08	1.80E-08	2.19E-07	1.15E-09	2.90E-10
MAHs										
benzene	0.029		3.45E-04		4.22E-04	3.87E-04	3.08E-04	1.50E-05	7.87E-06	3.92E-06
toluene		0.11		0.11	2.03E-04	1.83E-04	1.43E-04	1.98E-05	6.66E-06	2.15E-06
ethylbenzene		0.029		0.029	6.30E-05	5.69E-05	4.40E-05	1.09E-05	2.35E-06	6.84E-07
xylene		0.09		0.09	2.39E-04	2.16E-04	1.68E-04	2.16E-05	7.68E-06	2.53E-06
Aromatics										
naphthalene		0.004		0.004	7.90E-06	7.13E-06	5.50E-06	3.84E-06	3.31E-07	8.78E-08
pyrene		0.03		0.03	8.51E-10	7.96E-10	6.68E-10	5.02E-08	6.10E-11	1.53E-11
benzo (a) pyrene	7.3		1.37E-06		1.08E-11	1.05E-11	9.87E-12	4.68E-09	1.95E-12	4.87E-13

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							2.95E+05	6.25E+05	1.36E+06	1.73E+04	1.89E+04	2.39E+04
C_{10} - C_{14}							2.04E+05	1.75E+06	6.46E+06	9.50E+04	1.05E+05	1.36E+05
C_{15} - C_{36}							2.50E+07	4.74E+09	1.89E+10	4.06E+08	3.13E+08	4.06E+08
MAHs												
benzene	1.95E+02	3.73E+02	7.49E+02	9.27E+00	1.01E+01	1.27E+01						
toluene							2.03E+04	6.03E+04	1.87E+05	2.64E+03	2.92E+03	3.76E+03
ethylbenzene							9.69E+03	4.51E+04	1.55E+05	2.24E+03	2.48E+03	3.21E+03
xylene							1.52E+04	4.28E+04	1.30E+05	1.83E+03	2.02E+03	2.60E+03
Aromatics												
naphthalene							3.80E+03	4.40E+04	1.66E+05	2.46E+03	2.73E+03	3.54E+03
pyrene							2.18E+06	1.79E+09	7.17E+09	1.72E+08	1.83E+08	2.19E+08
benzo (a) pyrene	2.49E+03	6.00E+06	2.40E+07	1.44E+06	1.48E+06	1.58E+06						

Table 4D2a Preliminary Health Risk Based Acceptance Criteria - Soil *Commercial/Industrial Site Use* SAND Soil Type

Site Use:	Residential	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	4.13E-03	4.01E-03	3.67E-03	7.65E-05	6.94E-05	5.92E-05
C_{10} - C_{14}		0.3		0.3	3.48E-04	3.32E-04	2.92E-04	5.47E-05	2.62E-05	1.08E-05
C_{15} - C_{36}		1.5		1.5	5.75E-07	6.56E-07	5.75E-07	2.24E-06	9.85E-08	2.53E-08
MAHs										
benzene	0.029		3.45E-04		1.50E-03	1.45E-03	1.33E-03	2.68E-05	2.44E-05	2.10E-05
toluene		0.11		0.11	1.78E-03	1.71E-03	1.53E-03	7.65E-05	5.78E-05	3.88E-05
ethylbenzene		0.029		0.029	9.41E-04	9.01E-04	7.97E-04	7.65E-05	4.58E-05	2.49E-05
xylene		0.09		0.09	1.91E-03	1.84E-03	1.64E-03	7.65E-05	5.90E-05	4.06E-05
Aromatics										
naphthalene		0.004		0.004	1.94E-04	1.85E-04	1.63E-04	3.89E-05	1.72E-05	6.34E-06
pyrene		0.03		0.03	2.27E-08	2.16E-08	1.89E-08	4.06E-07	3.34E-09	8.39E-10
benzo (a) pyrene	7.3		1.37E-06		8.86E-11	8.44E-11	7.38E-11	2.70E-08	1.31E-11	3.28E-12

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							6.96E+05	7.67E+05	8.99E+05	1.29E+04	1.33E+04	1.45E+04
C_{10} - C_{14}							5.84E+04	1.22E+05	2.96E+05	9.19E+03	9.63E+03	1.09E+04
C_{15} - C_{36}							7.14E+06	1.62E+08	6.30E+08	2.78E+07	2.43E+07	2.78E+07
MAHs												
benzene	4.80E+02	5.26E+02	6.12E+02	8.58E+00	8.85E+00	9.65E+00						
toluene							1.53E+04	2.03E+04	3.02E+04	6.58E+02	6.85E+02	7.68E+02
ethylbenzene							4.04E+03	6.74E+03	1.24E+04	3.28E+02	3.43E+02	3.87E+02
xylene							1.25E+04	1.62E+04	2.36E+04	5.00E+02	5.21E+02	5.83E+02
Aromatics												
naphthalene							1.09E+03	2.47E+03	6.72E+03	2.19E+02	2.30E+02	2.61E+02
pyrene							7.87E+05	9.57E+07	3.81E+08	1.41E+07	1.48E+07	1.69E+07
benzo (a) pyrene	1.89E+03	3.89E+06	1.56E+07	5.76E+05	6.05E+05	6.92E+05						

Table 4D2b Preliminary Health Risk Based Acceptance Criteria - Soil *Commercial/Industrial Site Use* SILT Soil Type

Site Use:	Residential	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/kg$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	5.95E-03	5.42E-03	4.26E-03	7.65E-05	6.18E-05	4.49E-05
C_{10} - C_{14}		0.3		0.3	3.73E-04	3.06E-04	2.00E-04	2.51E-05	8.78E-06	2.88E-06
C_{15} - C_{36}		1.5		1.5	3.52E-07	5.55E-07	3.52E-07	1.02E-06	2.10E-08	5.33E-09
MAHs										
benzene	0.029		3.45E-04		1.97E-03	1.78E-03	1.38E-03	2.68E-05	2.11E-05	1.49E-05
toluene		0.11		0.11	2.50E-03	2.14E-03	1.49E-03	7.65E-05	3.90E-05	1.91E-05
ethylbenzene		0.029		0.029	1.22E-03	1.02E-03	6.87E-04	4.99E-05	2.36E-05	9.41E-06
xylene		0.09		0.09	2.68E-03	2.30E-03	1.61E-03	7.65E-05	4.08E-05	2.05E-05
Aromatics										
naphthalene		0.004		0.004	1.91E-04	1.57E-04	1.02E-04	1.77E-05	4.87E-06	1.49E-06
pyrene		0.03		0.03	2.27E-08	2.12E-08	1.78E-08	3.46E-07	2.42E-09	6.09E-10
benzo (a) pyrene	7.3		1.37E-06		8.86E-11	8.81E-11	8.69E-11	4.98E-08	1.38E-10	3.47E-11

Contaminant	Risk Based Screening Level (mg/kg) Carcinogenic Outdoors			Carcinogenic Indoors			Non-carcinogenic Outdoors			Non-carcinogenic Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							6.96E+05	8.62E+05	1.19E+06	8.95E+03	9.82E+03	1.25E+04
C_{10} - C_{14}							1.27E+05	3.64E+05	1.11E+06	8.57E+03	1.04E+04	1.60E+04
C_{15} - C_{36}							1.56E+07	7.59E+08	3.00E+09	4.53E+07	2.87E+07	4.53E+07
MAHs												
benzene	4.80E+02	6.09E+02	8.64E+02	6.53E+00	7.21E+00	9.29E+00						
toluene							1.53E+04	3.00E+04	6.13E+04	4.69E+02	5.48E+02	7.87E+02
ethylbenzene							6.18E+03	1.31E+04	3.28E+04	2.52E+02	3.01E+02	4.49E+02
xylene							1.25E+04	2.35E+04	4.66E+04	3.57E+02	4.16E+02	5.94E+02
Aromatics												
naphthalene							2.40E+03	8.74E+03	2.86E+04	2.23E+02	2.72E+02	4.19E+02
pyrene							9.24E+05	1.32E+08	5.25E+08	1.41E+07	1.51E+07	1.80E+07
benzo (a) pyrene	1.02E+03	3.69E+05	1.47E+06	5.76E+05	5.79E+05	5.87E+05						

Table 4D2c Preliminary Health Risk Based Acceptance Criteria - Soil *Commercial/Industrial Site Use* SILTY CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	4.44E-03	2.21E-03	8.48E-04	3.84E-05	1.72E-05	6.40E-06
C_{10} - C_{14}		0.3		0.3	2.32E-04	3.13E-05	8.69E-06	3.53E-06	2.51E-07	6.57E-08
C_{15} - C_{36}		1.5		1.5	1.47E-08	5.52E-08	1.47E-08	1.44E-07	4.45E-10	1.11E-10
MAHs										
benzene	0.029		3.45E-04		1.35E-03	6.39E-04	2.39E-04	1.19E-05	5.08E-06	1.82E-06
toluene		0.11		0.11	1.33E-03	3.76E-04	1.18E-04	1.33E-05	3.04E-06	8.95E-07
ethylbenzene		0.029		0.029	6.22E-04	1.17E-04	3.39E-05	7.80E-06	9.37E-07	2.57E-07
xylene		0.09		0.09	1.43E-03	4.14E-04	1.31E-04	1.40E-05	3.35E-06	9.93E-07
Aromatics										
naphthalene		0.004		0.004	1.53E-04	3.94E-05	1.22E-05	4.27E-06	3.64E-07	9.62E-08
pyrene		0.03		0.03	2.26E-08	2.21E-08	2.07E-08	5.82E-07	7.23E-09	1.82E-09
benzo (a) pyrene	7.3		1.37E-06		8.86E-11	8.85E-11	8.82E-11	9.63E-08	5.69E-10	1.43E-10

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							1.39E+06	3.10E+06	8.32E+06	1.20E+04	2.40E+04	6.28E+04
C_{10} - C_{14}							9.05E+05	1.27E+07	4.86E+07	1.38E+04	1.02E+05	3.68E+05
C_{15} - C_{36}							1.11E+08	3.59E+10	1.43E+11	1.09E+09	2.89E+08	1.09E+09
MAHs												
benzene	1.08E+03	2.53E+03	7.06E+03	9.53E+00	2.01E+01	5.37E+01						
toluene							8.81E+04	3.85E+05	1.31E+06	8.80E+02	3.11E+03	9.95E+03
ethylbenzene							3.96E+04	3.29E+05	1.20E+06	4.96E+02	2.63E+03	9.11E+03
xylene							6.83E+04	2.86E+05	9.65E+05	6.71E+02	2.31E+03	7.34E+03
Aromatics												
naphthalene							9.98E+03	1.17E+05	4.43E+05	2.78E+02	1.08E+03	3.49E+03
pyrene							5.49E+05	4.42E+07	1.75E+08	1.41E+07	1.44E+07	1.54E+07
benzo (a) pyrene	5.30E+02	8.96E+04	3.57E+05	5.76E+05	5.77E+05	5.79E+05						

Table 4D2d Preliminary Health Risk Based Acceptance Criteria - Soil *Commercial/Industrial Site Use* CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	240 d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20 yr		
Target Risk:	0.00001	Exposure Dur:	20 yr		
Target HI:	1	Body Weight:	70 kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/kg$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	8.72E-04	1.10E-04	2.99E-05	6.54E-06	8.15E-07	2.22E-07
C_{10} - C_{14}		0.3		0.3	6.68E-05	9.41E-07	2.38E-07	5.75E-07	6.99E-09	1.76E-09
C_{15} - C_{36}		1.5		1.5	3.99E-10	1.59E-09	3.99E-10	2.35E-08	1.18E-11	2.96E-12
MAHs										
benzene	0.029		3.45E-04		9.20E-04	3.17E-04	1.04E-04	7.45E-06	2.43E-06	7.77E-07
toluene		0.11		0.11	8.74E-04	1.49E-04	4.21E-05	7.77E-06	1.14E-06	3.15E-07
ethylbenzene		0.029		0.029	2.06E-04	8.22E-06	2.11E-06	4.27E-06	6.12E-08	1.57E-08
xylene		0.09		0.09	9.18E-04	1.59E-04	4.52E-05	8.06E-06	1.22E-06	3.38E-07
Aromatics										
naphthalene		0.004		0.004	1.51E-04	3.63E-05	1.11E-05	4.05E-06	3.29E-07	8.68E-08
pyrene		0.03		0.03	2.26E-08	2.23E-08	2.12E-08	6.72E-07	9.63E-09	2.43E-09
benzo (a) pyrene	7.3		1.37E-06		8.86E-11	8.85E-11	8.83E-11	1.11E-07	7.60E-10	1.91E-10

Contaminant	Risk Based Screening Level (mg/kg) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							8.14E+06	6.53E+07	2.40E+08	6.11E+04	4.85E+05	1.78E+06
C_{10} - C_{14}							5.56E+06	4.57E+08	1.81E+09	4.78E+04	3.39E+06	1.34E+07
C_{15} - C_{36}							6.79E+08	1.35E+12	5.40E+12	4.00E+10	1.00E+10	4.00E+10
MAHs												
benzene	1.73E+03	5.29E+03	1.65E+04	1.40E+01	4.05E+01	1.24E+02						
toluene							1.51E+05	1.03E+06	3.72E+06	1.34E+03	7.89E+03	2.78E+04
ethylbenzene							7.23E+04	5.04E+06	1.97E+07	1.50E+03	3.75E+04	1.46E+05
xylene							1.19E+05	7.85E+05	2.83E+06	1.04E+03	6.01E+03	2.12E+04
Aromatics												
naphthalene							1.05E+04	1.29E+05	4.91E+05	2.82E+02	1.17E+03	3.85E+03
pyrene							4.75E+05	3.32E+07	1.31E+08	1.41E+07	1.43E+07	1.51E+07
benzo (a) pyrene	4.59E+02	6.71E+04	2.67E+05	5.76E+05	5.77E+05	5.78E+05						

Table 4D2e Preliminary Health Risk Based Acceptance Criteria - Soil *Commercial/Industrial Site Use* PUMICE Soil Type

Site Use:	Residential	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	4.88E-03	4.39E-03	3.35E-03	6.85E-05	5.27E-05	3.61E-05
C_{10} - C_{14}		0.3		0.3	2.28E-04	1.85E-04	1.19E-04	1.79E-05	5.38E-06	1.68E-06
C_{15} - C_{36}		1.5		1.5	2.06E-07	3.30E-07	2.06E-07	7.32E-07	1.20E-08	3.04E-09
MAHs										
benzene	0.029		3.45E-04		1.60E-03	1.42E-03	1.07E-03	2.40E-05	1.79E-05	1.18E-05
toluene		0.11		0.11	1.79E-03	1.51E-03	1.02E-03	6.18E-05	2.94E-05	1.33E-05
ethylbenzene		0.029		0.029	8.03E-04	6.63E-04	4.34E-04	3.58E-05	1.60E-05	5.93E-06
xylene		0.09		0.09	1.95E-03	1.65E-03	1.12E-03	6.62E-05	3.12E-05	1.44E-05
Aromatics										
naphthalene		0.004		0.004	1.16E-04	9.45E-05	6.03E-05	1.27E-05	2.96E-06	8.73E-07
pyrene		0.03		0.03	1.36E-08	1.30E-08	1.14E-08	3.01E-07	2.06E-09	5.17E-10
benzo (a) pyrene	7.3		1.37E-06		5.31E-11	5.30E-11	5.25E-11	4.56E-08	1.32E-10	3.31E-11

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9							7.78E+05	1.01E+06	1.48E+06	1.09E+04	1.21E+04	1.59E+04
C_{10} - C_{14}							1.78E+05	5.94E+05	1.90E+06	1.40E+04	1.72E+04	2.69E+04
C_{15} - C_{36}							2.18E+07	1.33E+09	5.25E+09	7.74E+07	4.84E+07	7.74E+07
MAHs												
benzene	5.36E+02	7.19E+02	1.09E+03	8.05E+00	9.02E+00	1.20E+01						
toluene							1.89E+04	3.98E+04	8.83E+04	6.53E+02	7.76E+02	1.14E+03
ethylbenzene							8.62E+03	1.93E+04	5.21E+04	3.84E+02	4.66E+02	7.11E+02
xylene							1.45E+04	3.07E+04	6.64E+04	4.91E+02	5.81E+02	8.52E+02
Aromatics												
naphthalene							3.34E+03	1.44E+04	4.88E+04	3.66E+02	4.51E+02	7.06E+02
pyrene							1.06E+06	1.55E+08	6.18E+08	2.35E+07	2.46E+07	2.80E+07
benzo (a) pyrene	1.12E+03	3.87E+05	1.54E+06	9.61E+05	9.63E+05	9.72E+05						

Table 4D2f Preliminary Health Risk Based Acceptance Criteria - Soil *Commercial/Industrial Site Use* PEATS and HIGH ORGANIC Soil Type

Site Use:	Residential	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/kg$) Indoors			Volatilisation factor ($mg/m^3/mg/kg$) Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes										
C_7 - C_9		5		5	9.39E-04	8.57E-04	6.79E-04	6.18E-05	2.92E-05	1.35E-05
C_{10} - C_{14}		0.3		0.3	1.02E-05	9.23E-06	7.13E-06	5.36E-06	6.26E-07	1.69E-07
C_{15} - C_{36}		1.5		1.5	1.20E-08	1.55E-08	1.20E-08	2.19E-07	1.15E-09	2.90E-10
MAHs										
benzene	0.029		3.45E-04		3.23E-04	2.95E-04	2.34E-04	2.14E-05	1.01E-05	4.64E-06
toluene		0.11		0.11	1.35E-04	1.22E-04	9.50E-05	1.98E-05	6.66E-06	2.15E-06
ethylbenzene		0.029		0.029	4.20E-05	3.79E-05	2.94E-05	1.09E-05	2.35E-06	6.84E-07
xylene		0.09		0.09	1.59E-04	1.44E-04	1.12E-04	2.16E-05	7.68E-06	2.53E-06
Aromatics										
naphthalene		0.004		0.004	5.27E-06	4.75E-06	3.67E-06	3.84E-06	3.31E-07	8.78E-08
pyrene		0.03		0.03	5.67E-10	5.31E-10	4.45E-10	5.02E-08	6.10E-11	1.53E-11
benzo (a) pyrene	7.3		1.37E-06		2.21E-12	2.20E-12	2.14E-12	5.74E-09	1.95E-12	4.87E-13

Contaminant	Risk Based Screening Level (mg/kg) Carcinogenic Outdoors			Carcinogenic Indoors			Non-carcinogenic Outdoors			Non-carcinogenic Indoors		
	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m	Surface	>1m	>4m
Alkanes												
C_7 - C_9							8.61E+05	1.82E+06	3.96E+06	5.67E+04	6.21E+04	7.83E+04
C_{10} - C_{14}							5.96E+05	5.10E+06	1.89E+07	3.12E+05	3.46E+05	4.48E+05
C_{15} - C_{36}							7.30E+07	1.38E+10	5.51E+10	1.33E+09	1.03E+09	1.33E+09
MAHs												
benzene	6.01E+02	1.27E+03	2.77E+03	3.98E+01	4.36E+01	5.50E+01						
toluene							5.91E+04	1.76E+05	5.45E+05	8.67E+03	9.58E+03	1.23E+04
ethylbenzene							2.83E+04	1.31E+05	4.51E+05	7.35E+03	8.14E+03	1.05E+04
xylene							4.44E+04	1.25E+05	3.79E+05	6.01E+03	6.64E+03	8.53E+03
Aromatics												
naphthalene							1.11E+04	1.28E+05	4.85E+05	8.08E+03	8.96E+03	1.16E+04
pyrene							6.36E+06	5.23E+09	2.09E+10	5.63E+08	6.02E+08	7.18E+08
benzo (a) pyrene	8.90E+03	2.62E+07	1.05E+08	2.31E+07	2.32E+07	2.38E+07						

Table 4D3a Preliminary Health Risk-Based Acceptance Criteria - Surface Soil *Residential and Agricultural Site Use* SAND Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30 yr		
Target Risk:	0.00001	Exposure Dur:	30 yr		
Target HI:	1	Body Weight:	70 kg		

			Acceptable CDI		Volatilisation Factor ($mg/m^3/mg/kg$)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.54E-02		
C_{10} - C_{14}		0.3		0.3	6.95E-04		
C_{15} - C_{36}		1.5		1.5	1.21E-06		
MAHs							
benzene	0.029		3.45E-04		3.59E-03		
toluene		0.11		0.11	7.93E-03		
ethylbenzene		0.029		0.029	2.65E-03		
xylene		0.09		0.09	9.21E-03		
Aromatics							
naphthalene		0.004		0.004	3.35E-04		
pyrene		0.03		0.03	3.76E-08		
benzo (a) pyrene	7.3		1.37E-06		4.62E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface			Surface		
C_7 - C_9				1.58E+03		
C_{10} - C_{14}				2.10E+03		
C_{15} - C_{36}				6.06E+06		
MAHs						
benzene	1.09E+00					
toluene				6.75E+01		
ethylbenzene				5.33E+01		
xylene				4.76E+01		
Aromatics						
naphthalene				5.80E+01		
pyrene				3.89E+06		
benzo (a) pyrene	3.36E+04					

Table 4D3b
Preliminary Health Risk Based Acceptance Criteria - Surface Soil
Residential and Agricultural Site Use
Silt Soil Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.54E-02		
C_{10} - C_{14}		0.3		0.3	6.19E-04		
C_{15} - C_{36}		1.5		1.5	1.05E-06		
MAHs							
benzene	0.029		3.45E-04		3.59E-03		
toluene		0.11		0.11	6.55E-03		
ethylbenzene		0.029		0.029	2.38E-03		
xylene		0.09		0.09	7.39E-03		
Aromatics							
naphthalene		0.004		0.004	3.07E-04		
pyrene		0.03		0.03	3.43E-08		
benzo (a) pyrene	7.3		1.37E-06		4.33E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface			Surface		
C_7 - C_9				1.58E+03		
C_{10} - C_{14}				2.36E+03		
C_{15} - C_{36}				6.96E+06		
MAHs						
benzene	1.09E+00					
toluene				8.17E+01		
ethylbenzene				5.94E+01		
xylene				5.93E+01		
Aromatics						
naphthalene				6.34E+01		
pyrene				4.26E+06		
benzo (a) pyrene	3.59E+04					

Table 4D3c Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Residential and Agricultural Site Use* SILTY CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30 yr		
Target Risk:	0.00001	Exposure Dur:	30 yr		
Target HI:	1	Body Weight:	70 kg		

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	9.05E-03		
C_{10} - C_{14}		0.3		0.3	4.58E-04		
C_{15} - C_{36}		1.5		1.5	1.04E-06		
MAHs							
benzene	0.029		3.45E-04		2.24E-03		
toluene		0.11		0.11	2.61E-03		
ethylbenzene		0.029		0.029	1.32E-03		
xylene		0.09		0.09	2.80E-03		
Aromatics							
naphthalene		0.004		0.004	2.80E-04		
pyrene		0.03		0.03	3.41E-08		
benzo (a) pyrene	7.3		1.37E-06		4.32E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface			Surface		
C_7 - C_9				2.69E+03		
C_{10} - C_{14}				3.19E+03		
C_{15} - C_{36}				7.00E+06		
MAHs						
benzene	1.75E+00					
toluene				2.05E+02		
ethylbenzene				1.07E+02		
xylene				1.57E+02		
Aromatics						
naphthalene				6.95E+01		
pyrene				4.28E+06		
benzo (a) pyrene	3.60E+04					

Table 4D3d Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Residential and Agricultural Site Use* CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30	yr		
Target Risk:	0.00001	Exposure Dur:	30	yr		
Target HI:	1	Body Weight:	70	kg		

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.63E-03		
C_{10} - C_{14}		0.3		0.3	1.29E-04		
C_{15} - C_{36}		1.5		1.5	1.00E-06		
MAHs							
benzene	0.029		3.45E-04		1.45E-03		
toluene		0.11		0.11	1.69E-03		
ethylbenzene		0.029		0.029	8.60E-04		
xylene		0.09		0.09	1.77E-03		
Aromatics							
naphthalene		0.004		0.004	2.76E-04		
pyrene		0.03		0.03	3.39E-08		
benzo (a) pyrene	7.3		1.37E-06		4.30E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface			Surface		
C_7 - C_9				1.49E+04		
C_{10} - C_{14}				1.13E+04		
C_{15} - C_{36}				7.27E+06		
MAHs						
benzene	2.71E+00					
toluene				3.18E+02		
ethylbenzene				1.64E+02		
xylene				2.48E+02		
Aromatics						
naphthalene				7.06E+01		
pyrene				4.31E+06		
benzo (a) pyrene	3.61E+04					

Table 4D3e Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Residential and Agricultural Site Use* PUMICE Soil Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.38E-02		
C_{10} - C_{14}		0.3		0.3	9.50E-04		
C_{15} - C_{36}		1.5		1.5	1.83E-06		
MAHs							
benzene	0.029		3.45E-04		3.21E-03		
toluene		0.11		0.11	7.31E-03		
ethylbenzene		0.029		0.029	2.92E-03		
xylene		0.09		0.09	8.33E-03		
Aromatics							
naphthalene		0.004		0.004	3.95E-04		
pyrene		0.03		0.03	4.99E-08		
benzo (a) pyrene	7.3		1.37E-06		5.68E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface			Surface		
C_7 - C_9				1.77E+03		
C_{10} - C_{14}				1.54E+03		
C_{15} - C_{36}				4.00E+06		
MAHs						
benzene	1.22E+00					
toluene				7.32E+01		
ethylbenzene				4.83E+01		
xylene				5.25E+01		
Aromatics						
naphthalene				4.93E+01		
pyrene				2.92E+06		
benzo (a) pyrene	2.74E+04					

Table 4D3f Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Residential and Agricultural Site Use* PEATS and HIGHLY ORGANIC soil type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	2.04E-03		
C_{10} - C_{14}		0.3		0.3	1.57E-05		
C_{15} - C_{36}		1.5		1.5	2.62E-08		
MAHs							
benzene	0.029		3.45E-04		6.90E-04		
toluene		0.11		0.11	2.12E-04		
ethylbenzene		0.029		0.029	6.47E-05		
xylene		0.09		0.09	2.52E-04		
Aromatics							
naphthalene		0.004		0.004	8.00E-06		
pyrene		0.03		0.03	8.57E-10		
benzo (a) pyrene	7.3		1.37E-06		1.08E-11		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface			Surface		
C_7 - C_9				1.19E+04		
C_{10} - C_{14}				9.31E+04		
C_{15} - C_{36}				2.78E+08		
MAHs						
benzene	5.68E+00					
toluene				2.52E+03		
ethylbenzene				2.18E+03		
xylene				1.74E+03		
Aromatics						
naphthalene				2.43E+03		
pyrene				1.70E+08		
benzo (a) pyrene	1.44E+06					

Table 4D4a Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Commercial/Industrial Site use* SAND Soil Type

Site Use:	Commercial/Industrial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20	yr		
Target Risk:	0.00001	Exposure Dur:	20	yr		
Target HI:	1	Body Weight:	70	kg		

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.02E-02		
C_{10} - C_{14}		0.3		0.3	4.53E-04		
C_{15} - C_{36}		1.5		1.5	2.35E-05		
MAHs							
benzene	0.029		3.45E-04		3.59E-03		
toluene		0.11		0.11	5.23E-03		
ethylbenzene		0.029		0.029	1.74E-03		
xylene		0.09		0.09	6.06E-03		
Aromatics							
naphthalene		0.004		0.004	2.21E-04		
pyrene		0.03		0.03	2.46E-08		
benzo (a) pyrene	7.3		1.37E-06		3.04E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9				5.19E+03		
C_{10} - C_{14}				7.05E+03		
C_{15} - C_{36}				6.81E+05		
MAHs						
benzene	3.58E+00					
toluene				2.24E+02		
ethylbenzene				1.77E+02		
xylene				1.58E+02		
Aromatics						
naphthalene				1.93E+02		
pyrene				1.30E+07		
benzo (a) pyrene	1.68E+05					

Table 4D4b Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Commercial/Industrial Site use* SILt Soil Type

Site Use:	Commercial/Industrial	Exposure Frequency:	240 d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20 yr		
Target Risk:	0.00001	Exposure Dur:	20 yr		
Target HI:	1	Body Weight:	70 kg		

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/kg$)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.02E-02		
C_{10} - C_{14}		0.3		0.3	4.12E-04		
C_{15} - C_{36}		1.5		1.5	2.09E-05		
MAHs							
benzene	0.029		3.45E-04		3.59E-03		
toluene		0.11		0.11	4.36E-03		
ethylbenzene		0.029		0.029	1.58E-03		
xylene		0.09		0.09	4.92E-03		
Aromatics							
naphthalene		0.004		0.004	2.05E-04		
pyrene		0.03		0.03	2.28E-08		
benzo (a) pyrene	7.3		1.37E-06		2.89E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9				5.19E+03		
C_{10} - C_{14}				7.76E+03		
C_{15} - C_{36}				7.64E+05		
MAHs						
benzene	3.58E+00					
toluene				2.68E+02		
ethylbenzene				1.95E+02		
xylene				1.95E+02		
Aromatics						
naphthalene				2.08E+02		
pyrene				1.40E+07		
benzo (a) pyrene	1.77E+05					

Table 4D4c Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Commercial/Industrial Site use* SILTY CLAY Soil Type

Site Use:	Commercial/Industrial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20	yr		
Target Risk:	0.00001	Exposure Dur:	20	yr		
Target HI:	1	Body Weight:	70	kg		

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	6.03E-03		
C_{10} - C_{14}		0.3		0.3	3.05E-04		
C_{15} - C_{36}		1.5		1.5	2.08E-05		
MAHs							
benzene	0.029		3.45E-04		1.80E-03		
toluene		0.11		0.11	1.74E-03		
ethylbenzene		0.029		0.029	8.79E-04		
xylene		0.09		0.09	1.86E-03		
Aromatics							
naphthalene		0.004		0.004	1.87E-04		
pyrene		0.03		0.03	2.27E-08		
benzo (a) pyrene	7.3		1.37E-06		2.88E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9				8.82E+03		
C_{10} - C_{14}				1.05E+04		
C_{15} - C_{36}				7.67E+05		
MAHs						
benzene	7.15E+00					
toluene				6.73E+02		
ethylbenzene				3.51E+02		
xylene				5.14E+02		
Aromatics						
naphthalene				2.28E+02		
pyrene				1.41E+07		
benzo (a) pyrene	1.77E+05					

Table 4D4d Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Commercial/Industrial Site use* CLAY Soil Type

Site Use:	Commercial/Industrial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20	yr		
Target Risk:	0.00001	Exposure Dur:	20	yr		
Target HI:	1	Body Weight:	70	kg		

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	1.09E-03		
C_{10} - C_{14}		0.3		0.3	8.58E-05		
C_{15} - C_{36}		1.5		1.5	2.01E-05		
MAHs							
benzene	0.029		3.45E-04		1.17E-03		
toluene		0.11		0.11	1.12E-03		
ethylbenzene		0.029		0.029	5.73E-04		
xylene		0.09		0.09	1.18E-03		
Aromatics							
naphthalene		0.004		0.004	1.84E-04		
pyrene		0.03		0.03	2.26E-08		
benzo (a) pyrene	7.3		1.37E-06		2.87E-10		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9				4.90E+04		
C_{10} - C_{14}				3.72E+04		
C_{15} - C_{36}				7.96E+05		
MAHs						
benzene	1.10E+01					
toluene				1.04E+03		
ethylbenzene				5.39E+02		
xylene				8.13E+02		
Aromatics						
naphthalene				2.32E+02		
pyrene				1.41E+07		
benzo (a) pyrene	1.78E+05					

Table 4D4e Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Commercial/Industrial Site use* PUMICE Soil Type

Site Use:	Commercial/Industrial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20	yr		
Target Risk:	0.00001	Exposure Dur:	20	yr		
Target HI:	1	Body Weight:	70	kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/kg$) Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C_7 - C_9		5		5	9.17E-03		
C_{10} - C_{14}		0.3		0.3	5.89E-04		
C_{15} - C_{36}		1.5		1.5	3.32E-05		
MAHs							
benzene	0.029		3.45E-04		3.21E-03		
toluene		0.11		0.11	4.72E-03		
ethylbenzene		0.029		0.029	1.87E-03		
xylene		0.09		0.09	5.37E-03		
Aromatics							
naphthalene		0.004		0.004	2.51E-04		
pyrene		0.03		0.03	3.11E-08		
benzo (a) pyrene	7.3		1.37E-06		3.61E-10		

Contaminant	Risk Based Screening Level (mg/kg) Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m
C_7 - C_9				5.81E+03		
C_{10} - C_{14}				5.43E+03		
C_{15} - C_{36}				4.80E+05		
MAHs						
benzene	4.00E+00					
toluene				2.48E+02		
ethylbenzene				1.65E+02		
xylene				1.79E+02		
Aromatics						
naphthalene				1.70E+02		
pyrene				1.03E+07		
benzo (a) pyrene	1.41E+05					

Table 4D4f Preliminary Health Risk Based Acceptance Criteria - Surface Soil *Commercial/Industrial Site use* PEATS AND HIGHLY ORGANIC Soil Type

Site Use:	Commercial/Industrial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20	yr		
Target Risk:	0.00001	Exposure Dur:	20	yr		
Target HI:	1	Body Weight:	70	kg		

			Acceptable CDI		Volatilisation factor (mg/m^3/mg/kg)		
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors		
	Inhalation	Inhalation	Inhalation	Inhalation	Surface		
Alkanes							
C$_7$ - C$_9$		5		5	1.36E-03		
C$_{10}$ - C$_{14}$		0.3		0.3	1.04E-05		
C$_{15}$ - C$_{36}$		1.5		1.5	5.23E-07		
MAHs							
benzene	0.029		3.45E-04		4.63E-04		
toluene		0.11		0.11	1.41E-04		
ethylbenzene		0.029		0.029	4.31E-05		
xylene		0.09		0.09	1.68E-04		
Aromatics							
naphthalene		0.004		0.004	5.33E-06		
pyrene		0.03		0.03	5.70E-10		
benzo (a) pyrene	7.3		1.37E-06		7.22E-12		

	Risk Based Screening Level (mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic		
	Indoors			Indoors		
Alkanes	Surface	>1m	>4m	Surface	>1m	>4m
C$_7$ - C$_9$				3.91E+04		
C$_{10}$ - C$_{14}$				3.06E+05		
C$_{15}$ - C$_{36}$				3.05E+07		
MAHs						
benzene	2.77E+01					
toluene				8.28E+03		
ethylbenzene				7.16E+03		
xylene				5.70E+03		
Aromatics						
naphthalene				7.99E+03		
pyrene				5.60E+08		
benzo (a) pyrene	7.07E+06					

Appendix 4E
Leaching modelling

1.1 Overview

Preliminary estimates of the impact of contaminated soil on groundwater beneath the contaminated zone have been determined in order to assist with the assessment of the impact of residual soil contamination on groundwater quality (refer Modules 1 and 5 for further details). A conservative approach has been adopted in order to be protective of groundwater quality, however, the leaching modelling presented in this appendix should not be used as a substitute for monitoring groundwater quality where impact on groundwater is suspected.

The modelling has been configured to determine the soil concentration which would give rise to a groundwater concentration equal to the potable water quality criteria (the most stringent, refer Module 5) for a given scenario of soil type, depth to contamination and depth to groundwater.

Combinations of the following factors have been considered in determining the scenarios for leaching modelling:

Soil type:	Six soil types were incorporated in the leaching modelling (fractured basalts and gravel were not considered). The soil type was used to determine an indicative infiltration rate and groundwater throughflow.
Depth to contamination:	Surface (< 1 metres), 1 to 4 metres, > 4 metres (in each case contaminated zone 2 metres thick has been assumed)
Depth to groundwater:	2 to 4 metres, 4 to 8 metres, >8 metres

In practice, the combinations of depth to soil contamination (assuming an arbitrary 2 metres thickness) and depth to groundwater give separations between the base of the contaminated soil layer and the groundwater of 0, 1, 2, 4, 5 and 6 metres.

1.2 Modelling approach

The approach adopted for modelling the leaching of contaminants from soil into groundwater is based on a one dimensional fate and transport equation by van Genuchten and Alves (1982), as used in the RISC model (BP, 1996) to calculate groundwater concentrations as a function of time. The van Genuchten and Alves fate and transport equation results in estimated groundwater concentrations that increase with time as the leaching of contaminants approaches a pseudo-steady state, followed by decreasing contaminant concentrations in groundwater as the source depletes with time.

For each combination of soil type, depth to the contaminated layer and depth to groundwater, an iterative method was used to estimate the maximum groundwater concentration for a given soil concentration, and hence, the maximum value of the leaching factor.

The modelling approach may be summarised as follows:

- an infiltration/recharge rate and hydraulic conductivity were assumed based on a given soil type
- the concentration of contaminants in leachate leaving the contaminated soil zone was determined using normal equilibrium relationships (refer to Appendix 4D, Module 4)
- the pore water velocity (downward infiltration rate) and groundwater velocity were estimated for use in determining the time of travel from the source to the groundwater in order to estimate biodegradation and to estimate dilution of the leachate by groundwater through flow
- source depletion taking into account biodegradation, losses due to leaching to the groundwater and volatilisation to the ambient air
- simple mixing of the leachate entering the groundwater, over an given aquifer thickness, giving an estimate of the contaminant concentration in groundwater at the site or immediately downgradient of the site.

No allowance is made for the biodegradation and attenuation of contaminants in groundwater between the site and any possible point of exposure.

The half-lives for biodegradation for each chemical, and the assumed infiltration rates and the hydraulic conductivities for each soil type are presented in Tables 4E1a, 4E1b and 4E1c respectively.

Table E1a Biodegradation half-life for selected petroleum contaminants

Contaminant	Half-life (yrs)
TPH: C7 to C9	2
TPH: C10 to C14	5
TPH: C15 to C36	10
Benzene	5
Toluene	5
Ethyl benzene	5
Xylene	5
Naphthalene	5
Pyrene	10
Benzo(a)pyrene	10

The biodegradation half-life of a compound is highly dependent on site-specific conditions. The values presented in Table 4E1a are conservative estimates for biodegradation in the unsaturated zone, taking into consideration the impact of aerobic and anaerobic conditions within the bulk and the fringes of the hydrocarbon plume respectively. The adopted half-lives for biodegradation of selected petroleum hydrocarbons are based on professional judgement, giving consideration to the limited range of published information available. The adopted half-lives are expected to be conservative, resulting in an overestimate of the concentrations of petroleum hydrocarbons in leachate entering the groundwater, however, there is limited information available to confirm this expectation. Further research is ongoing in this area.

Table 4E1b Summary of infiltration/recharge rates

Soil Type	Infiltration/Recharge Rate (cm/yr)
Sand	10.2
Silty sand	8.2
Silty clay	3.4
Clay	1.4
Pumice	13.6
Peats	1.4

The infiltration/recharge rates were selected as long term average values based on the proportion of rainfall likely to infiltrate for different soil types, based on a rainfall of 700 mm/year and relatively flat topography. Clearly some areas of New Zealand may receive considerably more rainfall and the screening criteria based on leaching of contaminants to groundwater may be revised to account for this. The values presented above (and similar values used in other references such as the ASTM RBCA guidance) refer to infiltration rate, however in practice the groundwater recharge rate is of more interest and may from the infiltration based on site-specific considerations.

The values selected for the hydraulic conductivity and infiltration rate are designed to reflect typical (rather than conservative) values for each soil type. The selection of, for example, a conservative estimate for the hydraulic conductivity and a typical estimate for the infiltration rate would artificially underestimate the dilution of leachate in the aquifer. Hence it is important that the estimates of infiltration and hydraulic conductivity are matched.

Table 4E1c Summary of hydraulic conductivities

Soil Type	Hydraulic Conductivity (m/d)
Sand	10
Silty sand	1
Silty clay	10^{-2}
Clay	10^{-3}
Pumice	10
Peats	1

In considering the expected trend in soil acceptance criteria for the protection of groundwater, the influence of the following should be factors should be evaluated:

- in sands the infiltration rate is reasonably high, however on a relative basis the groundwater flow velocity is higher, and hence, relatively high dilution may be expected (from sand to clay the infiltration rate varies by a factor of 10, whereas the groundwater flow velocity varies by a factor of 10,000). However, in sand the travel time for leachate between the source and the water table is relatively short, and hence, biodegradation is negligible.
- in clay the dilution of infiltration by groundwater through flow is reduced, however the time of travel for leachate from the source to groundwater is increased to the point at which biodegradation becomes important.

These factors act in opposing directions, and therefore, the trend in soil acceptance criteria through the range of soil types reflects the extent to which either of the mechanisms is dominant.

1.3 Model equations

The leaching process is simulated by transport of contaminants in the vadose zone; both volatilisation and leaching. The transport equations are solved using a one-dimensional solute transport equation (van Genuchten and Alves, 1982):

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x} - \mu C \qquad \text{(E1)}$$

where:

C = concentration of component in the aqueous phase in the vadose zone (mg/L^3)

D = dispersion coefficient in the unsaturated zone (L^2/T)

V = horizontal pore water velocity (L/T)

μ = first-order decay coefficient (1/T)

x = distance below the source (L])

R = retardation factor

The thickness of contaminated layer is assumed to be 2 metres as for the volatilisation modelling. The depth to the groundwater table is determined from the base of the contaminated layer. The solution to the advection-dispersion equation is given by:

$$C = C_o . B(x,t) . e^{-\beta t} \qquad \text{[E2]}$$

where

$$B(x,t) = \frac{1}{2}\exp\left[\frac{(V-w)x}{2D}\right] erfc\left(\frac{Rx - wt}{2\sqrt{DRt}}\right) + \frac{1}{2}\exp\left[\frac{(V+w)x}{2D}\right] erfc\left(\frac{Rx + wt}{2\sqrt{DRt}}\right) \qquad \text{[E3]}$$

and

$$w = V\sqrt{1 + \frac{4D}{V^2}[\mu - R\beta]} \qquad \text{[E4]}$$

Source Concentration

The initial source concentration is calculated by using an equilibrium phase partitioning equation (refer to Module 4 for greater detail):

$$C_o = \frac{\rho_s C_s}{\rho_s K_{oc} f_{oc} + \theta_w + \theta_a H} \qquad \text{[E5]}$$

where:

C_o = initial water phase concentration (mg/L)

C_s = measured soil concentration (standardised at 1 mg/kg)

ρ_s= soil bulk density (tonnes/m^3)

K_{oc} = organic carbon partition coefficient

f_{oc} = fraction organic carbon

θ_w= water filled porosity

θ_a = air filled porosity

H = Henry coefficient (c/c)

The above expression is limited to estimating the concentration in water phase associated with adsorbed phase hydrocarbons, ie. no separate phase hydrocarbons. As discussed for the volatilisation modelling this is expected to result in an overestimate of leaching.

Water Velocities

The net infiltration rate, *q*, for different soil types are presented in Table 4E1b . The vertical pore water velocity, *V*, in the vadose zone is determined as follows:

$$V = \frac{q}{\theta_w} \qquad \text{[E6]}$$

In the saturated zone, Darcy's velocity D_v is calculated as follows:

$$D_v = K \times i \qquad \text{[E7]}$$

where

K = hydraulic conductivity (L^2/T)

I = hydraulic gradient (L/L)

An hydraulic gradient of 0.01 m/m has been assumed. This is consistent with typical values assumed for similar modelling, however, it should be acknowledged that lower gradients (potentially resulting in lower dilution ratios) may be expected some sites. The assumed hydraulic conductivities are presented in Table 4E1c.

Dilution

Dilution occurs as the contaminant leaches from the vadose zone into the groundwater. A simple box model is assumed where the length of the contaminated soil zone parallel to the direction of groundwater flow is 15 metres (which is selected as a reasonable value for a service station or small depot site). A groundwater mixing depth of 2 metres is assumed (ie. the depth over which the leached contaminants may be expected to mix with the groundwater within a short distance of the source). The dilution contaminants leaching from the contaminated soil zone, *DE*, is calculated as:

$$DE = \frac{q \times L}{(q \times L) + (D_v \times d)} \qquad \text{[E8]}$$

where

L = length of contamination downgradient (15 metres)

d = mixing depth (2 metres)

Leaching Factor

Leaching factors (*LF*) are used to relate the predicted contaminant concentrations in groundwater to the measured soil concentrations. The contaminant concentration in the groundwater is calculated using:

$$C_{GW} = C \times DE \qquad \text{[E9]}$$

where

C = water phase concentration due to leaching immediately above the groundwater (as a function of time) estimated using equation E2.

DE = dilution effect (from equation E8).

The Leaching Factor may then be determined as follows:

$$LF = \frac{C_{GW}}{C_s} \qquad \text{[E10]}$$

For the purposes of deriving the Tier 1 soil acceptance criteria protective of groundwater quality the Leaching Factor was determined using the initial soil concentration and the maximum predicted groundwater concentration.

Source Depletion

Three mechanisms for depletion of source (ie. contaminated soil layer) are considered as follows:

- leaching from source to groundwater
- volatilisation from source to ambient air
- biodegradation.

Source depletion by leaching and volatilisation is accounted for by the ρ term. This may be separated into its components as follows:

$$\beta = \beta_w + \beta_v \qquad \text{[E11]}$$

$$\beta_w = \frac{q}{(\rho_s K_{oc} f_{oc} + \theta_w + \theta_a H) L_w} \qquad \text{[E12]}$$

$$\beta_v = \frac{D_s^{eff} H}{(\rho_s K_{oc} f_{oc} + \theta_w + \theta_a H) L_d L_w} \qquad \text{[E13]}$$

where

L_w = thickness of source contamination layer

L_d = distance from soil surface to centre of source contamination

$$D_s^{eff} = D_{air}\left(\frac{\theta_a^{10/3}}{\theta_T^2}\right) + \frac{D_{wat}}{H}\left(\frac{\theta_w^{10/3}}{\theta_T^2}\right) \qquad \text{[E14]}$$

D_{air} = air diffusion coefficient (L^2/T)

D_{wat} = water diffusion coefficient (L^2/T)

θ_T = total porosity $(\theta_a + \theta_w)$

The β term is incorporated in equations E2 to E4.

Biodegradation is characterised by the following expression:

$$\mu = \frac{t_{1/2}}{\ln 2} \qquad \text{[E15]}$$

where

μ = first order biodegradation constant [T^{-1}]

$t_{1/2}$ = contaminant half-life [T]

The half-life of contaminants are presented in Table 4E1a. The degradation term, μ, is then substituted into equation E4.

Adsorption

The retardation factor, R, (accounting for attenuation of contaminant migration by adsorption/desorption processes) is estimated as follows:

$$R = 1 + \frac{\rho_s f_{oc} K_{oc}}{\theta_w} \qquad \text{[E16]}$$

Dispersion

Empirical equations are used to estimate longitudinal dispersivity (Gelhar et al, 1986), as follows:

$$\ln \alpha_L = -4.933 + 3.811 \ln x \qquad 1m \le x \le 2m \qquad \text{[E17]}$$

$$\ln \alpha_L = -2.727 + 0.584 \ln x \qquad x \ge 2m \qquad \text{[E18]}$$

where x is the distance from the bottom of the source.

$$D = \alpha_L V \qquad \text{[E19]}$$

where

D = dispersion coefficient in the unsaturated zone (L^2/T)

V = vertical pore water velocity (L/T).

For a distance less than 1 m, a value of 1 m is used. If equation E4 calculates a negative square root, then a value of 1 x 10^{-6} m^2/d is assumed.

1.4 References

Gelhar, L.W., Gutjahr, A.L., and Naff, R.L., (1979) **Stochastic analysis of macrodispersion in a stratified aquifer**, Water Resources Research 15, no. 6:1387-91

van Genuchten, M. Th. and Alves, W.J. (1982) **Analytical Solutions of the One-Dimensional Convective-Dispersive Solute Transport Equation**, United States Department of Agriculture, Technical Bulletin Number 1661.

Table 4E2a Preliminary Health Risk-Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* SAND Soil Type

Site Use:	Residential, Groundwater for Potable Use
Receptor:	Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2 m	4 m	8 m	2 m	4 m	8 m	GW 2 m	GW 4 m	GW 8 m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	4.39E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	5.40E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	1.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				5.99E-02	3.61E-03	1.09E-03	1.28E-02	1.98E-03	7.72E-03
toluene				8.00E-01	8.00E-01	8.00E-01	2.04E-02	1.15E-03	1.33E-04	3.93E-03	6.31E-04	2.47E-03
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	6.05E-03	1.74E-05	2.49E-156	1.06E-03	1.25E-49	3.81E-04
xylene				6.00E-01	6.00E-01	6.00E-01	2.49E-02	1.45E-03	4.40E-04	5.06E-03	7.97E-04	3.11E-03
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	5.22E-03	1.90E-04	6.75E-33	2.73E-03	9.08E-13	5.05E-04
pyrene				1.00E-02	1.00E-02	1.00E-02	1.80E-04	9.55E-96	0.00E+00	2.53E-297	0.00E+00	9.55E-96
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				1.76E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4 m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2 m	GW 4 m	GW 8 m	GW 4 m	GW 8 m	GW 8 m	GW 2 m	GW 4 m	GW 8 m	GW 4m	GW 8m	GW 8m
hexane							4.55E+03	-	-	-	-	-
nonane							7.40E+05	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	1.67E-01	2.77E+00	9.16E+00	7.83E-01	5.06E+00	1.30E+00						
toluene							3.92E+01	6.96E+02	6.00E+03	2.04E+02	1.27E+03	3.24E+02
ethylbenzene							4.96E+01	1.72E+04	1.21E+155	2.84E+02	2.41E+48	7.87E+02
xylene							2.41E+01	4.13E+02	1.36E+03	1.19E+02	7.53E+02	1.93E+02
Aromatics												
naphthalene							1.92E+00	5.26E+01	1.48E+30	3.67E+00	1.10E+10	1.98E+01
pyrene							5.56E+01	1.05E+93	-	3.95E+294	-	1.05E+93
benzo (a)pyrene	3.98E+01	-	-	-	-	-						

Table 4E2b Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* SILTY SAND Soil Type

Site Use:	Residential, Groundwater for Potable Use
Receptor:	Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
Hexane				2.00E+00	2.00E+00	2.00E+00	3.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nonane				4.00E+00	4.00E+00	4.00E+00	3.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eicosane				-	-	-	9.59E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				3.50E-01	2.18E-02	2.08E-03	1.19E-01	4.93E-03	4.83E-02
toluene				8.00E-01	8.00E-01	8.00E-01	1.34E-01	7.97E-03	5.98E-06	4.38E-02	1.48E-03	1.76E-02
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	4.17E-02	1.14E-04	7.69E-60	1.29E-02	4.36E-20	1.73E-03
xylene				6.00E-01	6.00E-01	6.00E-01	1.62E-01	9.89E-03	4.26E-04	5.43E-02	2.40E-03	2.19E-02
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	3.60E-02	6.09E-04	1.36E-16	1.61E-02	1.14E-12	1.94E-75
pyrene				1.00E-02	1.00E-02	1.00E-02	1.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a)pyrene	7.00E-04	7.00E-04	7.00E-04				1.24E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							5.76E+02	-	-	-	-	-
nonane							1.05E+05	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	2.86E-02	4.60E-01	4.82E+00	8.39E-02	2.03E+00	2.07E-01						
toluene							5.95E+00	1.00E+02	1.34E+05	1.83E+01	5.40E+02	4.54E+01
ethylbenzene							7.20E+00	2.62E+03	3.90E+58	2.32E+01	6.88E+18	1.74E+02
xylene							3.70E+00	6.06E+01	1.41E+03	1.11E+01	2.50E+02	2.73E+01
Aromatics												
naphthalene							2.78E-01	1.64E+01	7.33E+13	6.20E-01	8.75E+09	5.16E+72
pyrene							7.92E+00	-	-	-	-	-
benzo (a) pyrene	5.67E+00	-	-	-	-	-						

Table 4E2c Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* SILTY CLAY Soil Type

Site Use:	Residential, Groundwater for Potable Use
Receptor:	Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	2.55E-02	0.00E+00	0.00E+00	7.26E-286	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	2.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	5.82E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				1.75E+00	1.52E-02	3.19E-33	9.08E-02	7.13E-13	2.96E-02
toluene				8.00E-01	8.00E-01	8.00E-01	7.55E-01	9.02E-05	5.32E-270	9.67E-02	8.35E-162	9.13E-05
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	2.47E-01	1.23E-95	0.00E+00	3.56E-12	0.00E+00	1.23E-95
xylene				6.00E-01	6.00E-01	6.00E-01	8.98E-01	1.17E-02	7.19E-196	1.02E-01	1.41E-112	1.21E-02
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	2.13E-01	5.19E-122	0.00E+00	1.52E-17	0.00E+00	5.19E-122
pyrene				1.00E-02	1.00E-02	1.00E-02	7.65E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				7.49E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							7.83E+01	-	-	-	-	-
nonane							1.73E+04	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	5.72E-03	6.57E-01	3.14E+30	1.10E-01	1.40E+10	3.38E-01						
toluene							1.06E+00	8.87E+03	1.50E+269	8.28E+00	9.59E+160	8.76E+03
ethylbenzene							1.22E+00	2.43E+94	-	8.42E+10	-	2.43E+94
xylene							6.68E-01	5.13E+01	8.34E+194	5.87E+00	4.25E+111	4.96E+01
Aromatics												
naphthalene							4.70E-02	1.93E+119	-	6.59E+14	-	1.93E+119
pyrene							1.31E+00	-	-	-	-	-
benzo (a) pyrene	9.34E-01	-	-	-	-	-						

Table 4E2d Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* CLAY soil type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	3.06E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	2.56E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	6.43E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				1.87E+00	1.17E-05	2.87E-121	1.33E-02	3.20E-75	1.20E-05
toluene				8.00E-01	8.00E-01	8.00E-01	8.22E-01	8.29E-27	0.00E+00	1.31E-05	4.95E-250	8.31E-27
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	2.72E-01	3.81E-129	0.00E+00	3.80E-45	0.00E+00	3.81E-129
xylene				6.00E-01	6.00E-01	6.00E-01	9.76E-01	1.04E-19	3.21E-303	7.12E-04	2.31E-199	1.05E-19
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	2.34E-01	1.25E-154	0.00E+00	6.75E-56	0.00E+00	1.25E-154
pyrene				1.00E-02	1.00E-02	1.00E-02	8.45E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				8.28E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							6.54E+01	-	-	-	-	-
nonane							1.56E+04	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	5.36E-03	8.53E+02	3.49E+118	7.54E-01	3.12E+72	8.34E+02						
toluene							9.73E-01	9.65E+25	-	6.11E+04	1.62E+249	9.63E+25
ethylbenzene							1.10E+00	7.88E+127	-	7.90E+43	-	7.88E+127
xylene							6.15E-01	5.75E+18	1.87E+302	8.43E+02	2.60E+198	5.74E+18
Aromatics												
naphthalene							4.27E-02	8.02E+151	-	1.48E+53	-	8.02E+151
pyrene							1.18E+00	-	-	-	-	-
benzo (a) pyrene	8.46E-01	-	-	-	-	-						

Table 4E2e Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and Agricultural Site Use* PUMICE Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	4.22E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	4.31E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	1.08E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				4.20E-02	4.06E-03	5.86E-04	1.92E-02	1.23E-03	9.07E-03
toluene				8.00E-01	8.00E-01	8.00E-01	1.56E-02	1.44E-03	7.55E-05	6.88E-03	5.05E-04	3.23E-03
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	4.75E-03	1.64E-04	3.41E-31	2.03E-03	6.67E-12	4.13E-04
xylene				6.00E-01	6.00E-01	6.00E-01	1.89E-02	1.80E-03	2.78E-04	8.52E-03	5.45E-04	4.01E-03
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	4.09E-03	1.66E-04	1.67E-15	2.49E-03	4.69E-12	7.93E-66
pyrene				1.00E-02	1.00E-02	1.00E-02	1.43E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				1.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							4.74E+03	-	-	-	-	-
nonane							9.29E+05	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	2.38E-01	2.46E+00	1.71E+01	5.22E-01	8.11E+00	1.10E+00						
toluene							5.14E+01	5.56E+02	1.06E+04	1.16E+02	1.58E+03	2.47E+02
ethylbenzene							6.32E+01	1.83E+03	8.80E+29	1.48E+02	4.50E+10	7.27E+02
xylene							3.18E+01	3.34E+02	2.16E+03	7.04E+01	1.10E+03	1.50E+02
Aromatics												
naphthalene							2.45E+00	6.01E+01	5.99E+12	4.02E+00	2.13E+09	1.26E+63
pyrene							7.00E+01	-	-	-	-	-
benzo (a) pyrene	5.01E+01	-	-	-	-	-						

Table 4E2f Preliminary Health Risk Based Acceptance Criteria - Soil Due to Leaching *Residential and agricultural site use* PEATS and HIGHLY ORGANIC Soil Type

Site Use: Residential, Groundwater for Potable Use
Receptor: Adults

	Acceptable GW conc (outdoor) (mg/L)						Leaching factor (outdoor air) (mg/L/mg/kg)					
Contaminant	Carcinogenic			Non-carcinogenic			Surface Soil to			1m Soil to		4m Soil to
	2m	4m	8m	2m	4m	8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
Alkanes												
hexane				2.00E+00	2.00E+00	2.00E+00	2.30E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
nonane				4.00E+00	4.00E+00	4.00E+00	1.85E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
eicosane				-	-	-	4.65E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MAHs												
benzene	1.00E-02	1.00E-02	1.00E-02				2.70E-03	0.00E+00	0.00E+00	5.32E-154	0.00E+00	1.01E-52
toluene				8.00E-01	8.00E-01	8.00E-01	7.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-186
ethylbenzene				3.00E-01	3.00E-01	3.00E-01	2.12E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
xylene				6.00E-01	6.00E-01	6.00E-01	9.58E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E-148
Aromatics												
naphthalene				1.00E-02	1.00E-02	1.00E-02	1.80E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
pyrene				1.00E-02	1.00E-02	1.00E-02	6.13E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
benzo (a) pyrene	7.00E-04	7.00E-04	7.00E-04				5.99E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Risk Based Screening Level (mg/kg)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Surface Soil to			1m Soil to		4m Soil to	Surface Soil to			1m Soil to		4m Soil to
Alkanes	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m	GW 2m	GW 4m	GW 8m	GW 4m	GW 8m	GW 8m
hexane							8.71E+04	-	-	-	-	-
nonane							2.16E+07	-	-	-	-	-
eicosane							-	-	-	-	-	-
MAHs												
benzene	3.70E+00	-	-	1.88E+151	-	9.86E+49						
toluene							1.05E+03	-	-	-	-	4.41E+185
ethylbenzene							1.42E+03	-	-	-	-	-
xylene							6.27E+02	-	-	-	-	5.02E+147
Aromatics												
naphthalene							5.54E+01	-	-	-	-	-
pyrene							1.63E+03	-	-	-	-	-
benzo (a) pyrene	1.17E+03	-	-	-	-	-						

Appendix 4F
Plant uptake

1.1 Overview

The uptake of contaminants by plants is a complex biological process. There is no accurate, theoretically robust model for predicting the concentration of a contaminant in plant material, however, empirical formula have been derived by numerous sources to simulate contaminant uptake by plants.

A number of models are available for the uptake of contaminants by plants (e.g. HESP (Shell, 1994), CAPCOA (1992)), but in general they reduce to empirical correlations (e.g. Travis (1988), Ryan et al (1988)) and hence are limited by the relevance of the source data on which they are based.

For the purposes of this appendix the following approach has been adopted:

- modelling the distribution of contaminants between the soil moisture, adsorbed and vapour phases in soil using a fugacity approach (HESP (1994))
- modelling the uptake of contaminants by plants using the relationship developed by Ryan et al (1988)
- comparison with published contaminant concentrations in soil and plants.

The Ryan et al (1988) model was selected on the basis that it relates plant uptake to pore water concentrations, and therefore, when combined with a partitioning relationship can account for differences in soil type. In contrast the Travis (1988) model depends on Kow only. In addition, Ryan considers a range of chlorinated and non-chlorinated compounds in derivation of the correlation, whereas the Travis relationship is based largely on chlorinated compounds.

Patterson (1989) developed a similar approach based on fugacity partitioning and use of an empirical correlation, however modifications to the empirical correlation incorporated in the Patterson model result in prediction of high level of uptake for highly lipophilic compounds such as benzo(a)pyrene. Further benzo(a)pyrene lies outside the Kow range for the chemicals used in deriving the empirical correlation use.

As discussed in Module 4, the uptake of contaminants by plants has only been considered for the PAH compounds i.e. naphthalene, pyrene and benzo(a)pyrene. The BTEX compounds are not expected to persist in surface soils used for gardening (i.e. regularly watered, fertilised and aerated).

For the purposes of this module only contamination of a uniform surface soil is considered, representing a range of garden soils. In particular the organic carbon content of the soil has been increased to allow for the use of compost and other organic supplements in gardens.

1.2 Phase partitioning in the soil environment

HESP (1994) uses a fugacity approach to phase partitioning based on the Mackay level 3 fugacity model. The fugacity and phase compositions are calculated as follows:

$$Z_a = \frac{1}{R \times T_{soil}} \qquad [F1]$$

$$Z_w = \frac{S(T)}{P(T)} \qquad [F2]$$

where

$P(T)$ = vapour pressure at T_{soil} (Pa)

$S_w(T)$ = solubility in water at T_{soil} (mg/L)

$S(T)$ = $S_w(T)/M$ (mole/m^3)

Z_a = fugacity capacity constant air (mole/m^3.Pa)

Z_w = fugacity capacity constant water (mole/m^3.Pa)

R = gas constant (8.3143) (Pa.m^3/mole.K)

T_{soil} = temperature of the soil (°K) -assumed 298 °K

or $$Z_w = \frac{1}{H_s} \qquad [F3]$$

where H_s = Henry's constant corrected for temperature. In this application it is assumed that the soil temperature is the same as the reference temperature (298K) and so no correction is necessary.

$$Z_s = \frac{K_{oc} \times f_{oc} \times SG \times Z_w}{SN_s} \qquad [F4]$$

where

Z_s = fugacity capacity constant soil (mole/m^3.Pa)

K_{oc} = partition coefficient for octanol-water (dm^3/kg)

f_{oc} = fraction organic carbon

SG = specific gravity (g/cm^3)

SN_s = volume phase of solid phase

$$P_a = \frac{Z_a \times SN_a}{Z_a \times SN_a + Z_w \times SN_w + Z_s \times SN_s} \qquad [F5]$$

$$P_w = \frac{Z_w \times SN_w}{Z_a \times SN_a + Z_w \times SN_w + Z_s \times SN_s} \qquad [F6]$$

$$P_s = \frac{Z_s \times SN_s}{Z_a \times SN_a + Z_w \times SN_w + Z_s \times SN_s} \qquad [F7]$$

where

P_a = mass fraction in soil gas phase

P_w = mass fraction in soil liquid phase (water)

P_s = mass fraction in soil solid phase

SN_a = volume phase of gas fraction

SN_w = volume phase of liquid phase

SN_s = volume phase of solid phase

$=1 - SN_a - SN_w$

The soil type used for the model calculations is standard soil 10% OM, used by the Netherlands (HESP). This is expected to be reasonably typical of garden soils amended with organic supplements (e.g. compost). A list of the soil parameters used are presented in Table 4F3.

Table 4F1 **Plant uptake soil parameters**

Parameter	Standard Soil 10% OM
SG - kg/dm^3	1.5
SNa	0.2
SNw	0.2
foc	0.058

1.3 Uptake model

The reference to Ryan et al, 1988 is used for modelling the uptake of contaminants by plants.

Ryan et al produced correlations between the contaminant concentration in the soil water and that in produce based on published information on the uptake of chemicals by plants. The chemicals used during the tests were mainly pesticides, of lower octanol-water values than the chemicals considered in this model, however, in some cases the chemicals included extend to species more similar to the chemicals of interest than in the case for other models. The Ryan model has been found to produce predictions of uptake closer to published data (Edwards (1983)) than other references.

Ryan et al. define a root concentration factor:

$$\text{RCF} = \frac{\text{concentration in root } (\mu\text{g / g fresh wt})}{\text{concentration in external solution } (\mu\text{g / mL})} \qquad [F8]$$

The RCF is estimated by the following correlation:

$$\log(\text{RCF} - 0.82) = 0.77 \log K_{ow} - 1.52 \qquad [F9]$$

where K_{ow} = octanol-water partition coefficient

Likewise, a stem concentration factor is defined as:

$$\text{SCF} = \frac{\text{concentration in stem } (\mu\text{g / g fresh wt})}{\text{concentration in external solution } (\mu\text{g / mL})} \qquad [F10]$$

The SCF is estimated using the following correlation:

$$\left[10^{(0.95 \log Kow - 2.05)} + 0.82\right] \times (0.784) 10^{\frac{-0.434(\log Kow - 1.78)^2}{2.44}} \qquad [F11]$$

The calculated RCF and SCF are combined to give a weighted plant uptake factor (PUF). The weightings are based on the range of home-grown produced food types in Australia (ABS, 1994). Weighting is given as follows:

- root crops are subject to root uptake characterised by the RCF
- close to ground fruits and vegetables (e.g. strawberries, radishes), and vines (e.g. tomatoes, beans) are subject to uptake and translocation described by the SCF
- tree fruits (e.g. apples, lemons) are not subjected to uptake (deposition not considered).

The proportions of home-grown produce in Australia were calculated from the Australian Bureau of Statistics (ABS) and are presented in Table 4F2.

Table 4F2 **Home-grown produce types**

Food Type	Proportion Percent
root crops	10
other fruit and vegetables	50
tree fruits	40

The PUF is calculated using the following relationship:

$$PUF = f_r \times RCF + f_s \times SCF \qquad \text{[F12]}$$

where f_x = fraction produce type x

and plant concentration is calculated by:

$$C_p = PUF \times C_t \qquad \text{[F13]}$$

where C_t = total measured soil concentration

1.4 Review of published information

The uptake of contaminants by plants is plant species, chemical and site specific and hence there is considerable variability in the published uptake information. The following information is drawn from a review article by Edwards (1983) unless otherwise specified:

- The published ratios of benzo(a)pyrene concentrations in plants to that in soil range from 0.002 to 0.33, corresponding to concentrations in the plant material of 0.1 to 150 μg/kg (fresh basis, typically 1 to 10 μg/kg).
- The published ratios of total PAH concentrations in plants to that in soil range from 0.001 to 0.183 (fresh basis).
- Travis and Arms (1988) used a ratio of plant concentration to soil concentration 0.05 as part of the development of an empirical correlation.
- Actively growing green plant parts may naturally contain in the range 10 to 20 μg/kg benzo(a)pyrene, but storage tissues generally contain 1-10% of that in green plant portions
- Washing typically removes less than 25% of the PAHs from vegetables.
- PAH concentrations in plant skin and peel are higher than those in internal tissues.
- Most PAH contamination of vegetation occurs through atmospheric deposition.

For comparison the benzo(a)pyrene concentrations corresponding to an incremental lifetime risk of cancer of one in 100,000 are in the range 0.5 to 5 µg/kg fresh basis (refer Appendix 4G).

The predicted uptake of contaminants using the Ryan model as outlined above is broadly consistent with the published total benzo(a)pyrene concentrations, but the published information accounts for naturally occurring benzo(a)pyrene and the contribution from other sources (e.g. atmospheric deposition). On this basis the Ryan model may be regarded reasonable, although depending on the significance of other sources it may be conservative. It is of note that the benzo(a)pyrene concentrations in produce corresponding to an incremental lifetime risk of cancer of one in 100,000 for the exposure scenarios considered are of the same order or less than concentrations that may be naturally occurring.

1.5 References

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Table 4F3 Plant uptake of PAHs

Soil Parameters	
SG (t/m^3)	1.5
Sna	0.2
SNw	0.2
Foc	0.058

Chemical Parameters			
	Naphthalene	Pyrene	Benzo(a)pyrene
Koc	8.44E+02	2.50E+04	1.31E+05
log(Kow)	3.37	5.18	6.04
S (mg/L)	31	0.132	0.0038
P (atm)	3.63E-04	1.17E-07	2.10E-10
MW (g/mol)	12819	202.3	252.3

Consumer Parameters	
fraction root	0.1
fraction stem	0.5
fraction leaves/fruit	0.4

Fugacity Calculations							
	H (Pa.m^3/mol)	Za	Zw	Zs	Pa	Pw	Ps
naphthalene	15210	4.04E-04	6.57E-05	8.05E-03	1.64E-02	2.67E-03	9.81E-01
pyrene	18.17	4.04E-04	5.50E-02	2.00E+02	6.74E-07	9.19E-05	1.00E+00
benzo(a)pyrene	1.413	4.04E-04	7.08E-01	1.34E+04	1.00E-08	1.75E-05	1.00E+00

Plant Concentration Calculations			
	BCFroot	BCFstem	BCFave
naphthalene	2.55E-01	8.36E-02	6.73E-02
pyrene	2.03E-01	3.53E-03	2.21E-02
benzo(a)pyrene	1.78E-01	2.98E-04	1.79E-02

Appendix 4G
Calculation of Tier 1 acceptance criteria (tables)

Table 4G1a Preliminary Health Risk Based Acceptance Criteria *Residential Site Use,*

Site Use:	Residential	Exposure Frequency:	350	d/yr	Exposure Dur.(1-6 yrs):	6	yr
Receptor:	Children resident on site for up to 30 yr	Averaging Time (carc.):	70	Yr	Exposure Dur.(7-31 yrs):	24	yr
		(non-carc.):	30	Yr	Ingestion Rate (1-6 yrs):	100	Mg/d
		Age-adjusted ingestion factor:	48.57	mg.yr/kg.d	Ingestion Rate (7-31 yrs):	25	mg/d
	0.00001				Skin Area (1-6 yr) (cm²):	2625	
Target HI:	1	Age-adjusted Dermal Exposure Factor	2.7E+03		Skin Area (7-30 yr) (cm²):	4700	
					Soil Adherence (mg/sq.cm):	0.5	
		Body Weight (1-6 yr):	15	kg			
		Body Weight (7-31 yr):	70	kg	Produce Ing (1-6yr, kg):	0.13	
					Produce Ing (7-30yr, kg):	0.45	
					Proportion of produce from contaminated source	0.1	

				Acceptable CDI				Preliminary Remediation Goal (mg/kg) (2)					
Contaminant	Skin Absorption Factor	SF (1/(mg/kg/d))	RfD (mg/kg/d)	Carcinogenic		Non-carcinogenic		Carcinogenic			Non-carcinogenic		
		Oral	Oral	Oral	Dermal	Oral	Dermal	Oral	Dermal	Produce (1)	Oral	Dermal	Produce (1)
Alkanes													
C_7 - C_9	0.1		5.00E+00			5.0E+00	5.0E+00				7.8E+05	6.0E+05	
C_{10} - C_{14}	0.1		1.00E-01			1.0E-01	1.0E-01				1.6E+04	1.2E+04	
C_{15} - C_{36}	0.01		1.50E+00			1.5E+00	1.5E+00				2.3E+05	1.8E+06	
MAHs													
benzene	0.1	2.90E-02		3.4E-04	3.4E-04			5.2E+02	1.9E+02				
toluene	0.1		2.00E-01			2.0E-01	2.0E-01				3.1E+04	2.4E+04	
ethylbenzene	0.1		1.00E-01			1.0E-01	1.0E-01				1.6E+04	1.2E+04	
xylene	0.1		1.80E-01			1.8E-01	1.8E-01				2.8E+04	2.1E+04	
Aromatics													
naphthalene	0.01		4.00E-03			4.0E-03	4.0E-03				6.3E+02	4.8E+03	7.15E+01
pyrene	0.01		3.00E-02			3.0E-02	3.0E-02				4.7E+03	3.6E+04	1.63E+03
benzo(a)pyrene	0.01	7.30E+00		1.4E-06	1.4E-06			2.1E+00	7.5E+00	2.71E-01			

Note:
(1) Ingestion of produce.
(2) Preliminary remediation goal for carcinogens based on entire 30 yr, PRG for non-carc. based on most critical 6 yr.
(3) Limiting values are shaded

Table 4G1b Preliminary Health Risk Based Acceptance Criteria *Residential Site Use*
Estimation of Target Soil Concentrations: - Produce Based

	Target Produce Concentration (mg/kg)		Kow	Uptake	1/(Plant Uptake	Target Soil Concentration (mg/kg)	
Contaminant	Carcinogenic	Non-carcinogenic		Factor	Factor)	Carcinogenic	Non-carcinogenic
Alkanes							
hexane		6.02E+03	7.94E+03				
nonane		1.20E+02	4.68E+04				
eicosane		1.80E+03					
MAHs							
benzene	1.22E+00		1.32E+02				
toluene		2.41E+02	5.37E+02				
ethylbenzene		1.20E+02	1.41E+03				
xylene		2.17E+02	1.82E+03				
Aromatics							
naphthalene		4.81E+00	2.34E+03	6.73E-02	1.49E+01		7.15E+01
pyrene		3.61E+01	1.51E+05	2.21E-02	4.52E+01		1.63E+03
benzo(a)pyrene	4.85E-03		1.02E+06	1.79E-02	5.59E+01	2.71E-01	

Table 4G1c Preliminary Health Risk Based Acceptance Criteria *Residential Site Use*

Site Use:	Residential	Exposure Frequency:	350 d/yr	Exposure Dur.(1-6 yrs):	6 yr
Receptor:	Children resident on site for up to 30 yr	Averaging Time (carc.):	70 Yr	Exposure Dur.(7-31 yrs):	24 yr
		(non-carc.):	30 Yr	Ingestion Rate (1-6 yrs):	100 Mg/d
		Age-adjusted ingestion factor:	48.57 mg.yr/kg.d	Ingestion Rate (7-31 yrs):	25 mg/d
Target Risk:	0.00001			Skin Area (1-6 yr) (cm²):	2625
Target HI:	1	Age-adjusted Dermal Exposure Factor	2.7E+03	Skin Area (7-30 yr) (cm²):	4700
				Soil Adherence (mg/sq.cm):	0.5
		Body Weight (1-6 yr):	15 kg		
		Body Weight (7-31 yr):	70 kg	Produce Ing (1-6yr, kg):	0.13
				Produce Ing (7-30yr, kg):	0.45
				Proportion of produce from contaminated source	0.5

				Acceptable CDI				Preliminary Remediation Goal (mg/kg) (2)					
Contaminant	Skin Absorption Factor	SF (1/(mg/kg/d)	RfD (mg/kg/d)	Carcinogenic		Non-carcinogenic		Carcinogenic			Non-carcinogenic		
		Oral	Oral	Oral	Dermal	Oral	Dermal	Oral	Dermal	Produce (1)	Oral	Dermal	Produce (1)
Alkanes													
C_7 - C_9	0.1		5.00E+00			5.0E+00	5.0E+00				7.8E+05	6.0E+05	
C_{10} - C_{14}	0.1		1.00E-01			1.0E-01	1.0E-01				1.6E+04	1.2E+04	
C_{15} - C_{36}	0.01		1.50E+00			1.5E+00	1.5E+00				2.3E+05	1.8E+06	
MAHs													
benzene	0.1	2.90E-02		3.4E-04	3.4E-04			5.2E+02	1.9E+02				
toluene	0.1		2.00E-01			2.0E-01	2.0E-01				3.1E+04	2.4E+04	
ethylbenzene	0.1		1.00E-01			1.0E-01	1.0E-01				1.6E+04	1.2E+04	
xylene	0.1		1.80E-01			1.8E-01	1.8E-01				2.8E+04	2.1E+04	
Aromatics													
naphthalene	0.01		4.00E-03			4.0E-03	4.0E-03				6.3E+02	4.8E+03	1.43E+01
pyrene	0.01		3.00E-02			3.0E-02	3.0E-02				4.7E+03	3.6E+04	3.27E+02
benzo(a)pyrene	0.01	7.30E+00		1.4E-06	1.4E-06			2.1E+00	7.5E+00	5.42E-02			

Note: (1) Ingestion of produce.
(2) Preliminary remediation goal for carcinogens based on entire 30 yr, PRG for non-carc. based on most critical 6 yr.
(3) Limiting values are shaded

Table 4G1d Preliminary Health Risk Based Acceptance Criteria *Residential Site Use* Estimation of Target Soil Concentrations: - Produce Based

	Target Produce Concentration (mg/kg)		Kow	Uptake Factor	1/(Plant Uptake Factor)	Target Soil Concentration (mg/kg)	
Contaminant	Carcinogenic	Non-carcinogenic				Carcinogenic	Non-carcinogenic
Alkanes							
hexane		1.20E+03	7.94E+03				
nonane		2.41E+01	4.68E+04				
eicosane		3.61E+02					
MAHs							
benzene	2.44E-01		1.32E+02				
toluene		4.81E+01	5.37E+02				
ethylbenzene		2.41E+01	1.41E+03				
xylene		4.33E+01	1.82E+03				
Aromatics							
naphthalene		9.63E-01	2.34E+03	6.73E-02	1.49E+01		1.43E+01
pyrene		7.22E+00	1.51E+05	2.21E-02	4.52E+01		3.27E+02
benzo(a)pyrene	9.70E-04		1.02E+06	1.79E-02	5.59E+01	5.42E-02	

Table 4G2 Preliminary Health Risk Based Acceptance Criteria *Commercial Site Use*

Site Use:	Commercial/	Exposure Frequency:	240 d/yr	Exposure Duration:	20 yr
Receptor:	Industrial Adult	Averaging Time (carc.):	70 yr		
	Worker for 20 yr	(non-carc.):	20 yr	Ingestion Rate (1-6 yr):	25 mg/d
Target Risk:	0.00001	ingestion Factor:		Skin Area (cm²):	4700
Target HI:	1				
		Exposure Factor:		Soil Adherence (mg/cm²):	1
		Body Weight:	70 kg		

				Acceptable CDI				Preliminary Remediation Goal (mg/kg) (2)					
Contaminant	Skin Absorption Factor	SF (1/(mg/kg/d)	RfD (mg/kg/d)	Carcinogenic		Non-carcinogenic		Carcinogenic			Non-carcinogenic		
		Oral	Oral	Oral	Dermal	Oral	Dermal	Oral	Dermal	Produce (1)	Oral	Dermal	Produce (1)
Alkanes													
C_7 - C_9	0.1		5.00E+00			5.0E+00	5.0E+00				2.1E+07	1.1E+06	
C_{10} - C_{14}	0.1		1.00E-01			1.0E-01	1.0E-01				4.3E+05	2.3E+04	
C_{15} - C_{36}	0.01		1.50E+00			1.5E+00	1.5E+00				6.4E+06	3.4E+06	
MAHs													
benzene	0.1	2.90E-02		3.4E-04	3.4E-04			5.1E+03	2.7E+02				
toluene	0.1		2.00E-01			2.0E-01	2.0E-01				8.5E+05	4.5E+04	
ethylbenzene	0.1		1.00E-01			1.0E-01	1.0E-01				4.3E+05	2.3E+04	
xylene	0.1		1.80E-01			1.8E-01	1.8E-01				7.7E+05	4.1E+04	
Aromatics													
naphthalene	0.01		4.00E-03			4.0E-03	4.0E-03				1.7E+04	9.1E+03	
pyrene	0.01		3.00E-02			3.0E-02	3.0E-02				1.3E+05	6.8E+04	
benzo(a)pyrene	0.01	7.30E+00		1.4E-06	1.4E-06			2.0E+01	1.1E+01				

Table 4G3a Preliminary Health Risk Based Acceptance Criteria *Agricultural Site Use*

Site Use:	Residential	Exposure Frequency:	350	d/yr	Exposure Dur.(1-6 yrs):	6	yr
Receptor:	Children resident on site for up to 30 yr	Averaging Time (carc.):	70	Yr	Exposure Dur.(7-31 yrs):	24	yr
		(non-carc.):	30	Yr	Ingestion Rate (1-6 yrs):	100	Mg/d
		Age-adjusted ingestion factor:	48.57	mg.yr/kg.d	Ingestion Rate (7-31 yrs):	25	mg/d
Target Risk: 0.00001					Skin Area (1-6 yr) (cm²):	2625	
Target HI:	1	Age-adjusted Dermal Exposure Factor	2.7E+03		Skin Area (7-30 yr) (cm²):	4700	
					Soil Adherence (mg/sq.cm):	1	
		Body Weight (1-6 yr):	15	kg			
		Body Weight (7-31 yr):	70	kg	Produce Ing (1-6yr, kg):	0.13	
					Produce Ing (7-30yr, kg):	0.45	
					Proportion of produce from contaminated source	1	

				Acceptable CDI				Preliminary Remediation Goal (mg/kg) (2)					
Contaminant	Skin Absorption	SF (1/(mg/kg/d)	RfD (mg/kg/d)	Carcinogenic		Non-carcinogenic		Carcinogenic			Non-carcinogenic		
	Factor	Oral	Oral	Oral	Dermal	Oral	Dermal	Oral	Dermal	Produce (1)	Oral	Dermal	Produce (1)
Alkanes													
C_7 - C_9	0.1		5.00E+00			5.0E+00	5.0E+00				7.8E+05	3.0E+05	
C_{10} - C_{14}	0.1		1.00E-01			1.0E-01	1.0E-01				1.6E+04	6.0E+03	
C_{15} - C_{36}	0.01		1.50E+00			1.5E+00	1.5E+00				2.3E+05	8.9E+05	
MAHs													
benzene	0.1	2.90E-02		3.4E-04	3.4E-04			5.2E+02	9.5E+01				
toluene	0.1		2.00E-01			2.0E-01	2.0E-01				3.1E+04	1.2E+04	
ethylbenzene	0.1		1.00E-01			1.0E-01	1.0E-01				1.6E+04	6.0E+03	
xylene	0.1		1.80E-01			1.8E-01	1.8E-01				2.8E+04	1.1E+04	
Aromatics													
naphthalene	0.01		4.00E-03			4.0E-03	4.0E-03				6.3E+02	2.4E+03	7.15E+00
pyrene	0.01		3.00E-02			3.0E-02	3.0E-02				4.7E+03	1.8E+04	1.63E+02
benzo(a)pyrene	0.01	7.30E+00		1.4E-06	1.4E-06			2.1E+00	3.8E+00	2.71E-02			

Note:
(1) Ingestion of produce.
(2) Preliminary remediation goal for carcinogens based on entire 30 yr, PRG for non-carc. based on most critical 6 yr.
(3) Limiting values are shaded

Table 4G3b **Preliminary Health Risk Based Acceptance Criteria *Agricultural Site Use* Estimation of Target Soil Concentrations: - Produce Based**

	Target Produce Concentration (mg/kg)		Koc	Kow	Uptake	1/(Plant Uptake	Target Soil Concentration (mg/kg)	
Contaminant	Carcinogenic	Non-carcinogenic			Factor	Factor)	Carcinogenic	Non-carcinogenic
Alkanes								
hexane		6.02E+02	4.45E+03	7.94E+03				
nonane		1.20E+01	2.34E+04	4.68E+04				
eicosane		1.80E+02						
MAHs								
benzene	1.22E-01		8.30E+01	1.32E+02				
toluene		2.41E+01	3.02E+02	5.37E+02				
ethylbenzene		1.20E+01	1.10E+03	1.41E+03				
xylene		2.17E+01	2.40E+02	1.82E+03				
Aromatics								
naphthalene		4.81E-01	1.29E+03	2.34E+03	6.73E-02	1.49E+01		7.15E+00
pyrene		3.61E+00	3.80E+04	1.51E+05	2.21E-02	4.52E+01		1.63E+02
benzo(a)pyrene	4.85E-04		3.89E+05	1.02E+06	1.79E-02	5.59E+01	2.71E-02	

Table 4G4 Preliminary Health Risk Based Acceptance Criteria *Commercial Site Use*

Site Use: Maintenance
Receptor: Worker for 20 yr

Exposure Frequency: 50 d/yr
Averaging Time (carc.): 70 yr
(non-carc.): 20 yr

Exposure Duration: 20 yr
Ingestion Rate (1-6 yr): 100 mg/d

Target Risk 0.00001
Target HI: 1

ingestion Factor:

Skin Area (cm²): 4700

Exposure Factor:
Body Weight: 70 kg

Soil Adherence (mg/cm²): 1.5

				Acceptable CDI				Preliminary Remediation Goal (mg/kg) (2)					
Contaminant	Skin Absorption Factor	SF (1/(mg/kg/d)	RfD (mg/kg/d)	Carcinogenic		Non-carcinogenic		Carcinogenic			Non-carcinogenic		
		Oral	Oral	Oral	Dermal	Oral	Dermal	Oral	Dermal	Produce (1)	Oral	Dermal	Produce (1)
Alkanes													
C_7 - C_9	0.1		5.00E+00			5.0E+00	5.0E+00				2.6E+07	3.6E+06	
C_{10} - C_{14}	0.1		1.00E-01			1.0E-01	1.0E-01				5.1E+05	7.2E+04	
C_{15} - C_{36}	0.01		1.50E+00			1.5E+00	1.5E+00				7.7E+06	1.1E+07	
MAHs													
benzene	0.1	2.90E-02		3.4E-04	3.4E-04			6.2E+03	8.7E+02				
toluene	0.1		2.00E-01			2.0E-01	2.0E-01				1.0E+06	1.4E+05	
ethylbenzene	0.1		1.00E-01			1.0E-01	1.0E-01				5.1E+05	7.2E+04	
xylene	0.1		1.80E-01			1.8E-01	1.8E-01				9.2E+05	1.3E+05	
Aromatics													
naphthalene	0.01		4.00E-03			4.0E-03	4.0E-03				2.0E+04	2.9E+04	
pyrene	0.01		3.00E-02			3.0E-02	3.0E-02				1.5E+05	2.2E+05	
benzo(a)pyrene	0.01	7.30E+00		1.4E-06	1.4E-06			2.5E+01	3.5E+01				

Appendix 4H
Target air and produce concentration

Table 4H1 Health-based target indoor air concentrations

Contaminant	Indoor Air Concentration ($\mu g/m^3$)
RESIDENTIAL / AGRICULTURAL LAND USE	
TPHs	
C_7-C_9	24,000
C_{10}-C_{14}	1,500
C_{15}-C_{36}	7,300
MAHs	
Benzene	3.9
Toluene	540
Ethylbenzene	140
Xylene	440
PAHs	
Naphthalene	19
Non-carc. (Pyrene)	150
Benzo(a)pyrene	0.016
COMMERCIAL / INDUSTRIAL LAND USE	
TPHs	
C_7-C_9	53,000
C_{10}-C_{14}	3,200
C_{15}-C_{36}	16,000
MAHs	
Benzene	13
Toluene	1,200
Ethylbenzene	310
Xylene	960
PAHs	
Naphthalene	43
Non-carc. (Pyrene)	320
Benzo(a)pyrene	0.051

Table 4H2 Health-based target produce concentration

Contaminant	Produce Concentration (mg/kg fresh weight)
RESIDENTIAL LAND USE	
TPHs	
C_7-C_9	-
C_{10}-C_{14}	-
C_{15}-C_{36}	-
MAHs	
Benzene	-
Toluene	-
Ethylbenzene	-
Xylene	-
PAHs	
Naphthalene	4.8
Non-carc. (Pyrene)	36
Benzo(a)pyrene	0.0049
AGRICULTURAL LAND USE	
TPHs	
C_7-C_9	-
C_{10}-C_{14}	-
C_{15}-C_{36}	-
MAHs	
Benzene	-
Toluene	-
Ethylbenzene	-
Xylene	-
PAHs	
Naphthalene	0.48
Non-carc. (Pyrene)	3.6
Benzo(a)pyrene	0.00049

Appendix 4I
Ecological assessment checklist

Tier 1 Ecological Assessment Checklist

Receptor (Non-Human) and Exposure Pathway Identification (adapted from Idaho RBCA Guidance, 1996 and ASTM draft RBCA guidance for Chemical Release Sites, 1997) Site Identification

Site Name:	Location
Date:	Assessor:

Background

Product released:		Approximate date of release:	
Approximate volume of release:		Geology:	
Depth to groundwater:		Distance to nearest surface water:	

Identification of receptors

1. Are marshes, swamps, tidal flats or other ecologically sensitive wetlands near[1] the site?	Y/N
2. Are other aquatic habitats such as rivers, lakes or streams near the site?	Y/N
3. Are ecologically important marine or estuarine environments near the site?	Y/N
4. Are ecologically important or sensitive environments such as national parks or nature reserves located near the site?	Y/N
5. Are habitats for rare, threatened or endangered species near the site?	Y/N
6. Are culturally important ecological receptors located the site?	Y/N
7. Are commercially or recreationally important ecological receptors near the site?	Y/N
8. Are forested, grassland or other habitats of significance located near the site?	Y/N

If a potentially significant ecological receptor has been identified proceed to the exposure pathway analysis.

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[1] “Near” should be judged on a site-specific basis given the likely contaminant’s transport by wind, surface run-off or groundwater transport

Exposure pathway analysis	Receptors		
	1	2	3
1. **Could contaminants reach receptor via groundwater?** - Can contaminants leach or dissolve into groundwater? - Are contaminants mobile in groundwater? - Does groundwater discharge into receiving environments such that it can impact on the receptor?	Y/N	Y/N	Y/N
2. **Could contaminants reach the receptor via the migration of separate phase hydrocarbons?** - Are separate phase hydrocarbons present at the site? - Is the separate phase migrating toward the receptor? - Could discharge of separate phase hydrocarbons to a receiving environment occur such that an impact on the receptor may occur?	Y/N	Y/N	Y/N
3. **Could contaminants reach the receptors via runoff?** - Are the contaminants present in the surface soil? - Is the surface soil exposed? - Can the contaminants be leached from or eroded with the surface soils? - Is the receptor downhilll from the source?	Y/N	Y/N	Y/N
4. **Could the receptors come in direct contact with contaminated soil at the site?** - Is the receptor located within a contaminated area? - Is the contamination present at the surface or otherwise located so that receptors may come in contact with it?	Y/N	Y/N	Y/N
5. **Are there visible indications of stressed receptors or habitats for ecologically significant receptors at or near the site?**	Y/N	Y/N	Y/N

If a potentially complete exposure pathway is identified for an ecologically significant receptor, **proceed with more detailed, site-specific assessment (Tier 2).**

Receptor/habitat description

Receptor /habitat	Description
1	
2	
3	

Observed impacts on ecological receptors or habitats associated with the site

Receptor	Assessment of Impact		
	None	Limited	Significant
On-site vegetation			
Off-site vegetation			
On-site animal life (eg. invertebrates, birds, fish)			
Off-site animal life (eg. invertebrates, birds, fish)			
Other impacts			

Appendix 4J
Soil gas acceptance criteria for the protection of indoor air quality

1.1 Overview

Modelling of the migration of volatiles from contaminated soil or groundwater based on contaminant concentrations in soil and/or groundwater and soil properties, incorporates a significant level of uncertainty. While most volatilisation models can account for diffusive and/or advective transport together with source depletion and possibly adsorption/desorption processes, a range of other processes, most notably biodegradation, may mitigate the transport of contaminants.

Direct measurement of indoor air concentrations would circumvent these uncertainties however such measurements are subject to confounding from other sources. Measurement of contaminant concentrations at a depth of, say, 1metre, allows the estimate of volatilisation to be refined by accounting for some of the processes occuring between the source and point of measurement, particularly biodegradation. This approach is most useful where the source of vapours is located at depth of, say, > 4 metres.

This approach also has the following advantages:

- Only the top 1 metre of soil needs to be homogeneous (although adjustments in calculations can account for multiple soil types).
- There is no need to model phase partitioning.
- One set of criteria can be used for both soil and groundwater contamination source (provided that the source is below 1 metre).
- Model is not limited by the presence of separate phase hydrocarbons.

A limitation of this approach is that it is unable to account for source depletion or the time dependency of the volatilisation, as information regarding the source is not considered in the calculations. Notwithstanding this, the measurement of contaminant concentrations in soil gas at a depth of 1 metre allows estimates of the risk associated with the volatilisation of contaminants to be refined.

Note that this approach is subject to being able to obtain reliable measurements of the contaminant concentrations in soil gas (e.g. minimising infiltration and short circuiting during soil gas sampling).

1.2 Volatilisation model

The Johnson-Ettinger (1991) equation for emissions from soil through a concrete slab into a building has been rearranged and presented in terms of a Volatilisation Factor (refer equation J1). This equation is notable in that it relates soil gas concentrations to indoor air concentrations. The original Johnson and Ettinger model has to be combined with an equilibrium partitioning relationship if indoor air concentrations are to be determined from measured soil concentrations. The Volatilisation Factor relating indoor air concentrations to soil gas concentrations is as follows:

$$VF_{soil-air}\left|\frac{mg/m^{3}{}_{air}}{mg/m^{3}{}_{soil-gas}}\right| = \frac{\left[\dfrac{D_s^{eff}\ /\ L_s}{ER.\,L_B}\right]}{1+\left[\dfrac{D_s^{eff}\ /\ L_s}{ER.\,L_B}\right]+\left[\dfrac{D_s^{eff}\ /\ L_s}{(D_{crack}^{eff}\ /\ L_{crack})\eta}\right]}\times 10^{3}\ \frac{cm^{3}kg}{m^{3}g} \qquad \text{(J1)}$$

where:

VF = Volatilisation Factor (Attenuation Factor) for soil air to indoor air

D_s^{eff} = Effective diffusivity (cm^2/s)

Ls = Depth to soil measurement (100 cm)

ER = Air Exchange Rate (s^{-1})

L_B = Ratio of Air Volume to Infiltration Area (cm)

D_{crack} = Effective Diffusivity in Cracks in Foundation (cm^2/s)

L_{crack} = Thickness of Foundation (cm)

h = Areal fraction of cracks in foundation

Diffusion coefficients and other parameters are defined in Appendix 4D. Note that the equation J1 represents a simple diffusion controlled, non-depleting source form of the Johnson and Ettinger model.

1.3 Volatilisation factors

The estimated Volatilisation Factors (or Attenuation Factors) for soil-air to indoor air are presented in Table 4J2 and Table 4J4 for residential and commercial respectively. Table J1 present the maximum allowable indoor air concentrations. (See Appendix 4H).

To calculate the maximum allowable contaminant concentrations in soil-air gas at 1 m depth, the following relationship is used:

$$C_{soil-air} = \frac{C_{air}}{VF_{sa}} \qquad \text{(J2)}$$

where:

$C_{soil\text{-}air}$ = Maximum Soil-Air Concentration at 1 m (mg/m^3)

C_{air} = Maximum allowable indoor air concentration (mg/m^3)

VF_{sa} = Volatilisation Factor (or Attenuation Factor) for soil-air to indoor air (calculated in eq. J1)

Table 4J3 and 4J5 present the maximum allowable contaminant concentrations in soil-air gas at a depth of 1 metre, for residential and commercial land use respectively.

TABLE 4J1 Health-Based Target Indoor Air Concentrations

Contaminant	**Indoor Air Concentration ($\mu g/m^3$)**
RESIDENTIAL / AGRICULTURAL LAND USE	
TPHs	
C_7-C_9	24,000
C_{10}-C_{14}	1,500
C_{15}-C_{36}	7,300
MAHs	
Benzene	3.9
Toluene	540
Ethylbenzene	140
Xylene	440
PAHs	
Naphthalene	19
Non-carc. (Pyrene)	150
Benzo(a)pyrene	0.016
COMMERCIAL / INDUSTRIAL LAND USE	
TPHs	
C_7-C_9	53,000
C_{10}-C_{14}	3,200
C_{15}-C_{36}	16,000
MAHs	
Benzene	13
Toluene	1,200
Ethylbenzene	310
Xylene	960
PAHs	
Naphthalene	43
Non-carc. (Pyrene)	320
Benzo(a)pyrene	0.051

Table 4J2 Attenuation Factor for Soil-Air at 1 metre to Indoor Air Concentration *Residential*

Chemical	Soil at 1 m					
	Sand	**Silty Sand**	**Silty Clay**	**Clay**	**Pumice**	**Peats**
C_7-C_9	1.99E-02	1.69E-02	1.68E-03	4.89E-05	1.67E-02	1.88E-02
C_{10}-C_{14}	1.39E-02	1.18E-02	1.18E-03	3.39E-05	1.17E-02	1.32E-02
C_{15}-C_{36}	1.09E-02	9.28E-03	9.26E-04	2.67E-05	9.19E-03	1.04E-02
Benzene	3.09E-02	2.62E-02	3.56E-03	1.55E-03	2.59E-02	2.92E-02
Toluene	2.82E-02	2.39E-02	3.07E-03	1.14E-03	2.37E-02	2.67E-02
Ethylbenzene	2.52E-02	2.14E-02	2.64E-03	8.55E-04	2.12E-02	2.38E-02
Xylene	2.39E-02	2.03E-02	2.58E-03	9.29E-04	2.01E-02	2.26E-02
Naphthalene	2.39E-02	2.03E-02	5.25E-03	4.84E-03	2.01E-02	2.26E-02
Pyrene	1.68E-02	1.65E-02	1.72E-02	1.73E-02	1.68E-02	1.65E-02
Penzo(a)pyrene	2.39E-02	2.47E-02	2.50E-02	2.50E-02	2.49E-02	2.45E-02

Table 4J3 Target Soil-Air Concentration at 1 metre - *Residential*

Chemical	Soil-Air Target Concentrations at 1 m (mg/m^3)					
	Sand	**Silty Sand**	**Silty Clay**	**Clay**	**Pumice**	**Peats**
C_7-C_9	1.21E+03	1.42E+03	1.43E+04	4.91E+05	1.44E+03	1.27E+03
C_{10}-C_{14}	1.08E+02	1.27E+02	1.27E+03	4.43E+04	1.28E+02	1.14E+02
C_{15}-C_{36}	6.67E+02	7.86E+02	7.89E+03	2.73E+05	7.94E+02	7.05E+02
benzene	1.26E-01	1.49E-01	1.10E+00	2.52E+00	1.50E-01	1.34E-01
toluene	1.91E+01	2.26E+01	1.76E+02	4.73E+02	2.28E+01	2.02E+01
Ethylbenzene	5.55E+00	6.55E+00	5.30E+01	1.64E+02	6.61E+00	5.87E+00
Xylene	1.84E+01	2.17E+01	1.71E+02	4.73E+02	2.19E+01	1.95E+01
Naphthalene	7.95E-01	9.36E-01	3.62E+00	3.92E+00	9.44E-01	8.41E-01
Pyrene	8.95E+00	9.11E+00	8.72E+00	8.67E+00	8.94E+00	9.11E+00
Penzo(a)pyrene	6.69E-04	6.46E-04	6.39E-04	6.39E-04	6.43E-04	6.52E-04

Table 4J4 Attenuation Factor for Soil-Air at 1 metre to Indoor Air Concentration - *Commercial / Industrial*

Chemical	**Soil at 1 m**					
	Sand	**Silty Sand**	**Silty Clay**	**Clay**	**Pumice**	**Peats**
C_7-C_9	1.33E-02	1.13E-02	1.12E-03	3.26E-05	1.11E-02	1.26E-02
C_{10}-C_{14}	9.29E-03	7.88E-03	7.85E-04	2.26E-05	7.80E-03	8.79E-03
C_{15}-C_{36}	7.30E-03	6.19E-03	6.17E-04	1.78E-05	6.13E-03	6.90E-03
Benzene	2.06E-02	1.74E-02	2.37E-03	1.03E-03	1.73E-02	1.95E-02
Toluene	1.88E-02	1.59E-02	2.05E-03	7.61E-04	1.58E-02	1.78E-02
Ethylbenzene	1.68E-02	1.43E-02	1.76E-03	5.70E-04	1.41E-02	1.59E-02
Xylene	1.59E-02	1.35E-02	1.72E-03	6.20E-04	1.34E-02	1.51E-02
Naphthalene	1.59E-02	1.35E-02	3.50E-03	3.23E-03	1.34E-02	1.51E-02
Pyrene	1.12E-02	1.10E-02	1.15E-02	1.15E-02	1.12E-02	1.10E-02
Penzo(a)pyrene	1.59E-02	1.65E-02	1.67E-02	1.67E-02	1.66E-02	1.64E-02

Table 4J5 Target Soil-Air Concentration at 1 metre - *Commercial / Industrial*

Chemical	**Soil-Air Target Concentrations at 1 m (mg/m^3)**					
	Sand	**Silty Sand**	**Silty Clay**	**Clay**	**Pumice**	**Peats**
C_7-C_9	3.99E+03	4.71E+03	4.72E+04	1.63E+06	4.76E+03	4.22E+03
C_{10}-C_{14}	3.44E+02	4.06E+02	4.07E+03	1.42E+05	4.10E+02	3.64E+02
C_{15}-C_{36}	2.19E+03	2.59E+03	2.59E+04	8.98E+05	2.61E+03	2.32E+03
Benzene	6.32E-01	7.45E-01	5.48E+00	1.26E+01	7.52E-01	6.68E-01
Toluene	6.38E+01	7.53E+01	5.86E+02	1.58E+03	7.60E+01	6.75E+01
Ethylbenzene	1.84E+01	2.17E+01	1.76E+02	5.44E+02	2.20E+01	1.95E+01
Xylene	6.03E+01	7.11E+01	5.58E+02	1.55E+03	7.18E+01	6.37E+01
Naphthalene	2.70E+00	3.18E+00	1.23E+01	1.33E+01	3.21E+00	2.85E+00
Pyrene	2.86E+01	2.92E+01	2.79E+01	2.78E+01	2.86E+01	2.92E+01
Benzo(a)pyrene	3.20E-03	3.09E-03	3.06E-03	3.05E-03	3.07E-03	3.12E-03

Table 46a Volatilisation (soil-air) of sub-surface soil contamination at 1 metre to enclosed spaces SAND Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H 20^{o}C L-H_2OL-air	Koc	Deff cm^2/s	ks cm$^3H_2$O/g-soil	Defcrack cm^2/s
C_7-C_9	0.06	7.10E-06	1.2E+02	10000	4.7E-03	30	4.68E-03
C_{10}-C_{14}	0.042	4.80E-06	1.6E+02	1258925	3.3E-03	3776.775	3.28E-03
C_{15}-C_{36}	0.033	3.80E-06	1.4E+02	501187233	2.6E-03	1503561.699	2.58E-03
Bbenzene	0.093	1.1E-05	2.2E-01	83	7.3E-03	0.249	7.26E-03
Ttoluene	0.085	9.40E-06	2.6E-01	302	6.6E-03	0.906	6.63E-03
Eethylbenzene	0.076	8.50E-06	3.2E-01	1096	5.9E-03	3.288	5.93E-03
Xxylene	0.072	8.50E-06	2.9E-01	240	5.6E-03	0.72	5.62E-03
Nnaphthalene	0.072	9.40E-06	4.9E-02	1288	5.6E-03	3.864	5.62E-03
Ppyrene	0.048	7.24E-06	2.2E-04	38019	3.9E-03	114.057	3.94E-03
Bbenzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	5.6E-03	1167.135	5.63E-03

	T1	T2	Residential VFsa - indoor	Commercial VFsa - indoor
C_7-C_9	4.18E-04	20	1.99E-02	1.33E-02
C_{10}-C_{14}	2.93E-04	20	1.39E-02	9.29E-03
C_{15}-C_{36}	2.30E-04	20	1.09E-02	7.30E-03
benzene	6.48E-04	20	3.09E-02	2.06E-02
toluene	5.92E-04	20	2.82E-02	1.88E-02
ethylbenzene	5.30E-04	20	2.52E-02	1.68E-02
xylene	5.02E-04	20	2.39E-02	1.59E-02
naphthalene	5.02E-04	20	2.39E-02	1.59E-02
pyrene	3.52E-04	20	1.68E-02	1.12E-02
benzo(a)pyrene	5.02E-04	20	2.39E-02	1.59E-02

Table 4J6b Volatilisation (soil-air) of sub-surface soil contamination at 1metre to enclosed spaces SILT Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H 20^{o}C L-H_2O/L-air	Koc	Deff cm^2/s	ks cm$^3H_2$O/g-soil	Defcrack cm^2/s
C_7-C_9	0.06	7.10E-06	1.2E+02	10000	9.8E-04	30	4.68E-03
C_{10}-C_{14}	0.042	4.80E-06	1.6E+02	1258925	6.9E-04	3776.775	3.28E-03
C_{15}-C_{36}	0.033	3.80E-06	1.4E+02	501187233	5.4E-04	1503561.699	2.58E-03
Benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.249	7.26E-03
Toluene	0.085	9.40E-06	2.6E-01	302	1.4E-03	0.906	6.63E-03
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	3.288	5.93E-03
Xylene	0.072	8.50E-06	2.9E-01	240	1.2E-03	0.72	5.62E-03
Naphthalene	0.072	9.40E-06	4.9E-02	1288	1.2E-03	3.864	5.62E-03
Pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	114.057	3.94E-03
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.9E-02	1167.135	5.63E-03

	T1	T2	Residential VFsa - indoor	Commercial VFsa - indoor
C_7-C_9	8.76E-05	4	1.69E-02	1.13E-02
C_{10}-C_{14}	6.13E-05	4	1.18E-02	7.88E-03
C_{15}-C_{36}	4.82E-05	4	9.28E-03	6.19E-03
Benzene	1.36E-04	4	2.62E-02	1.74E-02
Toluene	1.24E-04	4	2.39E-02	1.59E-02
Ethylbenzene	1.11E-04	4	2.14E-02	1.43E-02
Xylene	1.05E-04	4	2.03E-02	1.35E-02
Naphthalene	1.06E-04	4	2.03E-02	1.35E-02
Pyrene	2.55E-04	15	1.65E-02	1.10E-02
Benzo(a)pyrene	1.71E-03	68	2.47E-02	1.65E-02

Table 4J6c Volatilisation (soil-air) of sub-surface soil contamination at 1 metre to enclosed spaces SILTY CLAY Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20°C L-$H_2$0/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s
C_7-C_9	0.06	7.10E-06	1.2E+02	10000	2.1E-05	30	4.68E-03
C_{10}-C_{14}	0.042	4.80E-06	1.6E+02	1258925	1.4E-05	3776.775	3.28E-03
C_{15}-C_{36}	0.033	3.80E-06	1.4E+02	501187233	1.1E-05	1503561.699	2.58E-03
Benzene	0.093	1.1E-05	2.2E-01	83	4.5E-05	0.249	7.26E-03
Toluene	0.085	9.40E-06	2.6E-01	302	3.8E-05	0.906	6.63E-03
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	3.3E-05	3.288	5.93E-03
Xylene	0.072	8.50E-06	2.9E-01	240	3.2E-05	0.72	5.62E-03
Naphthalene	0.072	9.40E-06	4.9E-02	1288	7.4E-05	3.864	5.62E-03
Pyrene	0.048	7.24E-06	2.2E-04	38019	8.6E-03	114.057	3.94E-03
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	7.5E-02	1167.135	5.63E-03

	T1	T2	Residential VFsa - indoor	Commercial VFsa - indoor
C_7-C_9	1.83E-06	0	1.68E-03	1.12E-03
C_{10}-C_{14}	1.28E-06	0	1.18E-03	7.85E-04
C_{15}-C_{36}	1.01E-06	0	9.26E-04	6.17E-04
Benzene	4.00E-06	0	3.56E-03	2.37E-03
Toluene	3.43E-06	0	3.07E-03	2.05E-03
Ethylbenzene	2.93E-06	0	2.64E-03	1.76E-03
Xylene	2.87E-06	0	2.58E-03	1.72E-03
Naphthalene	6.65E-06	0	5.25E-03	3.50E-03
Pyrene	7.65E-04	43	1.72E-02	1.15E-02
Benzo(a)pyrene	6.73E-03	268	2.50E-02	1.67E-02

Table 4J6d Volatilisation (soil-air) of sub-surface soil contamination at 1 metre to enclosed spaces CLAY Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20°C L-$H_2$0/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s
C_7-C_9	0.06	7.10E-06	1.2E+02	10000	5.5E-07	30	4.68E-03
C_{10}-C_{14}	0.042	4.80E-06	1.6E+02	1258925	3.8E-07	3776.775	3.28E-03
C_{15}-C_{36}	0.033	3.80E-06	1.4E+02	501187233	3.0E-07	1503561.699	2.58E-03
Benzene	0.093	1.1E-05	2.2E-01	83	1.8E-05	0.249	7.26E-03
Toluene	0.085	9.40E-06	2.6E-01	302	1.3E-05	0.906	6.63E-03
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	9.9E-06	3.288	5.93E-03
Xylene	0.072	8.50E-06	2.9E-01	240	1.1E-05	0.72	5.62E-03
Naphthalene	0.072	9.40E-06	4.9E-02	1288	6.7E-05	3.864	5.62E-03
Pyrene	0.048	7.24E-06	2.2E-04	38019	1.1E-02	114.057	3.94E-03
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.0E-01	1167.135	5.63E-03

	T1	T2	Residential VFsa - indoor	Commercial VFsa - indoor
C_7-C_9	4.90E-08	0	4.89E-05	3.26E-05
C_{10}-C_{14}	3.39E-08	0	3.39E-05	2.26E-05
C_{15}-C_{36}	2.68E-08	0	2.67E-05	1.78E-05
benzene	1.62E-06	0	1.55E-03	1.03E-03
toluene	1.19E-06	0	1.14E-03	7.61E-04
ethylbenzene	8.83E-07	0	8.55E-04	5.70E-04
xylene	9.65E-07	0	9.29E-04	6.20E-04
naphthalene	6.00E-06	0	4.84E-03	3.23E-03
pyrene	1.02E-03	58	1.73E-02	1.15E-02
benzo(a)pyrene	8.99E-03	358	2.50E-02	1.67E-02

Table 4J6e Volatilisation (soil-air) of sub-surface soil contamination at 1 metre to enclosed spaces PUMICE Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20^{o}C L-$H_2$0/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s
C_7-C_9	0.06	7.10E-06	1.2E+02	10000	9.3E-04	50	4.68E-03
C_{10}-C_{14}	0.042	4.80E-06	1.6E+02	1258925	6.5E-04	6294.625	3.28E-03
C_{15}-C_{36}	0.033	3.80E-06	1.4E+02	501187233	5.1E-04	2505936.165	2.58E-03
Benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.415	7.26E-03
Toluene	0.085	9.40E-06	2.6E-01	302	1.3E-03	1.51	6.63E-03
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	5.48	5.93E-03
Xylene	0.072	8.50E-06	2.9E-01	240	1.1E-03	1.2	5.62E-03
Naphthalene	0.072	9.40E-06	4.9E-02	1288	1.1E-03	6.44	5.62E-03
Pyrene	0.048	7.24E-06	2.2E-04	38019	4.0E-03	190.095	3.94E-03
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	3.0E-02	1945.225	5.63E-03

	T1	T2	Residential VFsa - indoor	Commercial VFsa - indoor
C_7-C_9	8.33E-05	4	1.67E-02	1.11E-02
C_{10}-C_{14}	5.83E-05	4	1.17E-02	7.80E-03
C_{15}-C_{36}	4.58E-05	4	9.19E-03	6.13E-03
Benzene	1.30E-04	4	2.59E-02	1.73E-02
Toluene	1.18E-04	4	2.37E-02	1.58E-02
Ethylbenzene	1.06E-04	4	2.12E-02	1.41E-02
Xylene	1.00E-04	4	2.01E-02	1.34E-02
Naphthalene	1.02E-04	4	2.01E-02	1.34E-02
Pyrene	3.61E-04	21	1.68E-02	1.12E-02
Benzo(a)pyrene	2.66E-03	106	2.49E-02	1.66E-02

Table 4J6f Volatilisation (soil-air) of sub-surface soil contamination at 1 metre to enclosed spaces PEATS AND HIGHLY ORGANIC Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20^{o}C L-$H_2$0/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s
C_7-C_9	0.06	7.10E-06	1.2E+02	10000	2.1E-03	1200	4.68E-03
C_{10}-C_{14}	0.042	4.80E-06	1.6E+02	1258925	1.5E-03	151071	3.28E-03
C_{15}-C_{36}	0.033	3.80E-06	1.4E+02	501187233	1.2E-03	60142467.96	2.58E-03
Benzene	0.093	1.1E-05	2.2E-01	83	3.3E-03	9.96	7.26E-03
Toluene	0.085	9.40E-06	2.6E-01	302	3.0E-03	36.24	6.63E-03
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	2.7E-03	131.52	5.93E-03
Xlene	0.072	8.50E-06	2.9E-01	240	2.6E-03	28.8	5.62E-03
Naphthalene	0.072	9.40E-06	4.9E-02	1288	2.6E-03	154.56	5.62E-03
Pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	4562.28	3.94E-03
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.2E-02	46685.4	5.63E-03

	T1	T2	Residential VFsa - indoor	Commercial VFsa - indoor
C_7-C_9	1.90E-04	9	1.88E-02	1.26E-02
C_{10}-C_{14}	1.33E-04	9	1.32E-02	8.79E-03
C_{15}-C_{36}	1.04E-04	9	1.04E-02	6.90E-03
Benzene	2.94E-04	9	2.92E-02	1.95E-02
Toluene	2.69E-04	9	2.67E-02	1.78E-02
Ethylbenzene	2.40E-04	9	2.38E-02	1.59E-02
Xylene	2.28E-04	9	2.26E-02	1.51E-02
Naphthalene	2.28E-04	9	2.26E-02	1.51E-02
Pyrene	2.56E-04	15	1.65E-02	1.10E-02
Benzo(a)pyrene	1.07E-03	43	2.45E-02	1.64E-02

Appendix 4K
Soil acceptance criteria for excavation workers

1.1 Overview

Excavation workers may be exposed to higher concentrations of volatile contaminants than many other site users, albeit generally for a shorter period of time. The volatilisation of contaminants from soil may impact on the health of the workers involved in subsurface works. Exposure via dermal contact and ingestion of soil was addressed previously as part of the derivation of acceptance criteria for maintenance workers.

The primary concern associated with the exposure of maintenance and construction workers involved in excavation works is the accumulation of volatiles within the excavation. The New Zealand Workplace Exposure Standards (WES) have been used as the basis for derivation of soil acceptance criteria protective of excavation workers. Volatilisation modelling is used to relate the WES to acceptable concentrations in soil.

Assuming air within the excavation is fully mixed, the estimated contaminant concentration in air within the excavation is expected to approach an effective steady state within a period of 1-2 hours. Within this period the diffusion path length is not expected to increase rapidly compared to the initial assumption of 10 cm.

1.2 Air standards

The New Zealand Workplace Exposure Standards (WES) 1994 developed by OSH and the Department of Labour have been used as target air concentrations within the excavation. The WES have been used as the basis for determining a tolerable level of exposure, rather than the risk-based limits used for other receptors, due to the occupational context and the intermittent exposure associated with excavation works.

The WESs are expressed as time-weighted average (TWA) concentrations, based on exposure over an eight-hour working day, for a five day working week. While exposure to volatiles within the excavation is unlikely to occur eight hours/day, five days/week, limits are usually nominated for short term exposures in order to avoid acute health effects. Therefore, the eight hour TWA WESs have been adopted as the basis for exposure to contaminants in the air.

1.3 Volatilisation models

1.3.1 Summary

Volatile contaminants may be expected to accumulate within excavations when the excavation intersects contaminated soil. Workers may be exposed when working in or near the excavation. The use of the WES as a target air concentration within the pit is expected to be conservative as workers are extremely unlikely to spend eight hours/day within the pit. Workers near the pit may be exposed to contaminants emanating from the pit and stockpiled material although this is expected to be at a lower level than would occur within the excavation.

1.3.2 Assumptions

A simple non-depleting source model was used to estimate the concentration of volatile contaminants in air within the excavation resulting from excavation into contaminated soil not previously exposed to the atmosphere. The soil on the base and the walls of the pit is assumed to be uniformly contaminated. The volatilisation model uses the following assumptions:

- The pit is 10 m x 10 m x 4 m deep
- The diffusion path for contaminants in the soil is 10 cm
- The air exchange rate for pit is 2 hr^{-1} (selected on the basis of professional judgement given, 2 hr^{-1} is adopted as a conservative air exchange rate for residential buildings).

1.3.3 Equations

The equation used is a modified form of the Johnson-Ettinger equation. Source depletion is neglected, as is the resistance associated with a concrete slab foundation included in the indoor air vapour intrusion model. The model resembles that of volatiles to indoor air in a basement, with the exception of the concrete wall. The calculation is given as:

$$VF\left[\frac{mg/m^3-air}{mg/kg-soil}\right]=\frac{H\rho_s}{(\theta_w+k_s\rho_s+H\theta_a)\left(1+\frac{L_s ER.L_B}{D_s}\right)}x10^3\,\frac{g}{kg} \qquad \text{(K1)}$$

where:

VF = Volatilisation Factor for soil to pit air

D_s^{eff} = Effective diffusivity (cm^2/s)

L_S = Contaminant diffusion path length (10 cm)

ER = Air Exchange Rate (s^{-1})

L_B = Ratio of Pit Volume to Infiltration Area (cm)

H = Henry Coefficients (cm/cm)

r_s = Bulk Density (t/m^3)

q_w = Water fraction in soil

q_a = Air fraction in soil

k_s = Soil-water sorption coefficient (foc x Koc)

foc = Fraction of Organic Carbon

Koc = Carbon-water Sorption Coefficient

Diffusion coefficients and other parameters are defined in Appendix 4D.

The estimated acceptance criteria based on protection of excavation workers are presented in Table 4K1b.

To calculate the maximum soil concentration for unprotected excavation workers, the following relationship was used:

$$C_{soil} = \frac{WES}{VF} \tag{K2}$$

where:

C_{soil} = Maximum Soil Concentration (mg/kg)

WES = Workplace Exposure Standard (TWA)

VF = Volatilisation Factor (from eq. K1)

Table 4K1a Workplace exposure standards

Contaminant	Workplace Exposure Standard [1] (mg/m^3)
C_7 - C_9	1640
C_{10} - C_{14}	1050
C_{15} - C_{36}	-
Benzene	16
Toluene	188
Ethylbenzene	434
Xylene	350
Naphthalene	52
Pyrene	-
Benzo(a)pyrene	-

Source: Workplace Exposure Standards 1994. OSH, Department of Labour, Wellington, NZ

Table 4K1b Soil Acceptance Criteria for the Protection of Excavation Workers

Contaminant	Soil Acceptance Criteria (mg/kg)					
	Sand	Silt	Silty Clay	Clay	Pumice	Peats
C_7 - C_9	120	500	20,000	-	810	6,700
C_{10} - C_{14}	6,500	31,000	-	-	-	-
C_{15} - C_{36}	-	-	-	-	-	-
Benzene	3.0	17	700	1,800	28	190
Toluene	94	480	-	-	820	7,500
Ethylbenzene	670	3,200	-	-	5,600	-
Xylene	150	780	-	-	1,300	-
Naphthalene	640	3,100	-	-	5,300	-
Pyrene	-	-	-	-	-	-
Benzo(a)pyrene	-	-	-	-	-	-

NOTES:
1. Concentrations based on TWA (Time Weighted Average) for Workers
2. Values not presented
3. " - " Denotes high concentrations not viable.

Table 4K2a Volatilisation from surface soils to excavation pits SAND Soil Type = LH_2O/Lair

Chemical	**Dair** cm^2/s	**Dwat** cm^2/s	**H @ 20°C** L-H_2O/L-air	**Koc**	**Deff** cm^3/s	**ks** $cm^3 H_2O$/g-soil
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	4.7E-03	30
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	3.3E-03	3776.775
C_{15} - C_{36}	0.033	3.80E-06	1.4E+02	501187233	2.6E-03	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	7.3E-03	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	6.6E-03	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	5.9E-03	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	5.6E-03	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	5.6E-03	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	3.9E-03	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	5.6E-03	1167.135

Chemical	**Air Standard** mg/m^3	**VF** $(mg/m^3)/(mg/kg)$	**Soil Criteria** mg/kg
C_7 - C_9	1640	1.41E+01	1.17E+02
C_{10} - C_{14}	1050	1.61E-01	6.53E+03
C_{15} - C_{36}		2.69E-04	
Benzene	16.0	5.41E+00	2.96E+00
Toluene	188	1.99E+00	9.44E+01
Ethylbenzene	434	6.49E-01	6.69E+02
Xylene	350	2.30E+00	1.52E+02
Naphthalene	52	8.13E-02	6.40E+02
Pyrene		8.84E-06	
Benzo(a)pyrene		1.12E-07	

Table 4K2b Volatilisation from surface soils to excavation pits SILT Soil Type

Chemical	**Dair** cm^2/s	**Dwat** cm^2/s	**H @ 20^{o}C** L-H_2O/L-air	**Koc**	**Deff** cm^2/s	**ks** cm^3H_2O/g-soil
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	9.8E-04	30
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	6.9E-04	3776.775
C_{15} - C_{36}	0.033	3.80E-06	1.4E+02	501187233	5.4E-04	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	1.4E-03	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	1.2E-03	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	1.2E-03	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.9E-02	1167.135

Chemical	Air Standard mg/m^3	VF (mg/m^3)/(mg/kg)	Soil Criteria mg/kg
C_7 - C_9	1640	3.31E+00	4.95E+02
C_{10} - C_{14}	1050	3.38E-02	3.10E+04
C_{15} - C_{36}		5.66E-05	
Benzene	16.0	9.50E-01	1.68E+01
Toluene	188	3.94E-01	4.77E+02
Ethylbenzene	434	1.34E-01	3.23E+03
Xylene	350	4.49E-01	7.80E+02
Naphthalene	52	1.70E-02	3.07E+03
Pyrene		6.42E-06	
Benzo(a)pyrene		3.74E-07	

Table 4K2c Volatilisation from surface soils to excavation pits Silty Clay Soil Type

Chemical	**Dair** cm^2/s	**Dwat** cm^2/s	**H @ 20^{o}C** L-H_2O/L-air	**Koc**	**Deff** cm^2/s	**ks** cm^3H_2O/g soil
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	2.1E-05	30
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	1.4E-05	3776.775
C_{15} - C_{36}	0.033	3.80E-06	1.4E+02	501187233	1.1E-05	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	4.5E-05	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	3.8E-05	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	3.3E-05	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	3.2E-05	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	7.4E-05	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	8.6E-03	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	7.5E-02	1167.135

Chemical	Air Standard mg/m³	VF (mg/m^3)/(mg/kg)	Soil Criteria mg/kg
C_7 - C_9	1640	8.40E-02	1.95E+04
C_{10} - C_{14}	1050	7.09E-04	1.48E+06
C_{15} - C_{36}		1.18E-06	
Benzene	16.0	2.30E-02	6.96E+02
Toluene	188	1.01E-02	1.87E+04
Ethylbenzene	434	3.47E-03	1.25E+05
Xylene	350	1.12E-02	3.12E+04
Naphthalene	52	1.04E-03	5.01E+04
Pyrene		1.91E-05	
Benzo(a)pyrene		1.39E-06	

Table 4K2d Volatilisation from surface soils to excavation pits Clay Soil Type

Chemical	**Dair** cm^2/s	**Dwat** cm^2/s	**H @ 20^{o}C** L-H_2O/L-air	**Koc**	**Deff** cm^2/s	**ks** cm^3H_2O/g soil
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	5.5E-07	30
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	3.8E-07	3776.775
C_{15} - C_{36}	0.033	3.80E-06	1.4E+02	501187233	3.0E-07	1503561.699
Benzene	0.093	1.1E-05	2.2E-01	83	1.8E-05	0.249
Toluene	0.085	9.40E-06	2.6E-01	302	1.3E-05	0.906
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	9.9E-06	3.288
Xylene	0.072	8.50E-06	2.9E-01	240	1.1E-05	0.72
Naphthalene	0.072	9.40E-06	4.9E-02	1288	6.7E-05	3.864
Pyrene	0.048	7.24E-06	2.2E-04	38019	1.1E-02	114.057
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.0E-01	1167.135

Chemical	**Air Standard** mg/m³	**VF** (mg/m^3)/(mg/kg)	**Soil Criteria** mg/kg
C_7 - C_9	1640	2.43E-03	6.74E+05
C_{10} - C_{14}	1050	1.88E-05	5.58E+07
C_{15} - C_{36}		3.16E-08	
Benzene	16.0	9.02E-03	1.77E+03
Toluene	188	3.44E-03	5.47E+04
Ethylbenzene	434	1.04E-03	4.17E+05
Xylene	350	3.70E-03	9.46E+04
Naphthalene	52	9.32E-04	5.58E+04
Pyrene		2.54E-05	
Benzo(a)pyrene		1.80E-06	

Table 4K2e Volatilisation from surface soils to excavation pits Pumice Soil Type

Chemical	**Dair** cm^2/s	**Dwat** cm^2/s	**H @ 20°C** L-H_2O/L-air	**Koc**	**Deff** cm^2/s	**ks** cm^3H_2O/g-soil
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	9.3E-04	50
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	6.5E-04	6294.625
C_{15} - C_{36}	0.033	3.80E-06	1.4E+02	501187233	5.1E-04	2505936.165
Benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.415
Toluene	0.085	9.40E-06	2.6E-01	302	1.3E-03	1.51
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	5.48
Xylene	0.072	8.50E-06	2.9E-01	240	1.1E-03	1.2
Naphthalene	0.072	9.40E-06	4.9E-02	1288	1.1E-03	6.44
Pyrene	0.048	7.24E-06	2.2E-04	38019	4.0E-03	190.095
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	3.0E-02	1945.225

Chemical	**Air Standard** mg/m^3	**VF** $(mg/m^3)/(mg/kg)$	**Soil Criteria** mg/kg
C_7 - C_9	1640	2.03E+00	8.07E+02
C_{10} - C_{14}	1050	1.93E-02	5.43E+04
C_{15} - C_{36}		3.23E-05	
Benzene	16.0	5.76E-01	2.78E+01
Toluene	188	2.30E-01	8.16E+02
Ethylbenzene	434	7.73E-02	5.62E+03
Xylene	350	2.64E-01	1.33E+03
Naphthalene	52	9.79E-03	5.31E+03
Pyrene		5.44E-06	
Benzo(a)pyrene		3.47E-07	

Table 4K2f Volatilisation from surface soils to excavation pits PEATS AND HIGH ORGANIC Soil Type

Chemical	**Dair** cm^2/s	**Dwat** cm^2/s	**H @ 20°C** L-H_2O/L-air	**Koc**	**Deff** cm^2/s	**ks** cm^3H_2O/g-soil
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	2.1E-03	1200
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	1.5E-03	151071
C_{15} - C_{36}	0.033	3.80E-06	1.4E+02	501187233	1.2E-03	60142467.96
Benzene	0.093	1.1E-05	2.2E-01	83	3.3E-03	9.96
Toluene	0.085	9.40E-06	2.6E-01	302	3.0E-03	36.24
Ethylbenzene	0.076	8.50E-06	3.2E-01	1096	2.7E-03	131.52
Xylene	0.072	8.50E-06	2.9E-01	240	2.6E-03	28.8
Naphthalene	0.072	9.40E-06	4.9E-02	1288	2.6E-03	154.56
Pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	4562.28
Benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.2E-02	46685.4

Chemical	**Air Standard** mg/m^3	**VF** $(mg/m^3)/(mg/kg)$	**Soil Criteria** mg/kg
C_7 - C_9	1640	2.44E-01	6.72E+03
C_{10} - C_{14}	1050	1.84E-03	5.72E+05
C_{15} - C_{36}		3.06E-06	
Benzene	16.0	8.33E-02	1.92E+02
Toluene	188	2.50E-02	7.51E+03
Ethylbenzene	434	7.62E-03	5.70E+04
Xylene	350	2.97E-02	1.18E+04
Naphthalene	52	9.43E-04	5.51E+04
Pyrene		1.61E-07	
Benzo(a)pyrene		5.94E-09	

Appendix 4L
Toxicity assessment

1.1 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 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. An overview of the approach to toxicity and dose response assessment is presented in Section 4.4 of Module 4. Details of the effects associated with particular chemicals and the justification for the dose response factors selected is presented in this appendix, together with some background information on the classification of carcinogens.

1.2 Classification of carcinogens

The International Agency for Research on Cancer (IARC) first developed (in 1977) a system for qualitatively categorising carcinogens. This system was based on weight-of-evidence data which involves assessment of all toxicity data originating from human, animal and in-vitro studies to ascertain if the chemical is carcinogenic or not. A similar classification system was also produced by the USEPA in the late 70s and was modelled on the IARC system[1] . Table 4L3 shows the carcinogenic classifications developed by the two agencies.

1.3 Toxicity and dose response assessment

1.3.1 General

While a range of terms have been used to describe dose response factors (e.g. tolerable daily intake, acceptable daily intake, unit risk), 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 WHO use the term tolerable daily intake (TDI) which is analogous to the RfD. The TDI is an estimate of the amount of a substance in food or drinking-water, expressed on a body weight basis (mg/kg or µg/kg of body weight) that can be ingested daily over a lifetime without appreciable health risk.

The dose response factors adopted for each chemical of concern are summarised in Tables 4L2 and 4L3. The dose response factors presented in Tables 4L2 and 4L3 are derived from published sources;

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[1] The USEPA have recently released proposed guidelines which revise the carcinogen classifications presented in Table 4L3. The proposed guidelines do not induce the letter descriptions. The guidelines are not be to released as final (USEPA, 1996).

no effort has been made to confirm the appropriateness of individual factors or assumptions or to derive dose response factors specifically for this work.

Table 4L1 IARC and EPA Classification of Carcinogenic Risk to Humans(1)

IARC				**Evaluation of Agent Mixture or Occupation**	**EPA**		
Classification grouping	**Evidence from(2)**				**Classification grouping**	**Evidence from(2)**	
	Humans	Animals	Other Relevant Data(3)			Humans	Animals
1	S			**IS** carcinogenic	A	S	
2A	L	S		is **PROBABLY** carcinogenic	B1	L	
or	L		Supp		B2	I	S
or	I/ND	S	Supp		or	ND	S
2B	L			is **POSSIBLY** carcinogenic	C	ND	L
or	I/ND	S					
or	I	L	Supp				
3	I/ND	L		is **NOT CLASSIFIABLE** as to its carcinogenicity	D	Inadequate evidence or no data available	
4	No evidence for carcinogenicity			is **PROBABLY NOT** carcinogenic	E	No evidence for carcinogenicity	

Notes
1. Based on table from Fitzgerald 1 993
2. S - sufficient Supp - supportive L - limited ND - no data I - inadequate
3. Other relevant data include structure - activity considerations, pharmacokinetics and metabolism, toxicity, genetic nd related effects.

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 Acceptance Criteria. The USEPA dose response factors were reviewed for consistency with the dose response factors implied in the NZDWS, and where the NZDWS suggest a significantly more stringent value this value was adopted.

Table 4L2 Comparison of dose response factors for carcinogens

Contaminant	Source	Slope Factor $(mg/kg/d)^{-1}$ Ingestion	Slope Factor $(mg/kg/d)^{-1}$ Inhalation
Benzene	USEPA[5]	0.029	0.029
	RIVM (Dutch)[3, 4]	0.016	0.016
	NZDWS[7]	0.035	
	WHO (Air Guidelines)[3, 6]		0.014
	Adopted	0.029	0.029
Benzo(a)pyrene	USEPA[5]	7.3	7.3
	NZDWS/WHO[1, 7](drinking water)	0.5	
	RIVM[2, 4]	0.05	
	Adopted	7.3	7.3

1. Inferred from supporting documentation
2. Inferred from unit risk.
3. Inferred from Tolerable Daily Intake
4. Swartjes & van der Berg, 1993
5. USEPA (1995)
6. WHO, 1987
7. MOH, 1995

The problems associated with chemical constituent ingested (i.e. via drinking-water or similar) arise primarily from their ability to cause adverse health effects after prolonged exposure. Of particular concern are the contaminants that have cumulative toxic effects (i.e. heavy metals) or carcinogenic effects.

The World Health Organization states that Tolerable Daily Intakes (TDI) should be regarded as representing intake for a lifetime. They are not so precise that they cannot be exceeded for short periods of time. Short term exposure exceeding the TDI is not a cause of concern provided the individuals intake over time does not appreciably exceed the level set. The large uncertainty factors generally involved in establishing TDI serve to provide assurance that exposures for short periods are unlikely to have any deleterious effects on human health.

Information from the TPHCWG has been used for the assessment of health effects associated with TPH.

Table 4L3 Comparison of dose response factors for non-carcinogens

Contaminant	Source	Oral Reference Dose (mg/kg/d)	Inhalation Reference Dose (mg/kg/d)
Toluene	USEPA[8]	0.2	0.11[1]
	RIVM (Dutch)[3]	0.43	
	NZDWS[7]	0.22	
	Adopted	0.2	0.11
Ethylbenzene	USEPA[8]	0.1	
	NZDWS (drinking water)[7]	0.1	
	RIVM[10]	0.14	
	Adopted	0.1	0.029[2]
Xylene	USEPA[8]	2	0.09
	NZDWS[4, 7]	0.18	
	RIVM	0.01	
	Adopted	0.18	0.09[3]
C6 to C9 TPH	USEPA (n-hexane)[8]	0.06-0.6	0.06
	MDEP (n-hexane)	0.06	
	TPHCWG (aliphatics)	5	5
	Adopted	5	5
C10 to C14 TPH	MDEP (n-nonane)[6]	0.6	
	TPHCWG (aliphatics)	0.1	0.3
	Adopted	0.1	0.3
C15 to C36 TPH	MDEP (eicosane)	6	
	TPHCWG	1.5[5]	1.5
	Adopted	1.5	1.5
Naphthalene	USEPA[9]	0.04-0.004	0.04 to 0.004
	RBCA[11]	0.004	0.004
	RIVM[10]	0.05	
	Adopted	0.004	0.004
Pyrene	USEPA[8]	0.03	
	RIVM	0.02	
	Adopted	0.03	0.03

1. Equates to reference concentration of 0.4 mg/m^3
2. Equates to a reference concentration of 0.1 mg/m^3
3. Equate to a reference concentration of 0.3 mg/m^3
4. Inferred from supporting information.
5. Based on a weighted mean of the dose response information for the C9 to C16 (oral RfD = 0.1 mg/kg/day) and C17 to C34 fractions (oral RfD = 2 mg/kg/day).
6. MDEP, 1994
7. MoH, 1995
8. USEPA, 1995
9. USEPA, 1991
10. Swartjes & van der Berg, 1993
11. ASTM, 1995

1.3.2 Benzene

This section discusses the health effects and dose response factors for benzene.

1.3.2.1 Health effects

Benzene is readily absorbed via oral and inhalation exposures with small amounts absorbed through the skin. The metabolism of benzene occurs mainly in the liver. The formation of toxic metabolites such as benzoquinone and mucoaldehyde is believed to be responsible for the adverse effects of benzene.

In human and experimental animals, exposure to benzene commonly caused haematological effects such as lymphocytopenia and aplastic anaemia. Epidemiological studies have established a causal relationship between the occupational exposure of benzene and the incidence of leukemia. Based on this information, benzene has been classified as a Class A (confirmed) human carcinogen by the USEPA.

Although not teratogenic, benzene has been found to cause embryotoxicity and geotoxicity at non-maternally toxic doses as low as 47 ppm (150 mg/m^3) in rats. Benzene was found to cross the placenta in human, but no association with fetotoxicity and birth defects has been reported. Benzene has also associated with adverse effects on the immune system in animals. Benzene, as with many other hydrocarbons, has been associated with neurological affects.

1.3.2.2 Dose response factors

Benzene is considered a non-threshold toxicant by the USEPA due to its carcinogenicity. An oral slope factor value of 0.029 (mg/kg/day)$^{-1}$ has been assigned. The oral slope factor has also been applied to the assessment of inhalation exposure.

1.3.3 Xylenes

This section discusses the health effects and dose response factors for xylene.

1.3.3.1 Health effects

Xylene is readily absorbed through inhalation and rapidly metabolised in the liver. Exposure to xylene by oral and inhalation caused mild toxicity in experimental animals without significant adverse effects. Although developmental effects were observed at high doses, in animal studies evidence regarding the teratogenicity of xylene was not conclusive. In humans, exposure to xylene vapour causes irritation of the eyes, nose and throat and some light-headedness at concentration of 200 ppm and above. Neurobehavioural effects were also reported after a 5-6 hour exposure of 100 ppm. According to the USEPA, xylene is a Class D chemical i.e. it is not classifiable with regard to human carcinogenicity due to inadequate human and animal evidence.

1.3.3.2 Dose response factors

In derivation of the NZDWS, the Ministry of Health adopted an acceptable daily intake of 0.18 mg/kg/day, and in accordance with the approach outlined in Section 4.3.3, this value has been adopted for the purposes of deriving Tier 1 Acceptance Criteria[1]. The NZDWS value was based on a NOAEL of 250 mg/kg/day for

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[1] Xylene was the only contaminant for which there was a significant discrepancy between the USEPA and NZDWS dose response factors, with the NZDWS more stringent, and therefore the dose response factor suggested by the NZDWS was adopted for xylene. The NZDWS nominate a less stringent dose response factor for benzo(a)pyrene and therefore the USEPA value was retained. Each of the contaminants assessed using a non-threshold model by the USEPA is regarded as a genotoxic carcinogen and therefore the assumption of a non-threshold model was retained.)

decreased body weight in a 103 week gavage study in rats. An uncertainty factor of 1000 and a correction from 5-7 days per week exposure was applied.

The USEPA has nominated an oral RfD for xylenes of 2.0 mg/kg/day, using a safety factor of 100, based on the NOAEL for hyperactivity, decreased body weight and increased mortality in rats (same study as used in NZDWS).

The USEPA and NZDWS refer to the same original study, however the NZDWS (and the WHO) includes an addition safety factor of 10 to account for limitations associated with the toxicological endpoint.

For comparison, a tolerable daily intake of 0.01 mg/kg/day may be inferred from the derivation of soil acceptance criteria by the Dutch agencies.

1.3.4 Toluene

The health effects and dose response factor for toluene are discussed in this section.

1.3.4.1 Health effects

Toluene is mildly toxic by inhalation and can cause systemic effects in humans. Exposure to toluene causes irritation to the eyes and skin. High doses lead to impairment of co-ordination and reaction time, narcosis and coma. According to the USEPA, toluene is a Class D chemical i.e. not classifiable with regard to human carcinogenicity, due to inadequate human and animal evidence.

1.3.4.2 Dose response factors

The USEPA has set RfD values for toluene of

- mg/kg/day by oral route, with a safety factor of 1000, based on NOAEL for effects on liver and kidneys;
- mg/m^3 by inhalation with a safety factor of 300, based on LOAEL for neurological effects observed in a small population of workers.

1.3.5 Ethylbenzene

The health effects and dose response factor for ethylbenzene are discussed in this section.

1.3.5.1 Health effects

Ethylbenzene is mildly toxic by skin contact and inhalation, and causes systemic effects in humans. It also causes irritation to the eyes, skin, nose and throat and respiratory tract at a concentration of 0.2%. The lowest acutely toxic concentration (TC_{l0}) by inhalation reported in humans is 100 ppm.

According to the USEPA, ethylbenzene is a Class D chemical i.e not classifiable with regard to human carcinogenicity due to inadequate humans and animal evidence.

1.3.5.2 *Dose response factors*

The USEPA has set RfD values for ethylbenzene of:

- mg/kg day with a safety factor of 1000, based on NOAEL by oral route for liver and kidney toxicity observed in animals

- mg/m^3 by inhalation, with a safety factor of 300, based on NOAEL for developmental toxicity in rats and rabbits.

1.3.6 Polycyclic aromatic hydrocarbons

Health effects for non-carcinogenic and carcinogenic PAHs are discussed in this section.

1.3.6.1 *Non-Carcinogenic*

Polycyclic aromatic hydrocarbons (PAHs) occur in the environment as complex mixtures of which only a few components have been adequately characterised. Only limited information is available on the relative toxicity of the “non-carcinogenic” PAHs.

PAH absorption following oral and inhalation exposure is inferred from the demonstrated toxicity of PAHs following these routes of administration. PAHs are also absorbed following dermal exposure. Acute effects from direct contact with PAHs and related materials are limited primarily to phototoxicity; the primary effect being dermatitis. PAHs have also been shown to cause cytotoxicity in rapidly proliferating cells throughout the body; the haematopoietic system, lymphoid systems, and testes are frequent targets. Some of the non-carcinogenic PAHs have been shown to cause systematic toxicity but these effects are generally seen at high doses. Slight morphological changes in the liver and kidney of rats have been reported following oral exposure to acenaphthene for 40 days.

Subchronic oral administration of naphthalene (50 mg/kg/day) to rats has resulted in decreased body weight gain. Mice subchronically exposed to fluoranthene developed adverse kidney, liver and haematological effects. Haematological and kidney effects have also been observed in mice following exposure to fluorene (125-500 mg/kg/day) and pyrene (127-917 mg/kg/day), respectively.

Many of the non-carcinogenic PAHs have been assigned similar Reference Doses (RfDs) by the USEPA and therefore pyrene has been selected as representative of the range of noncarcinogenic PAHs. Some PAHs have been assigned an RfD higher than that assigned to pyrene. However, this is not expected significantly to influence the overall assessment of risk as in most cases health effects associated with the carcinogenic PAHs are limiting. Naphthalene has also been considered given its relatively high volatility compared to other PAHs and the lower RfD (0.004 mg/kg/day) proposed. Refer to Table 4.5 for dose response factors for naphthalene and pyrene.

1.3.6.2 *Carcinogenic*

Of the 16 PAHs identified by the USEPA in their primary pollutants list seven are classified as probable human carcinogens (B2) i.e. benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(ah)anthracene, and indeno(123-cd)pyrene. PAH compounds are extremely lipophilic and are generally rapidly absorbed upon inhalation, ingestion or dermal exposure. The basis for the carcinogenic classification of these compounds is varied.

For example, no human data are available for chrysene, however, it has been found to produce skin carcinomas as well as malignant lymphoma in mice, while benzo(a)pyrene has been shown to be carcinogenic to rodent and non rodent species, following exposure by all three major pathways. Lung cancer in humans has been associated with various mixtures of PAHs known to contain benzo(a) pyrene, although it cannot be determined if one particular PAH is responsible for these effects.

The carcinogenic potency of these compounds is most commonly determined using data from animal studies. The dose associated with a particular increased lifetime cancer risk, or the slope of the dose-risk relationship (slope factor) is estimated using the available human and animal data.

To calculate the slope factors associated with these compounds, toxic equivalence factors (TEFs) are used to normalise the slope factors for each compound with reference to benzo(a) pyrene. The TEFs are shown in Table 4. The TEFs nominated in Table 4 are based on USEPA guidance and have been developed for the individual members of the class based on their relative potency, compared to the most potent member of the class i.e. benzo(a) pyrene. 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.[2]

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

As indicated in Table 2, there is a significant difference between the estimates of cancer potency for benzo(a)pyrene prepared by the USEPA (oral Slope Factor = 7.3 $(mg/kg/day)^{-1}$) and the WHO (inferred oral slope factor = 0.5 $(mg/kg/day)^{-1}$, as presented in the NZDWS). The basis for this difference lies in the low dose extrapolation methods and data sets used. The WHO/NZDWS apply a two-stage birth-death mutation model to the incidence of fore-stomach tumours in mice, given the data available was inadequate for the linearised multistage model normally used. The USEPA Slope Factor is derived from the geometric mean of four low dose extrapolations based on four combinations of base study and extrapolation model, including the combination used by the WHO/NZDWS. The USEPA Slope Factor is most commonly adopted in Australia and New Zealand for the assessment of contaminated land, is used in the derivation of the ANZECC/NHMRC Health Investigation Levels and appears to be more robust in derivation (i.e.. based on more than one approach) and therefore has been adopted for the purposes of these guidelines.

Table 4L4 Toxic equivalence factors (TEF) for carcinogenic PAHs (USEPA, 1993)

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

1.3.7 Petroleum hydrocarbons

A range of adverse health effects have been associated with petroleum products, however, in most cases the majority of the concern is associated with minority constituents such as polycyclic aromatic hydrocarbons and

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[2] 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. The products of the concentration of each carcinogenic PAH and its TEF may be summed to give a benzo(a)pyrene equivalent concentration, which may be compared with the relevant criterion nominated for benzo(a)pyrene. 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 the differences in the fate and transport characteristics of each of the carcinogenic PAHs are of secondary importance and therefore this approach should only be used for a preliminary evaluation.

monocyclic aromatic hydrocarbons. The health effects of such substances are usually addressed separately, refer discussion in Section 3.

For the alkanes, alkenes and similar compounds that make up the majority of products, narcotic and nervous system effects are commonly associated with acute exposure (e.g. headaches). Low level long term dermal exposure has also been associated with adverse skin effects, e.g. dermatitis. There is very little information quantifying the exposure to petroleum hydrocarbons associated with such health effects; however, experience has shown that criteria based on aesthetic effects are also generally protective of human health.

Petroleum hydrocarbons are normally considered in terms of the concentration of various fractions or carbon ranges. For the purposes of deriving Tier 1 Acceptance Criteria three carbon ranges have been considered, as shown in the following discussion. Slight variations in the definition of petroleum hydrocarbon fractions exist in guidance issued by different organisations. Guidance from the TPHCWG has been used as the basis for the following discussion. Information from the Massachusetts Department of Environmental Protection has also been presented in Table 3.

Summary information regarding the range of health effects associated with petroleum hydrocarbons based on information presented by the MDEP (1994) is outlined as follows:

Light Fraction Alkanes (C_7 to C_9)

Central nervous system (CNS) effects are commonly associated with exposure to C_5 to C_9 compounds, which perturb the lipid membrane of the nerve cells. Animal studies indicated that narcotic activity increases as a function of the carbon chain length in the C_5 to C_8 range and decreases beyond C_9.

N-hexane is a representative compound in the C_5 to C_8 range of alkanes and is the most toxic of these alkanes. N-hexane is neurotoxic. It neurotoxicity has been shown to be caused by its metabolite, 2,5-hexanedione.

The health effects associated with other alkanes (i.e. pentane, heptane and octane) are mainly narcosis and irritation to the mucus membrane due to inhalation exposure. C_7 and C_8 alkanes are also found to be immunotoxic.

Mid-range alkanes (C_{10} to C_{15})

As discussed earlier, information on the toxicity of C_{10} to C_{15} hydrocarbons is limited and therefore n-nonane has been used as the basis for deriving criteria in this range[3]. While n-nonane was found to cause neurotoxicity, C_{10} - C_{13} compounds cause no pathological changes in animal by inhalation exposure. Using the mouse ear adena model, dodecane (C_{12}) was found to be non-irritating and tridecane (C_{13}) showed a delay-response. The strongest irritant amongst these alkanes is tetradecane (C_{14}) with hexadecane (C_{16}), octadecane (C_{18}) and eicosane (C_{20}) showing progressively decreased activity.

Heavy Fraction Alkanes (C_{15} to C_{36})

Eicosane, a C_{20} alkane, is a representative compound for the C_{15} to C_{32} range by the MDEP. Eicosane can cause irritation and functional changes at the cellular level. These alkanes cause little neurotoxicity.

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[3] The selection of surrogate compounds at the lower end of the TPH range considered for both the C6 to C9 and C10 to C15 fractions is likely to result in conservative criteria (i.e.. risk will be overestimated).

Alkenes

Alkenes are not considered to be particularly toxicologically active and do not show neurotoxicity. Animal exposure to high levels of the smaller alkenes caused liver damage and hyperplasia of the bone marrow. Similar effects have not been reported in humans.

No RfD is available for alkenes, although the MDEP (1994) have assumed the heavier alkenes exhibit toxicity similar to the non-carcinogenic PAHs, e.g. pyrene.

The TPHCWG has reviewed toxicological information available for whole fuel products and for specific chemicals within each TPH fraction in order to determine representative dose response factors for each fraction. A summary of the reference doses proposed by the TPHCWG is presented in Table 4L5. In determining Reference Doses for TPH fractions for these guidelines, some modification of the TPHCWG information was required to remain consistent with the fractions adopted for these guidelines. The where TPH fractions span more than one fraction nominated by the TPHCWG a weighted mean approach was applied to determine the relevant Reference Dose. The Reference Doses adopted for the purposes of these guidelines are presented in Table 4L3.

Table 5 Fraction Specific Dose Response Factors for Total Petroleum Hydrocarbons

Carbon range	Aromatic RfD (mg/kg/day)	Critical effect	Aliphatic RfD (mg/kg/day)	Critical effect
C_6 - C_8 (Aliphatics) C_7 - C_8 (Aromatics)	0.20 - Oral 0.10 - Inhalation	Hepatoxicity Nephrotoxicity	5.0 - Oral 5.0 - Inhalation	Neurotoxicity
C_9 - C_{10} C_{11} - C_{12} C_{13} - C_{16}	0.04 - Oral 0.05 - Inhalation	Decreased bodyweight	0.1 - Oral 0.3 - Inhalation	Hepatic and haematological changes
C_{17} - C_{21} C_{22} - C_{34}	0.03 - Oral	Nephrotoxicity	2.0 - Oral	Hepatic (foreign) body reaction) granuloma

Appendix 4M
Phase partitioning relationships

Soil consists of matter in several phases, exhibiting complex equilibrium relationships. For simplicity in modelling the distribution of contaminants between the various phases, it has been assumed that soil is in a steady-state equilibrium condition. In practice, phase composition and properties are constantly changing in response to changes in pressure, temperature, water content and other factors. In hydrocarbon impacted soils, depending on the type of soil, the moisture content, and the composition and quantity of the hydrocarbons, hydrocarbons may be present in following phases:

- adsorbed
- dissolved in soil moisture
- vapour
- separate phase hydrocarbon liquids.

The general arrangement of the various phases in which hydrocarbons may be present in the soil environment is presented in Figure 4M1. Where the concentration of hydrocarbons is relatively low, hydrocarbons may be present in the following phases: adsorbed, dissolved and vapour. As the concentration of hydrocarbons increases, a separate phase hydrocarbon liquid may form. Due to the relative surface tensions of the soil moisture and the liquid hydrocarbons, the hydrocarbon layer will tend to form between the water and air layers, as shown in Figure 4M1. As the hydrocarbon concentration increases the hydrocarbon layer will tend to displace the water phase from the matrix, followed by the air phase.

An equilibrium exists between the hydrocarbons in the adsorbed, dissolved, vapour and separate liquid phases in the soil. These equilibrium relationships may be represented, as shown in Figure 4M2, as graphs of the relationships between the hydrocarbon concentrations in each of these phases.

At relatively low hydrocarbon concentrations, the concentration in each phase is linearly related to the concentration in other phases, e.g. as the concentration in the adsorbed phase increases, the dissolved phase concentration increases proportionally. Similarly, as the dissolved phase concentration increases, the soil-air or vapour phase concentration increases linearly (Henry’s Law). This relationship holds until the dissolved phase concentration reaches its solubility limit, at which point separate phase hydrocarbon liquids will begin to occur.

Once the solubility of the hydrocarbons in the soil moisture has been exceeded and separate phase hydrocarbon liquids have begun to form, the vapour phase concentration will remain constant for any increase in bulk concentration i.e. the vapour phase concentration is limited to that in equilibrium with the separate phase hydrocarbon mixture. It should be noted that the solubility of a compound which is part of a hydrocarbon mixture, is in water phase less than that of the pure compound by a ratio equal to the mole fraction of the compound in the mixture.

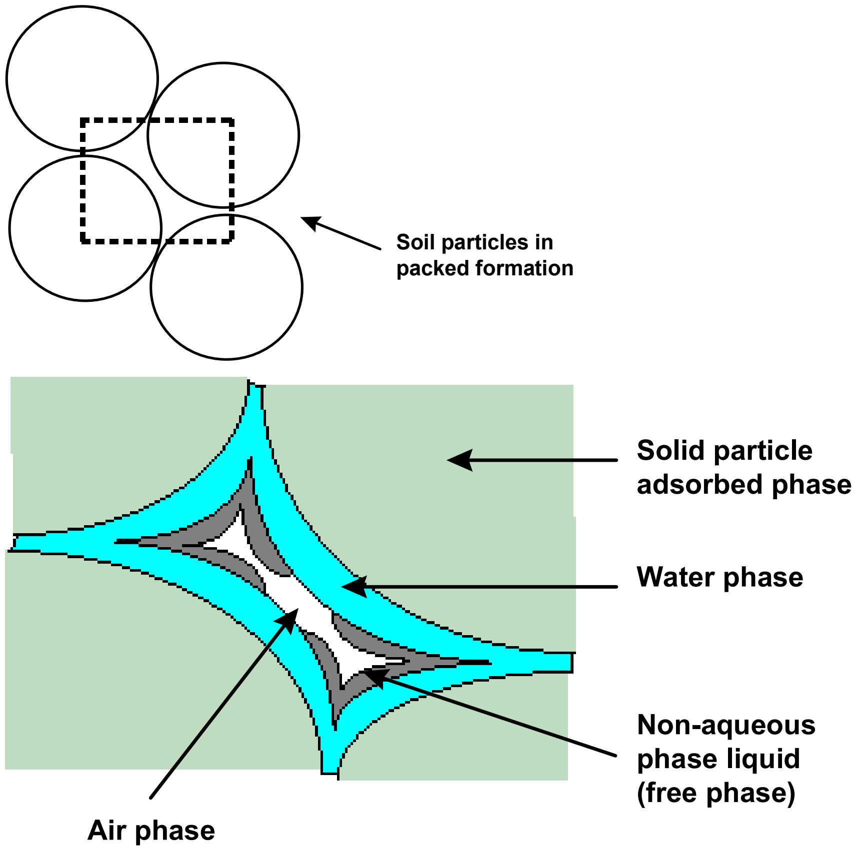


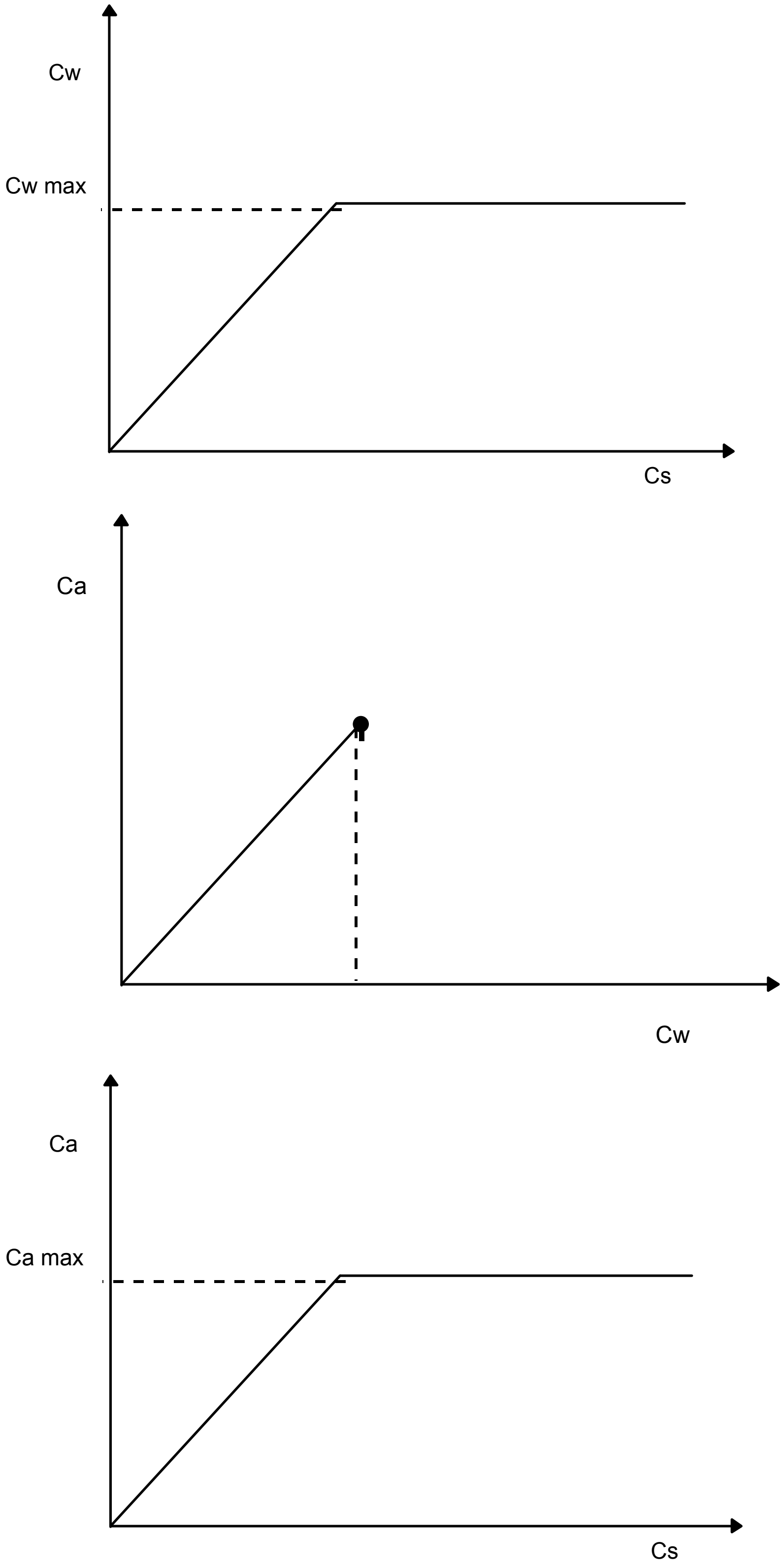
Figure 4M1 Hydrocarbon phase distribution in soils

The volatilisation model used to derive Tier 1 acceptance criteria does not account for the upper limit on the vapour phase concentration in the soil. Most volatilisation models incorporate a linear relationship between the soil, water and air phases, typical of that prior to the occurrence of separate phase hydrocarbon liquids. Hence if the soil concentration exceeds the threshold for the onset of separate phase hydrocarbon liquids, the vapour phase concentration, and hence the risk, will be overestimated.

The Tier 1 acceptance criteria tables (Tables 4.10 - 4.12 of Module 4) include criteria that are presented in brackets. These criteria exceed the threshold at which separate phase hydrocarbons may be expected to occur, and hence, are likely to overestimate the risk to human health. Similarly, for groundwater (Tables 5.9 - 5.10 of Module 5), calculated Tier 1 acceptance criteria which exceed the maximum solubility limit for a pure compound are indicated by an “S”. Tier 1 acceptance criteria which are greater than the solubility of a compound in water when part of a petrol mixture are indicated with brackets. The solubility of individual components in petrol mixtures are variable as the solubility is dependent upon composition of the mixture and may be influenced by fuel type and weathering.

Table 4M1 presents typical contaminant concentrations in soil at which separate phase is likely to begin to form in the soil matrix.

Figure 4M2 Equilibrium phase relationships



Where:

Ca = Soil-air contaminant concentration
Cw = Water phase contaminant concentration
Cs = Adsorbed phase contaminant concentration
Cwmax = Maximum solubility limit for contaminant (part of mixture) in water
Camax = Maximum soil-air concentration corresponding to maximum solubility limit

Table 4M1 Estimates of Total Concentration in Soil Corresponding to the Onset of Separate Phase [1,2,3,4,]

Chemical	**Soil concentration (mg/kg)**					
	Sand	**Silt**	**Silty Clay**	**Clay**	**Pumice**	**Peats**
C_7-C_9	150	140	110	100	210	450
C_{10}-C_{14}	16	16	16	16	27	65
C_{15}-C_{36}	35	35	35	35	58	140
Benzene	9.6	12	14	15	18	33
Toluene	31	33	36	37	54	120
Ethylbenzene	8.2	8.4	8.6	8.6	14	32
Xylenes	8.2	8.9	9.7	9.9	14	31
Naphthalene	120	120	130	130	210	480
Pyrene	15	15	15	15	25	60
Benzo(a)pyrene	1.4	1.4	1.4	1.4	2.3	5.6

Notes:

1. Composition based on API Document - for regular unleaded fuel.
2. Estimates directly proportional to composition mole fraction and hence values may change depending on fuel composition.
3. Refer to Table 4.7 of Module 4 for soil properties.
4. Where soil concentrations exceed values presented above then residual separate phase hydrocarbons may form within the soil matrix

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

August 1999

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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

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[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

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[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

	Guideline values (mg/L)		
Contaminant	**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:

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

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.

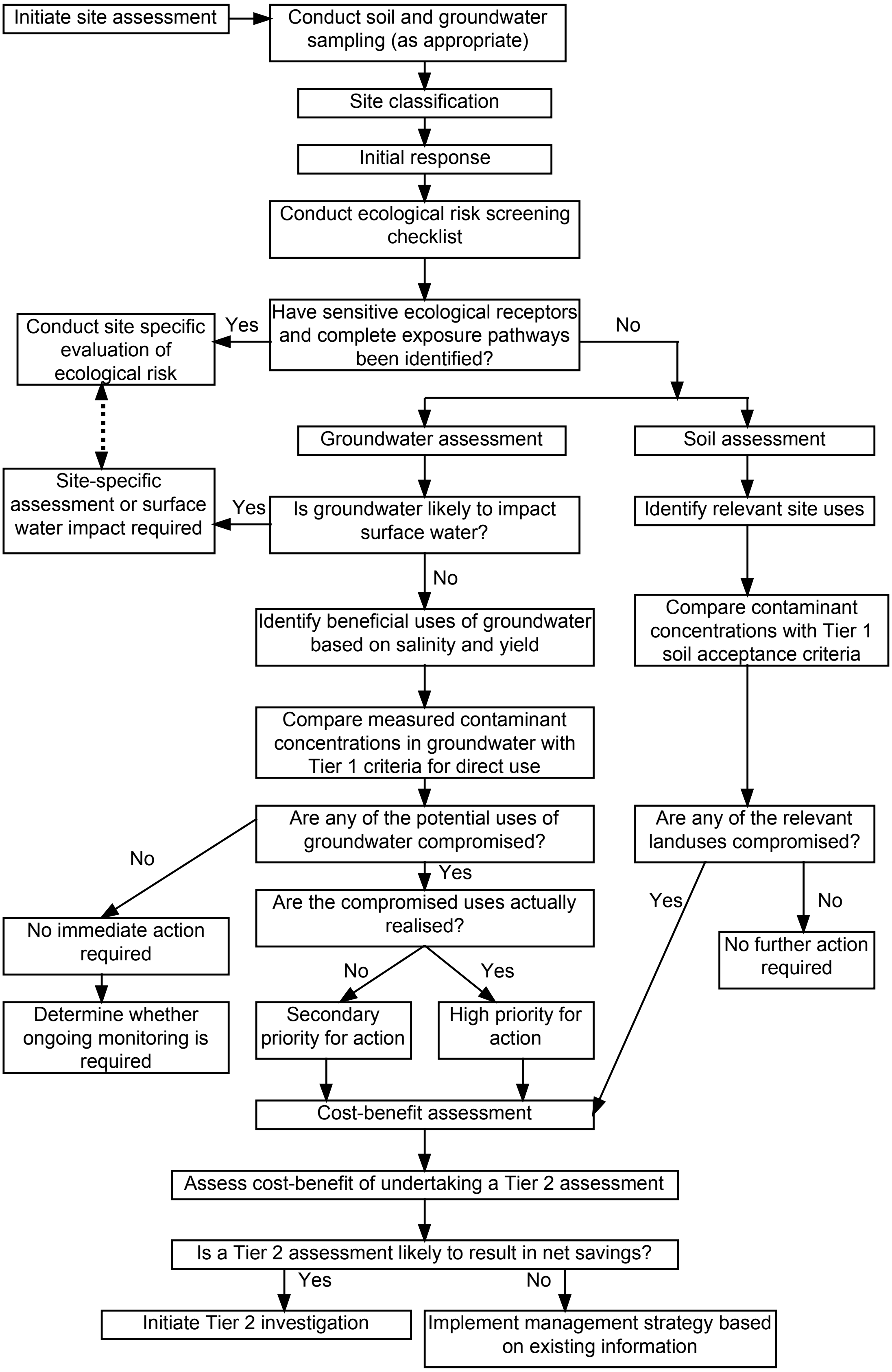

Figure 5.1 **Framework for the assessment of groundwater contamination**

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/	Depth to Contaminated Groundwater					
	2m		4m		8m	
Contaminant	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)**

	Depth to Contaminated Groundwater					
Soil Type/	**2m**		**4m**		**8m**	
Contaminant	**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

American Society for Testing Materials (ASTM). 1995**. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.** E-1739.

Australian and New Zealand Environment and Conservation Council (ANZECC). 1992. **Australian Water Quality Guidelines for Fresh and Marine Waters**.

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van Gemert L.J., and Nettenbriijer A.H. Eds. 1977. **Compilation of Odour Threshold Values in Air and Water**, National Institute for Water Supply, The Netherlands.

Walden T. and Spence L. 1996. **Risk-Based BTEX Clean-up Goals in Groundwater for an Irrigation Scenario**, BP Oil internal report[5].

World Health Organisation (WHO). 1995. **Guidelines for Drinking-water Quality**. World Health Organiztion, Geneva.

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

Appendix 5A
Irrigation water criteria

1.1 Overview

The derivation of Tier 1 groundwater acceptance criteria for the protection irrigation use has been based on consideration of:

- protection of the health of adults and children that may come in contact with contaminated groundwater during use for irrigation
- protection of the health of residents associated with the inhalation of vapours during use of contaminated groundwater
- protection of the health of residents consuming home grown produce that may have been affected by the use of contaminated groundwater for irrigation
- consideration of aesthetic impacts, including odour.

Walden and Spence (1996) developed a protocol for the development of groundwater acceptance criteria for irrigation use, and this has been used as the basis for the derivation of Tier 1 groundwater acceptance criteria for irrigation. Some modifications have been made to the exposure factors assumed by Walden and Spence in order to retain consistency with exposure factors used in other parts of these guidelines.

A general overview of the approach used in derivation of criteria for the protection of irrigation use is presented, however the reader is referred to Walden and Spence (1996) for further details.

The derivation of irrigation water criteria is discussed in terms of the following:

- shower model (used to estimate volatilisation of contaminants from irrigation water) and exposure via the inhalation of volatiles
- plant uptake and exposure via the consumption of home-grown produce
- dermal exposure
- odour impact.

For details of expressions for estimating exposure refer to Section 5.3 of Module 5(potable use) and Appendix 4C.

1.2 Shower model

The shower model is used to estimate the vapour emissions from the sprayed water and the concentration in water hitting the ground. The shower model was originally developed for estimating exposure to volatile contaminants during showering (Foster and Chrostowski, 1986). In this case the shower model is used to simulate a sprinkler system. The shower model has been modified to reflect the volatilisation from spray irrigation. However given the shower model does not account well for atmospheric dispersion (ie. models dilution of vapours in terms of a defined box and an air exchange rate) it is limited to estimating contaminant concentrations in air within and immediately downgradient of the spray. The concentrations in the air are estimated based on the following assumptions:

- the "shower" is fully mixed for the entire duration (ie. air within the spray area of the sprinkler is fully mixed)
- dilution can be estimated using a simple box model
- two film-model of gas-liquid mass transfer.

Volatilisation is limited by mass transfer rates. The overall mass transfer coefficient is calculated as:

$$K_L = \left[\frac{1}{k_l} + \frac{RT}{Hk_g} \right]^{-1} \qquad \text{(A1)}$$

where:

K_L = overall mass transfer coefficient (cm/hr)

H = Henry's Law constant for contaminant (atm.m^3 / mol)

R = gas constant (assumed to be 8.2 x 10^{-5}(atm.m^3 / mol.K)

T = absolute temperature (assumed to be (293°K)

k_g = gas phase mass transfer coefficient (cm/hr)

k_l = liquid phase mass transfer coefficient (cm/hr)

The gas and liquid phase mass transfer coefficients for contaminants may be estimated from measure values for CO_2 and H_2O and the following correlations:

$$k_{g(VOC)} = k_{g(H_20)} \left[\frac{18}{MW_{VOC}} \right]^{0.5} \qquad \text{(A2)}$$

$$k_{l(VOC)} = k_{l(CO_2)} \left[\frac{44}{MW_{VOC}} \right]^{0.5} \qquad \text{(A3)}$$

where:

$k_{g(H20)}$ = gas phase mass transfer coefficient for water (cm/hr)

=3000 cm/hr

$k_{l(CO2)}$ = liquid phase mass transfer coefficient for carbon dioxide

= 20 cm/hr

18 = molecular weight of water

44 = molecular weight of carbon dioxide

MW_{VOC} = molecular weight of contaminant

The overall mass transfer coefficient must be adjusted for shower temperature and the viscosity of water at the slower temperature.

$$K'_{L(Ts)} = K_L \left[\frac{T_l \mu_S}{T_S \mu_l} \right]^{-0.5} \qquad \text{(A4)}$$

where:

$K'_{L(Ts)}$ = adjusted overall mass transfer coefficient (cm/hr)

T_l = calibration water temperature of K_L (°K)

T_S = shower water temperature (°K)

m_l = water viscosity at T_l (g/m.s)

m_S = water viscosity at T_S (g/m.s)

Water viscosity may be estimated from the following relationships (T in ^oC):

If $T \leq 20^oC$: $m = 100 \,.\, 10^y$

where:

$$y = \frac{1301}{998.33 + 8.1855(T-20) + 0.00585(T-20)^2} - 3.30233 \qquad \text{(A5)}$$

If $T > 20^oC$: $m = 1.002 \,.\, 10^y$

where:

$$y = \frac{-1.37272(T-20) - 0.001053(T-20)^2}{T+105} \qquad \text{(A6)}$$

Volatilisation is assumed to be a first-order process:

$$C_{sh} = C_o e^{-K'_L t/600d} \qquad \text{(A7)}$$

where:

C_{sh} = concentration of contaminant in shower droplet after time t (mg/L)

C_o = concentration of contaminant in shower water (mg/L)

d = shower droplet diameter (cm)

= 0.2 cm

t = shower droplet drop time (s)

= 10 s (as estimated by Walder and Spence)

C_{sh} is the concentration of the shower drop which enters the soil.

The total amount of contaminant that volatilises is given by:

$$M_{sh} = f_v \,.\, Q \,.\, time_{sh} \,.\, C_o \qquad \text{(A8)}$$

where:

M_{sh} = mass of contaminant volatilised (mg)

f_v = the fraction of contaminant volatilised $(1 - e^{-K'_L t/600d})$ (mg/mg)

Q = the volumetric flow rate of water (L/min)

$time_{sh}$ = the duration for which the shower water is flowing (min)

C_o = the concentration of contaminant in the shower water (mg/L)

The concentration of the shower air can be estimated from:

$$C_{sh} = \frac{M_{sh}}{V_{sh}} \qquad \text{(A9)}$$

where: C_{sh} = air concentration in the shower (mg/m^3)

V_{sh} = volume of air in the shower (m^3)

In order to modify the shower model to reflect conditions occurring during use of a sprinkler, the volume of air in the shower is set equal to the product of the width of the sprinkler area (4 m), the breathing height of the receptor (1.5 m), the wind speed (2 ms^{-1}) and the duration of exposure (0.5 hr or 1800 s for children, and 2 hr or 7200 s for adults) giving a volume of 21,600 m^3 for children and 86,400 m^3 for adults.

1.3 Plant uptake

The uptake of contaminants by plants is a complex series of reactions. For the purpose of this module the following is assumed:

- plants consist of 80% water by fresh weight
- concentration of water in plant is the same as that calculated by the shower model
- no dilution of contaminants by rainfall
- no bioaccumulation of contaminants in the plants.

The modelling of uptake of contaminants from irrigation water differs from that for uptake from soil as it is assumed that water within the plant is the same as calculated by the shower model. Hence no distinction is made between contaminant concentrations in various plant parts reflecting that contaminants may be absorbed through the roots or leaves. This approach is expected to overestimate the uptake of lipophilic compounds such as benzo(a)pyrene (hence a less stringent criterion is adopted, refer Module 5).

The assumption that garden produce contains 80% moisture is expected to be a typical value although some produce may exhibit higher or lower moisture contents.

1.4 Derivation of water criteria based on ingestion of vegetables

This calculation is the same as the calculation for soil criteria (Appendix 4C). The calculation is performed for adults (30 years old), children (six years old) and for the combination (child for first six years followed by adults for next 24 years).

1.5 Dermal exposure

Children get wet playing under the sprinkler. It is assumed that the child's entire body is exposed to the contaminated water and that the concentration of the water is that of the groundwater Cw. The initial water concentration, Co, is used rather than the concentration following volatilisation, as children may contact water as soon as it leaves the sprinkler (this is a conservative assumption).

The average daily dose, ADD (mg/kg.d) is calculated by the equation:

$$\mathrm{ADD} = \frac{10^{-3}\,C_w \times SA \times AAF_{dermal} \times ET \times PC \times EF \times ED}{365\ AT \times BW} \qquad \text{(A10)}$$

where:

C_w = concentration of contaminant in groundwater (mg/L)

SA = total skin surface area (cm^2)

AAF = chemical specific adsorption adjustment factor

ET = activity duration (hr/day)

PC = chemical specific skin permeability coefficient (cm/hr)

EF = exposure frequency for playing/gardening (d/yr)

ED = exposure duration (yr)

AT = averaging time (yr)

= 70 yr for carcinogenic contaminants

= ED for non-carcinogenic contaminants

BW = body weight (kg)

The USEPA (Dermal Exposure Assessment: Principles and Applications, 1992) have estimates of permeability coefficients. These are estimated by the following equation:

$$\log K_p = -2.72 + 0.71 \log K_{o/w} - 0.0061\ MW \tag{A11}$$

where:

K_p = permeability coefficient (cm/hr)

$K_{o/w}$ = Octanol Water Partition Coefficient

MW = Molecular weight (g/mol)

Table 5A1 shows the permeability coefficients used in the model.

Table 5A1 Permeability coefficients for dermal exposure

Contaminant	Permeability Coefficient Kp (cm/hr)
C_7- C_9	0.205
C_{10}-C_{14}	1.53
C_{15}-C_{38}	2.40
Toluene	0.045
Ethylbenzene	0.074
Xylene	0.080
Naphthalene	0.069
Pyrene	0.32
Benzo(a)pyrene	1.2

Table 5A2 Exposure parameters for irrigation model

Parameter	Child	Adult
Water ingestion rate (L/day)	0.25	-
Vapour inhalation rate (m^3/hr)	0.83	0.83
Dermal AAF - Benzene	2.13	2.13
Dermal AAF - Toluene	2.0	2.0
Dermal AAF - Ethylbenzene	1.0	1.0
Dermal AAF - Xylene	1.1	1.1
Dermal AAF - other	1.0	1.0
Gardening/play activity duration (hr/d)	0.5	2
Gardening/play exposure frequency (d/yr)	54	54
Gardening exposure duration (yr)	6	30
Vegetable ingestion exposure freq (d/y)	350	350
Vegetable ing. exposure duration (yr)	6	30
Vegetable ingestion rate (g/day)	130	450
Fraction of vegetables homegrown	0.10	0.10
Vegetable water retention (%)	80	80
Skin surface area (cm^2)	6800	-
Wind speed (m/s)	2	2
Inhalation “box” volume (m^3)	21,600	86,400
Sprinkler flow rate (L/min)	30	30
Water temperature (^{o}C)	25	25
Lifetime (yr)	70	70
Body weight (kg)	15	70

1.6 Odour-based criteria

Odour-based criteria were determined using threshold values obtained from literature and air concentration values calculated from the shower model. Shower air concentrations were calculated for a water concentration of one milligram per litre. A proportional relationship was used to allow the calculation of the water concentration, which would produce a shower air concentration equal to the odour threshold.

Odour threshold air concentrations were obtained from Walden and Spence, 1996, and AIHA, 1989.

1.7 References

AIHA. 1989. **Odour Thresholds for Chemicals with Established Occupational Health Standard**, American Industrial Hygiene Association.

Foster S.A., and Chrostowski P.C. 1986. **Integrated Household Exposure Model for use of Tap Water Contaminated with Volatile Organic Chemicals,** Proc. 79th Ann. Meeting of Air Pollution Control Association, Minneapolis.

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Table 5A1 Preliminary Health Risk Based Acceptance Criteria *Residential Site Use* Estimation of Target Groundwater Concentrations:- Produce Based

Site Use:	Residential	Expo. Dur. (child):	6	yrs	garden dur.(child)	0.5	hr/d	Prod Ing. (child):	0.13	kg/d
Receptor:	Children residents on site for up to 30 yrs	Expo. Dur. (adult):	30	yrs	(adult)	2	hr/d	Prod Ing. (adult):	0.45	kg/d
		Expo. Dur. (ad,com):	24	yrs	garden exp. freq.	54	d/yr	Prop homegrown	0.1	
		Ave. Time (carc):	70	yrs	Inhale rate (child)	20	m3/d	Prod Expo.Freq.	350	d/yr
Target Risk:	0.00001	(non-carc, child):	6	yrs	Inhale rate (adult)	20	m3/d	Skin area (child)	6800	cm2
Target HI:	1	(non-carc, adult)	30	yrs	Water Ing (child)	0.25	L/d			
		Body Weight (child)	15	kg	Water Ing (adult)	0	L/d			
		(adult)	70	kg						

Contaminant	Skin Absorption cm/hr	SF (1/(mg/kg/d)) Oral	RfD (mg/kg/d) Oral	SF (1/(mg/kg/d)) Inhalation	RfD (mg/kg/d) Inhalation	Acceptable CDI (mg/kg/d)						Risk Based Screening Level (mg/L-H2O)		
						Carcinogenic			Non-carcinogenic			Child	Adult	Child->Adult (carc. only)
						Oral	Dermal	Inhalation	Oral	Dermal	Inhalation			
Alkanes														
C7-C9	2.05E-01		5.00E+00		5.00E+00				5.00E+00	5.00E+00	5.00E+00	5.15E+02	1.78E+04	
C10-C14	1.53E+00		1.00E-01		3.00E-01				1.00E-01	1.00E-01	3.00E-01	1.85E+00	3.90E+02	
C15-C36	2.40E+00		1.50E+00		1.50E+00				1.50E+00	1.50E+00	1.50E+00	1.80E+01	4.60E+03	
MAHs														
benzene	4.47E-02	2.90E-02		2.90E-02		3.45E-04	3.45E-04	3.45E-04				9.36E-01	3.09E+00	7.54E-01
toluene	9.00E-02		2.00E-01		1.10E-01				2.00E-01	2.00E-01	1.10E-01	3.38E+01	5.76E+02	
ethylbenzene	7.40E-02		1.00E-01		2.90E-02				1.00E-01	1.00E-01	2.90E-02	1.80E+01	2.00E+02	
xylene	8.80E-02		1.80E-01		9.00E-02				1.80E-01	1.80E-01	9.00E-02	3.06E+01	4.87E+02	
PAHs														
naphthalene	6.90E-02		4.00E-03		4.00E-03				4.00E-03	4.00E-03	4.00E-03	7.72E-01	1.29E+01	
pyrene	3.20E-01		3.00E-02		3.00E-02				3.00E-02	3.00E-02	3.00E-02	2.17E+00	6.15E+01	
benzo(a)pyrene	1.20E+00	7.30E+00		7.30E+00		1.37E-06	1.37E-06	1.37E-06				3.68E-04	6.49E-03	3.52E-04

Contaminant	Pathway Contribution to Risk											
	Child				Adult				Child->Adult			
	Inhalation	Produce Ingestion	Water Ingestion	Skin Absorption	Inhalation	Produce Ingestion	Water Ingestion	Skin Absorption	Inhalation	Produce Ingestion	Water Ingestion	Skin Absorption
Alkanes												
C7-C9	1.08%	2.67%	25.41%	70.84%	31.82%	68.18%	0.00%	0.00%	-	-	-	-
C10-C14	0.06%	0.58%	4.57%	94.80%	10.14%	89.86%	0.00%	0.00%	-	-	-	-
C15-C36	0.10%	0.41%	2.95%	96.54%	21.77%	78.23%	0.00%	0.00%	-	-	-	-
MAHs												
benzene	2.68%	5.06%	57.37%	34.90%	38.00%	62.00%	0.00%	0.00%	9.56%	16.15%	46.19%	28.10%
toluene	3.39%	3.98%	41.65%	50.98%	49.59%	50.41%	0.00%	0.00%	-	-	-	-
ethylbenzene	6.59%	4.52%	44.30%	44.58%	62.76%	37.24%	0.00%	0.00%	-	-	-	-
xylene	3.61%	4.29%	41.92%	50.17%	49.31%	50.69%	0.00%	0.00%	-	-	-	-
PAHs												
naphthalene	1.75%	6.03%	47.58%	44.64%	25.12%	74.88%	0.00%	0.00%	-	-	-	-
pyrene	0.02%	4.73%	17.80%	77.46%	0.46%	99.54%	0.00%	0.00%	-	-	-	-
benzo(a)pyrene	0.00%	1.53%	5.69%	92.78%	0.04%	99.96%	0.00%	0.00%	0.00%	5.81%	5.44%	88.75%

Table 5A2 A*gricultural Criteria Calculation* Shower Model

water conc:			1 mg/L					
viscosity:	T		25 C	drop diameter:	0.2 cm	gardening exposure time:		
	if T<20			drop time:	10 s		adult:	2 hr
		y	-2.050650852				child:	0.5 hr
		u	0.889916272	wind speed	2 m/s			
	if T>=20			sprinkler dia.	4 m	Box volume	adult:	86400 m3
		y	-0.051248654	receptor height	1.5 m		child:	21600 m3
		u	0.890469539	flowrate	30 L/min	Fraction of water in produce:		0.8
	u=		0.890469539 g/m.s					

Chemical	MW g/mol	H @ 20oC L-H20/L-air	H atm.m3/mol	kg cm/hr	kl cm/hr	Kl cm/hr	Kl' cm/hr	Cirrigation mg/L	Cshower mg/L	Mass vol (mg) adult	Csh (mg/m3) adult	Cplant g/g	Odour threshold mg/m3	Odour based Criteria (mg/L)
C_7-C_9	120	1.2E+02	2.93E+00	1161.895004	12.11060142	12.10956795	11.31957183	0.389341802	0.610658198	2198.369512	0.025444092	3.11473E-07	-	-
C_{10}-C_{14}	185	1.6E+02	3.91E+00	935.7754408	9.753724167	9.753099898	9.116833509	0.467789848	0.532210152	1915.956546	0.022175423	3.74232E-07	-	-
C_{15}-C_{36}	245	1.4E+02	3.30E+00	813.1571126	8.475655414	8.475012496	7.922125141	0.516759811	0.483240189	1739.664681	0.020135008	4.13408E-07	-	-
benzene	78	2.2E-01	5.38E-03	1441.153384	15.02135232	14.35320032	13.41683557	0.326910243	0.673089757	2423.123124	0.028045407	2.61528E-07	4.5	160.5
toluene	92.1	2.6E-01	6.36E-03	1326.257009	13.82377062	13.29989977	12.43224956	0.354863952	0.645136048	2322.489772	0.026880669	2.83891E-07	8	297.6
ethylbenzene	106.2	3.2E-01	7.82E-03	1235.080454	12.87342406	12.47420425	11.66042023	0.378438507	0.621561493	2237.621376	0.025898396	3.02751E-07	8.7	335.9
xylene	106.2	2.9E-01	7.09E-03	1235.080454	12.87342406	12.43431434	11.62313262	0.379616257	0.620383743	2233.381473	0.025849323	3.03693E-07	0.35	13.54
naphthalene	128.2	4.9E-02	1.20E-03	1124.122122	11.71688915	9.691362472	9.059123669	0.47004494	0.52995506	1907.838217	0.022081461	3.76036E-07	0.20	9.06
pyrene	202.3	2.2E-04	5.38E-06	894.8692109	9.327352555	0.196155807	0.183359122	0.984836219	0.015163781	54.58961195	0.000631824	7.87869E-07	-	-
benzo(a)pyrene	252.3	2.0E-05	4.89E-07	801.3068992	8.352138908	0.01627913	0.015217122	0.99873271	0.00126729	4.562243458	5.28037E-05	7.98986E-07	-	-

adult	risk/HI	risk/HI	risk/HI
Chemical	inhalation	produce	total
C_7-C_9	1.79E-05	3.84E-05	5.63E-05
C_{10}-C_{14}	2.60E-04	2.31E-03	2.57E-03
C_{15}-C_{36}	4.73E-05	1.70E-04	2.17E-04
benzene	1.23E-06	2.00E-06	3.23E-06
toluene	8.61E-04	8.75E-04	1.74E-03
ethylbenzene	3.15E-03	1.87E-03	5.01E-03
xylene	1.01E-03	1.04E-03	2.05E-03
naphthalene	1.94E-02	5.80E-02	7.74E-02
pyrene	7.42E-05	1.62E-02	1.63E-02
benzo(a)pyrene	5.82E-07	1.54E-03	1.54E-03

child	risk/HI	risk/HI	risk/HI	risk/HI	risk/HI
Chemical	inhalation	vegetation	water ing.	dermal	total
C_7-C_9	2.09E-05	5.18E-05	4.93E-04	1.37E-03	1.94E-03
C_{10}-C_{14}	3.04E-04	3.11E-03	2.47E-02	5.12E-01	5.40E-01
C_{15}-C_{36}	5.52E-05	2.29E-04	1.64E-03	5.37E-02	5.56E-02
benzene	2.86E-07	5.40E-07	6.13E-06	3.73E-06	1.07E-05
toluene	1.00E-03	1.18E-03	1.23E-02	1.51E-02	2.96E-02
ethylbenzene	3.67E-03	2.52E-03	2.47E-02	2.48E-02	5.57E-02
xylene	1.18E-03	1.40E-03	1.37E-02	1.64E-02	3.27E-02
naphthalene	2.27E-02	7.81E-02	6.16E-01	5.78E-01	1.30E+00
pyrene	8.66E-05	2.18E-02	8.22E-02	3.58E-01	4.62E-01
benzo(a)pyrene	1.36E-07	4.15E-04	1.54E-03	2.52E-02	2.71E-02

adult(com)	risk/HI	risk/HI
Chemical	inhalation	produce
C_7-C_9		
C_{10}-C_{14}		
C_{15}-C_{36}		
benzene	9.82E-07	1.60E-06
toluene		
ethylbenzene		
xylene		
naphthalene		
pyrene		
benzo(a)pyrene	4.66E-07	1.23E-03

child->adult	risk/HI	risk/HI	risk/HI	risk/HI	risk/HI
Chemical	inhalation	vegetation	water ing.	dermal	total
C_7-C_9					
C_{10}-C_{14}					
C_{15}-C_{36}					
benzene	1.27E-06	2.14E-06	6.13E-06	3.73E-06	1.33E-05
toluene					
ethylbenzene					
xylene					
naphthalene					
pyrene					
benzo(a)pyrene	6.01E-07	1.65E-03	1.54E-03	2.52E-02	2.84E-02

Appendix 5B
Volatilisation modelling

Table 5B1a Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces SAND Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20^{o}C L-H_20/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	4.7E-03	30	4.68E-03	7.76E-06	2.92E-04	5.49E-04	9.83E-04
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	3.3E-03	3776.775	3.28E-03	5.43E-06	2.04E-04	3.84E-04	6.88E-04
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	2.6E-03	1503561.699	2.58E-03	4.27E-06	1.60E-04	3.02E-04	5.40E-04
benzene	0.093	1.1E-05	2.2E-01	83	7.3E-03	0.249	7.26E-03	2.17E-05	7.78E-04	1.41E-03	2.36E-03
toluene	0.085	9.40E-06	2.6E-01	302	6.6E-03	0.906	6.63E-03	1.80E-05	6.51E-04	1.19E-03	2.01E-03
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	5.9E-03	3.288	5.93E-03	1.50E-05	5.45E-04	9.99E-04	1.71E-03
xylene	0.072	8.50E-06	2.9E-01	240	5.6E-03	0.72	5.62E-03	1.50E-05	5.43E-04	9.91E-04	1.68E-03
naphthalene	0.072	9.40E-06	4.9E-02	1288	5.6E-03	3.864	5.62E-03	4.66E-05	1.41E-03	2.25E-03	3.22E-03
pyrene	0.048	7.24E-06	2.2E-04	38019	3.9E-03	114.057	3.94E-03	6.40E-03	3.98E-03	3.96E-03	3.95E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	5.6E-03	1167.135	5.63E-03	5.64E-02	5.76E-03	5.69E-03	5.66E-03

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	5.12E-04	7.65E-05	6.04E-04	7.65E-05	5.06E-04	7.65E-05
C_{10} - C_{14}	5.47E-05	7.65E-05	4.02E-05	7.65E-05	1.46E-05	7.65E-05
C_{15} - C_{36}	2.24E-06	7.65E-05	1.03E-07	7.65E-05	2.57E-08	7.65E-05
toluene	1.93E-04	7.65E-05	2.06E-04	7.65E-05	1.33E-04	7.65E-05
ethylbenzene	1.10E-04	7.65E-05	1.05E-04	7.65E-05	5.30E-05	7.65E-05
xylene	2.07E-04	7.65E-05	2.24E-04	7.65E-05	1.48E-04	7.65E-05
naphthalene	3.89E-05	7.65E-05	2.37E-05	7.65E-05	7.59E-06	7.65E-05
pyrene	4.06E-07	7.65E-05	3.38E-09	7.65E-05	8.44E-10	7.65E-05
20 Year Average - Carcinogenic						
benzene	1.88E-04	2.68E-05	2.23E-04	2.68E-05	1.88E-04	2.68E-05
benzo(a)pyrene	2.70E-08	2.68E-05	4.28E-11	2.68E-05	1.07E-11	2.68E-05
30 Year Average - Carcinogenic						
benzene	1.54E-04	1.79E-05	1.84E-04	1.79E-05	1.60E-04	1.79E-05
benzo(a)pyrene	2.21E-08	1.79E-05	4.28E-11	1.79E-05	1.07E-11	1.79E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	4.66E-02	1.54E-02	4.51E-02	1.54E-02	4.05E-02	1.54E-02
C_{10} - C_{14}	6.12E-04	1.54E-02	5.86E-04	1.54E-02	5.13E-04	1.54E-02
C_{15} - C_{36}	1.03E-06	1.54E-02	9.83E-07	1.54E-02	8.60E-07	1.54E-02
toluene	7.45E-03	1.54E-02	7.14E-03	1.54E-02	6.28E-03	1.54E-02
ethylbenzene	2.46E-03	1.54E-02	2.36E-03	1.54E-02	2.07E-03	1.54E-02
xylene	8.56E-03	1.54E-02	8.21E-03	1.54E-02	7.23E-03	1.54E-02
naphthalene	3.11E-04	1.54E-02	2.97E-04	1.54E-02	2.60E-04	1.54E-02
pyrene	3.38E-08	1.54E-02	3.23E-08	1.54E-02	2.83E-08	1.54E-02
20 Year Average - Carcinogenic						
benzene	1.78E-02	5.38E-03	1.72E-02	5.38E-03	1.55E-02	5.38E-03
benzo(a)pyrene	4.28E-10	5.38E-03	4.10E-10	5.38E-03	3.59E-10	5.38E-03
30 Year Average - Carcinogenic						
benzene	1.68E-02	3.59E-03	1.63E-02	3.59E-03	1.48E-02	3.59E-03
benzo(a)pyrene	4.28E-10	3.59E-03	4.10E-10	3.59E-03	3.59E-10	3.59E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-H_20/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	7.78E-03	7.32E-03	6.55E-03
C_{10} - C_{14}	7.25E-03	6.83E-03	6.11E-03
C_{15} - C_{36}	4.81E-03	4.53E-03	4.05E-03
toluene	3.76E-05	3.43E-05	2.91E-05
ethylbenzene	3.88E-05	3.55E-05	3.04E-05
xylene	3.50E-05	3.19E-05	2.71E-05
naphthalene	1.53E-05	1.23E-05	8.75E-06
pyrene	1.95E-07	9.68E-08	4.83E-08
Carcinogenic			
benzene	3.81E-05	3.44E-05	2.88E-05
benzo(a)pyrene	2.56E-08	1.26E-08	6.29E-09

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-H_20/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	9.63E-01	9.27E-01	8.63E-01
C_{10} - C_{14}	8.98E-01	8.65E-01	8.05E-01
C_{15} - C_{36}	5.96E-01	5.74E-01	5.34E-01
toluene	3.81E-03	3.63E-03	3.32E-03
ethylbenzene	4.06E-03	3.87E-03	3.55E-03
xylene	3.58E-03	3.41E-03	3.12E-03
naphthalene	8.79E-04	8.20E-04	7.24E-04
pyrene	3.52E-06	3.23E-06	2.77E-06
Carcinogenic			
benzene	3.69E-03	3.51E-03	3.19E-03
benzo(a)pyrene	4.58E-07	4.19E-07	3.59E-07

Table 5B2a Preliminary Health Risk Based Acceptance Criteria - Groundwater - *Residential and Agricultural Site Use* SAND Soil Type

Site Use: Residential
Receptor: Adults

Target Risk: 0.00001
Target HI: 1

Exposure Frequency: 350 d/yr
Averaging Time (carc): 70 yr
(non carc): 30 yr
Exposure Dur: 30 yr
Body Weight: 70 kg

Inhalation rate indoor: 15 m^3/d
Inhalation rate outdoor: 20 m^3/d

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI		Volatilisation factor ($mg/m^3/mg/L-H_2O$)					
			Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	9.63E-01	9.27E-01	8.63E-01	7.78E-03	7.32E-03	6.55E-03
C_{10} - C_{14}		0.3		0.3	8.98E-01	8.65E-01	8.05E-01	7.25E-03	6.83E-03	6.11E-03
C_{15} - C_{36}		1.5		1.5	5.96E-01	5.74E-01	5.34E-01	4.81E-03	4.53E-03	4.05E-03
MAHs										
benzene	0.029		3.45E-04		3.69E-03	3.51E-03	3.19E-03	3.81E-05	3.44E-05	2.88E-05
toluene		0.11		0.11	3.81E-03	3.63E-03	3.32E-03	3.76E-05	3.43E-05	2.91E-05
ethylbenzene		0.029		0.029	4.06E-03	3.87E-03	3.55E-03	3.88E-05	3.55E-05	3.04E-05
xylene		0.09		0.09	3.58E-03	3.41E-03	3.12E-03	3.50E-05	3.19E-05	2.71E-05
Aromatics										
naphthalene		0.004		0.004	8.79E-04	8.20E-04	7.24E-04	1.53E-05	1.23E-05	8.75E-06
pyrene		0.03		0.03	3.52E-06	3.23E-06	2.77E-06	1.95E-07	9.68E-08	4.83E-08
benzo (a) pyrene	7.3		1.37E-06		4.58E-07	4.19E-07	3.59E-07	2.56E-08	1.26E-08	6.29E-09

Contaminant	Risk Based Screening Level ($mg/L-H_2O$)											
	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							2.35E+03	2.49E+03	2.79E+03	2.53E+01	2.62E+01	2.82E+01
C_{10} - C_{14}							1.51E+02	1.60E+02	1.79E+02	1.63E+00	1.69E+00	1.81E+00
C_{15} - C_{36}							1.14E+03	1.21E+03	1.35E+03	1.23E+01	1.27E+01	1.37E+01
MAHs												
benzene	7.72E+01	8.54E+01	1.02E+02	1.06E+00	1.12E+00	1.23E+00						
toluene							1.07E+04	1.17E+04	1.38E+04	1.40E+02	1.47E+02	1.61E+02
ethylbenzene							2.73E+03	2.98E+03	3.48E+03	3.48E+01	3.64E+01	3.98E+01
xylene							9.38E+03	1.03E+04	1.21E+04	1.22E+02	1.29E+02	1.41E+02
PAHs												
naphthalene							9.52E+02	1.19E+03	1.67E+03	2.22E+01	2.37E+01	2.69E+01
pyrene							5.63E+05	1.13E+06	2.27E+06	4.15E+04	4.52E+04	5.28E+04
benzo (a) pyrene	4.56E+02	9.23E+02	1.86E+03	3.40E+01	3.71E+01	4.33E+01						

Table 5B3a Preliminary Health Risk Based Acceptance Criteria - Groundwater - *Commercial/Industrial Site use* SAND Soil Type

Site Use:	Commercial	Exposure Frequency:	240 d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Workers	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20 yr		
Target Risk:	0.00001	Exposure Dur:	20 yr		
Target HI:	1	Body Weight:	70 kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI		Volatilisation factor (mg/m^3/mg/L-H_2O)					
			Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	6.42E-01	6.18E-01	5.75E-01	7.78E-03	7.32E-03	6.55E-03
C_{10} - C_{14}		0.3		0.3	5.99E-01	5.77E-01	5.37E-01	7.25E-03	6.83E-03	6.11E-03
C_{15} - C_{36}		1.5		1.5	3.97E-01	3.82E-01	3.56E-01	4.81E-03	4.53E-03	4.05E-03
MAHs										
benzene	0.029		3.45E-04		2.46E-03	2.34E-03	2.13E-03	3.81E-05	3.44E-05	2.88E-05
toluene		0.11		0.11	2.54E-03	2.42E-03	2.21E-03	3.76E-05	3.43E-05	2.91E-05
ethylbenzene		0.029		0.029	2.71E-03	2.58E-03	2.37E-03	3.88E-05	3.55E-05	3.04E-05
xylene		0.09		0.09	2.38E-03	2.27E-03	2.08E-03	3.50E-05	3.19E-05	2.71E-05
Aromatics										
naphthalene		0.004		0.004	5.86E-04	5.47E-04	4.82E-04	1.53E-05	1.23E-05	8.75E-06
pyrene		0.03		0.03	2.35E-06	2.15E-06	1.84E-06	1.95E-07	9.68E-08	4.83E-08
benzo (a) pyrene	7.3		1.37E-06		3.05E-07	2.80E-07	2.40E-07	2.56E-08	1.26E-08	6.29E-09

Contaminant	Risk Based Screening Level (mg/L-H_2O)											
	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							6.85E+03	7.27E+03	8.12E+03	8.29E+01	8.61E+01	9.25E+01
C_{10} - C_{14}							4.40E+02	4.68E+02	5.22E+02	5.33E+00	5.54E+00	5.95E+00
C_{15} - C_{36}							3.32E+03	3.53E+03	3.94E+03	4.02E+01	4.18E+01	4.49E+01
MAHs												
benzene	3.38E+02	3.74E+02	4.46E+02	5.22E+00	5.50E+00	6.04E+00						
toluene							3.11E+04	3.42E+04	4.03E+04	4.60E+02	4.83E+02	5.29E+02
ethylbenzene							7.96E+03	8.69E+03	1.02E+04	1.14E+02	1.20E+02	1.30E+02
xylene							2.74E+04	3.00E+04	3.53E+04	4.02E+02	4.22E+02	4.61E+02
PAHs												
naphthalene							2.78E+03	3.47E+03	4.86E+03	7.27E+01	7.79E+01	8.83E+01
pyrene							1.64E+06	3.30E+06	6.61E+06	1.36E+05	1.48E+05	1.73E+05
benzo (a) pyrene	2.00E+03	4.04E+03	8.12E+03	1.67E+02	1.83E+02	2.13E+02						

Table 5B1b Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces SILT Soil Type

Chemical	Dair cm²/s	Dwat cm²/s	H @ 20°C L-$H_2$0/L-air	Koc	Deff cm²/s	ks cm³H_2O/g-soil	Defcrack cm²/s	Defcap cm²/s	Deffws (2m) cm²/s	Deffws (4m) cm²/s	Deffws (8m) cm²/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	9.8E-04	30	4.68E-03	5.54E-06	3.58E-05	6.91E-05	1.29E-04
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	6.9E-04	3776.775	3.28E-03	3.88E-06	2.50E-05	4.83E-05	9.03E-05
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	5.4E-04	1503561.699	2.58E-03	3.05E-06	1.97E-05	3.80E-05	7.10E-05
benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.249	7.26E-03	2.15E-05	1.32E-04	2.44E-04	4.20E-04
toluene	0.085	9.40E-06	2.6E-01	302	1.4E-03	0.906	6.63E-03	1.71E-05	1.07E-04	1.98E-04	3.47E-04
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	3.288	5.93E-03	1.38E-05	8.68E-05	1.62E-04	2.87E-04
xylene	0.072	8.50E-06	2.9E-01	240	1.2E-03	0.72	5.62E-03	1.42E-05	8.85E-05	1.65E-04	2.89E-04
naphthalene	0.072	9.40E-06	4.9E-02	1288	1.2E-03	3.864	5.62E-03	5.61E-05	2.95E-04	4.73E-04	6.77E-04
pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	114.057	3.94E-03	8.49E-03	3.18E-03	3.01E-03	2.93E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.9E-02	1167.135	5.63E-03	7.47E-02	2.15E-02	2.02E-02	1.97E-02

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m³-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	2.48E-04	7.65E-05	2.75E-04	7.65E-05	1.93E-04	7.65E-05
C_{10} - C_{14}	2.51E-05	7.65E-05	1.12E-05	7.65E-05	3.19E-06	7.65E-05
C_{15} - C_{36}	1.02E-06	7.65E-05	2.15E-08	7.65E-05	5.38E-09	7.65E-05
toluene	8.55E-05	7.65E-05	7.55E-05	7.65E-05	3.38E-05	7.65E-05
ethylbenzene	4.99E-05	7.65E-05	3.51E-05	7.65E-05	1.23E-05	7.65E-05
xylene	9.13E-05	7.65E-05	8.23E-05	7.65E-05	3.80E-05	7.65E-05
naphthalene	1.77E-05	7.65E-05	5.99E-06	7.65E-05	1.61E-06	7.65E-05
pyrene	3.46E-07	7.65E-05	2.45E-09	7.65E-05	6.13E-10	7.65E-05
20 Year Average - Carcinogenic						
benzene	7.85E-05	2.68E-05	8.59E-05	2.68E-05	5.85E-05	2.68E-05
benzo(a)pyrene	4.98E-08	2.68E-05	1.46E-10	2.68E-05	3.64E-11	2.68E-05
30 Year Average - Carcinogenic						
benzene	6.41E-05	1.79E-05	7.19E-05	1.79E-05	5.22E-05	1.79E-05
benzo(a)pyrene	4.07E-08	1.79E-05	1.46E-10	1.79E-05	3.64E-11	1.79E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m³-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	3.76E-02	1.54E-02	3.42E-02	1.54E-02	2.57E-02	1.54E-02
C_{10} - C_{14}	5.98E-04	1.54E-02	4.95E-04	1.54E-02	3.15E-04	1.54E-02
C_{15} - C_{36}	1.01E-06	1.54E-02	8.33E-07	1.54E-02	5.28E-07	1.54E-02
toluene	6.39E-03	1.54E-02	5.43E-03	1.54E-02	3.57E-03	1.54E-02
ethylbenzene	2.31E-03	1.54E-02	1.93E-03	1.54E-02	1.24E-03	1.54E-02
xylene	7.20E-03	1.54E-02	6.13E-03	1.54E-02	4.06E-03	1.54E-02
naphthalene	2.98E-04	1.54E-02	2.47E-04	1.54E-02	1.57E-04	1.54E-02
pyrene	3.37E-08	1.54E-02	3.17E-08	1.54E-02	2.66E-08	1.54E-02
20 Year Average - Carcinogenic						
benzene	1.13E-02	5.38E-03	1.02E-02	5.38E-03	7.57E-03	5.38E-03
benzo(a)pyrene	4.30E-10	5.38E-03	4.24E-10	5.38E-03	4.06E-10	5.38E-03
30 Year Average - Carcinogenic						
benzene	1.02E-02	3.59E-03	9.32E-03	3.59E-03	7.13E-03	3.59E-03
benzo(a)pyrene	4.30E-10	3.59E-03	4.24E-10	3.59E-03	4.06E-10	3.59E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m³-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	9.55E-04	9.21E-04	8.60E-04
C_{10} - C_{14}	8.90E-04	8.59E-04	8.03E-04
C_{15} - C_{36}	5.90E-04	5.70E-04	5.32E-04
toluene	6.17E-06	5.73E-06	5.02E-06
ethylbenzene	6.17E-06	5.77E-06	5.11E-06
xylene	5.71E-06	5.31E-06	4.66E-06
naphthalene	3.21E-06	2.57E-06	1.84E-06
pyrene	1.55E-07	7.36E-08	3.59E-08
Carcinogenic			
benzene	6.48E-06	5.96E-06	5.14E-06
benzo(a)pyrene	9.56E-08	4.50E-08	2.18E-08

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m³-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	1.78E-01	1.72E-01	1.62E-01
C_{10} - C_{14}	1.66E-01	1.61E-01	1.51E-01
C_{15} - C_{36}	1.10E-01	1.07E-01	1.00E-01
toluene	1.07E-03	1.00E-03	8.91E-04
ethylbenzene	1.08E-03	1.02E-03	9.15E-04
xylene	9.90E-04	9.30E-04	8.29E-04
naphthalene	4.23E-04	3.64E-04	2.84E-04
pyrene	3.44E-06	3.07E-06	2.52E-06
Carcinogenic			
benzene	1.10E-03	1.02E-03	9.01E-04
benzo(a)pyrene	4.89E-07	4.76E-07	4.51E-07

Table 5B2b Preliminary Health Risk Based Acceptance Criteria - Groundwater
Residential and Agricultural Site Use SILT Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30 yr			
Target Risk:	0.00001	Exposure Dur:	30 yr			
Target HI:	1	Body Weight:	70 kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Volatilisation factor ($mg/m^3/mg/L-H_2O$) Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
$C_7 - C_9$		5		5	1.78E-01	1.72E-01	1.62E-01	9.55E-04	9.21E-04	8.60E-04
$C_{10} - C_{14}$		0.3		0.3	1.66E-01	1.61E-01	1.51E-01	8.90E-04	8.59E-04	8.03E-04
$C_{15} - C_{36}$		1.5		1.5	1.10E-01	1.07E-01	1.00E-01	5.90E-04	5.70E-04	5.32E-04
MAHs										
benzene	0.029		3.45E-04		1.10E-03	1.02E-03	9.01E-04	6.48E-06	5.96E-06	5.14E-06
toluene		0.11		0.11	1.07E-03	1.00E-03	8.91E-04	6.17E-06	5.73E-06	5.02E-06
ethylbenzene		0.029		0.029	1.08E-03	1.02E-03	9.15E-04	6.17E-06	5.77E-06	5.11E-06
xylene		0.09		0.09	9.90E-04	9.30E-04	8.29E-04	5.71E-06	5.31E-06	4.66E-06
PAHs										
naphthalene		0.004		0.004	4.23E-04	3.64E-04	2.84E-04	3.21E-06	2.57E-06	1.84E-06
pyrene		0.03		0.03	3.44E-06	3.07E-06	2.52E-06	1.55E-07	7.36E-08	3.59E-08
benzo (a) pyrene	7.3		1.37E-06		4.89E-07	4.76E-07	4.51E-07	9.56E-08	4.50E-08	2.18E-08

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Carcinogenic Indoors			Non-carcinogenic Outdoors			Non-carcinogenic Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
$C_7 - C_9$							1.91E+04	1.98E+04	2.12E+04	1.37E+02	1.41E+02	1.50E+02
$C_{10} - C_{14}$							1.23E+03	1.27E+03	1.36E+03	8.79E+00	9.08E+00	9.68E+00
$C_{15} - C_{36}$							9.27E+03	9.61E+03	1.03E+04	6.62E+01	6.85E+01	7.30E+01
MAHs												
benzene	4.54E+02	4.93E+02	5.72E+02	3.56E+00	3.82E+00	4.34E+00						
toluene							6.50E+04	7.00E+04	8.00E+04	5.01E+02	5.34E+02	6.01E+02
ethylbenzene							1.71E+04	1.83E+04	2.07E+04	1.30E+02	1.38E+02	1.54E+02
xylene							5.76E+04	6.19E+04	7.05E+04	4.42E+02	4.71E+02	5.28E+02
PAHs												
naphthalene							4.54E+03	5.67E+03	7.93E+03	4.60E+01	5.35E+01	6.84E+01
pyrene							7.05E+05	1.49E+06	3.05E+06	4.24E+04	4.76E+04	5.80E+04
benzo (a) pyrene	1.22E+02	2.59E+02	5.34E+02	3.18E+01	3.27E+01	3.45E+01						

Table 5B3b Preliminary Health Risk Based Acceptance Criteria - Groundwater, , , , , , , , , , , , *Commercial/Industrial Site use* SILT Soil Type, , , , , , , , , , , ,

Site Use:	Commercial		Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Workers		Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
			(non carc):	20	yr			
Target Risk:	0.00001		Exposure Dur:	20	yr			
Target HI:	1		Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI		Volatilisation factor ($mg/m^3/mg/L\text{-}H_2O$)					
			Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	1.19E-01	1.15E-01	1.08E-01	9.55E-04	9.21E-04	8.60E-04
C_{10} - C_{14}		0.3		0.3	1.11E-01	1.07E-01	1.01E-01	8.90E-04	8.59E-04	8.03E-04
C_{15} - C_{36}		1.5		1.5	7.35E-02	7.11E-02	6.67E-02	5.90E-04	5.70E-04	5.32E-04
MAHs										
benzene	0.029		3.45E-04		7.33E-04	6.83E-04	6.01E-04	6.48E-06	5.96E-06	5.14E-06
toluene		0.11		0.11	7.12E-04	6.68E-04	5.94E-04	6.17E-06	5.73E-06	5.02E-06
ethylbenzene		0.029		0.029	7.21E-04	6.80E-04	6.10E-04	6.17E-06	5.77E-06	5.11E-06
xylene		0.09		0.09	6.60E-04	6.20E-04	5.53E-04	5.71E-06	5.31E-06	4.66E-06
PAHs										
naphthalene		0.004		0.004	2.82E-04	2.43E-04	1.90E-04	3.21E-06	2.57E-06	1.84E-06
pyrene		0.03		0.03	2.30E-06	2.05E-06	1.68E-06	1.55E-07	7.36E-08	3.59E-08
benzo (a) pyrene	7.3		1.37E-06		3.26E-07	3.17E-07	3.00E-07	9.56E-08	4.50E-08	2.18E-08

Contaminant	Risk Based Screening Level ($mg/L\text{-}H_2O$)											
	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							5.58E+04	5.78E+04	6.19E+04	4.48E+02	4.63E+02	4.94E+02
C_{10} - C_{14}							3.59E+03	3.72E+03	3.98E+03	2.88E+01	2.98E+01	3.18E+01
C_{15} - C_{36}							2.70E+04	2.80E+04	3.00E+04	2.17E+02	2.25E+02	2.39E+02
MAHs												
benzene	1.98E+03	2.16E+03	2.50E+03	1.75E+01	1.88E+01	2.14E+01						
toluene							1.90E+05	2.04E+05	2.33E+05	1.64E+03	1.75E+03	1.97E+03
ethylbenzene							5.00E+04	5.35E+04	6.05E+04	4.28E+02	4.54E+02	5.06E+02
xylene							1.68E+05	1.81E+05	2.06E+05	1.45E+03	1.55E+03	1.73E+03
PAHs												
naphthalene							1.33E+04	1.65E+04	2.31E+04	1.51E+02	1.75E+02	2.25E+02
pyrene							2.06E+06	4.34E+06	8.90E+06	1.39E+05	1.56E+05	1.90E+05
benzo (a) pyrene	5.34E+02	1.13E+03	2.34E+03	1.56E+02	1.61E+02	1.70E+02						

Table 5B1c Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces SILTY CLAY Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20°C L-$H_2$0/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	2.1E-05	30	4.68E-03	4.49E-06	8.46E-06	1.20E-05	1.51E-05
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	1.4E-05	3776.775	3.28E-03	3.14E-06	5.91E-06	8.37E-06	1.06E-05
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	1.1E-05	1503561.699	2.58E-03	2.47E-06	4.65E-06	6.58E-06	8.31E-06
benzene	0.093	1.1E-05	2.2E-01	83	4.5E-05	0.249	7.26E-03	2.22E-05	3.18E-05	3.72E-05	4.06E-05
toluene	0.085	9.40E-06	2.6E-01	302	3.8E-05	0.906	6.63E-03	1.74E-05	2.59E-05	3.09E-05	3.43E-05
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	3.3E-05	3.288	5.93E-03	1.38E-05	2.12E-05	2.57E-05	2.89E-05
xylene	0.072	8.50E-06	2.9E-01	240	3.2E-05	0.72	5.62E-03	1.43E-05	2.15E-05	2.58E-05	2.86E-05
naphthalene	0.072	9.40E-06	4.9E-02	1288	7.4E-05	3.864	5.62E-03	6.40E-05	6.99E-05	7.21E-05	7.32E-05
pyrene	0.048	7.24E-06	2.2E-04	38019	8.6E-03	114.057	3.94E-03	1.01E-02	9.11E-03	8.83E-03	8.70E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	7.5E-02	1167.135	5.63E-03	8.87E-02	8.02E-02	7.77E-02	7.65E-02

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	3.84E-05	7.25E-05	2.40E-05	7.25E-05	7.77E-06	7.25E-05
C_{10} - C_{14}	3.53E-06	7.25E-05	2.69E-07	7.25E-05	6.74E-08	7.25E-05
C_{15} - C_{36}	1.44E-07	7.25E-05	4.50E-10	7.25E-05	1.12E-10	7.25E-05
toluene	1.33E-05	7.25E-05	3.65E-06	7.25E-05	9.54E-07	7.25E-05
ethylbenzene	7.80E-06	7.25E-05	1.30E-06	7.25E-05	3.29E-07	7.25E-05
xylene	1.40E-05	7.25E-05	4.04E-06	7.25E-05	1.06E-06	7.25E-05
naphthalene	4.27E-06	7.25E-05	3.92E-07	7.25E-05	9.86E-08	7.25E-05
pyrene	5.82E-07	7.25E-05	7.33E-09	7.25E-05	1.83E-09	7.25E-05
20 Year Average - Carcinogenic						
benzene	1.19E-05	2.54E-05	6.87E-06	2.54E-05	2.14E-06	2.54E-05
benzo(a)pyrene	9.63E-08	2.54E-05	5.74E-10	2.54E-05	1.43E-10	2.54E-05
30 Year Average - Carcinogenic						
benzene	9.70E-06	1.69E-05	6.35E-06	1.69E-05	2.12E-06	1.69E-05
benzo(a)pyrene	7.86E-08	1.69E-05	5.74E-10	1.69E-05	1.43E-10	1.69E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	8.39E-03	1.46E-02	4.58E-03	1.46E-02	1.53E-03	1.46E-02
C_{10} - C_{14}	2.64E-04	1.46E-02	4.97E-05	1.46E-02	1.33E-05	1.46E-02
C_{15} - C_{36}	4.82E-07	1.46E-02	8.31E-08	1.46E-02	2.21E-08	1.46E-02
toluene	2.13E-03	1.46E-02	6.63E-04	1.46E-02	1.86E-04	1.46E-02
ethylbenzene	9.58E-04	1.46E-02	2.35E-04	1.46E-02	6.44E-05	1.46E-02
xylene	2.30E-03	1.46E-02	7.35E-04	1.46E-02	2.07E-04	1.46E-02
naphthalene	2.09E-04	1.46E-02	6.24E-05	1.46E-02	1.86E-05	1.46E-02
pyrene	3.38E-08	1.46E-02	3.31E-08	1.46E-02	3.10E-08	1.46E-02
20 Year Average - Carcinogenic						
benzene	2.48E-03	5.10E-03	1.28E-03	5.10E-03	4.17E-04	5.10E-03
benzo(a)pyrene	4.30E-10	5.10E-03	4.29E-10	5.10E-03	4.24E-10	5.10E-03
30 Year Average - Carcinogenic						
benzene	2.09E-03	3.40E-03	1.19E-03	3.40E-03	4.13E-04	3.40E-03
benzo(a)pyrene	4.30E-10	3.40E-03	4.29E-10	3.40E-03	4.24E-10	3.40E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	2.25E-04	1.60E-04	1.01E-04
C_{10} - C_{14}	2.10E-04	1.49E-04	9.40E-05
C_{15} - C_{36}	1.39E-04	9.87E-05	6.23E-05
toluene	1.50E-06	8.94E-07	4.95E-07
ethylbenzene	1.50E-06	9.15E-07	5.13E-07
xylene	1.38E-06	8.30E-07	4.61E-07
naphthalene	7.61E-07	3.92E-07	1.99E-07
pyrene	4.45E-07	2.16E-07	1.06E-07
Carcinogenic			
benzene	1.56E-06	9.09E-07	4.97E-07
benzo(a)pyrene	3.56E-07	1.73E-07	8.50E-08

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	4.45E-02	3.17E-02	2.01E-02
C_{10} - C_{14}	4.15E-02	2.95E-02	1.87E-02
C_{15} - C_{36}	2.75E-02	1.96E-02	1.24E-02
toluene	2.89E-04	1.75E-04	9.82E-05
ethylbenzene	2.92E-04	1.80E-04	1.02E-04
xylene	2.68E-04	1.63E-04	9.15E-05
naphthalene	1.36E-04	7.41E-05	3.88E-05
pyrene	3.71E-06	3.55E-06	3.28E-06
Carcinogenic			
benzene	3.00E-04	1.78E-04	9.84E-05
benzo(a)pyrene	4.99E-07	4.95E-07	4.88E-07

Table 5B2c Preliminary Health Risk Based Acceptance Criteria - Groundwater - *Residential and Agricultural Site Use* SILTY CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor (mg/m^3/mg/L-H_2O) Indoors			Volatilisation factor Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	4.45E-02	3.17E-02	2.01E-02	2.25E-04	1.60E-04	1.01E-04
C_{10} - C_{14}		0.3		0.3	4.15E-02	2.95E-02	1.87E-02	2.10E-04	1.49E-04	9.40E-05
C_{15} - C_{36}		1.5		1.5	2.75E-02	1.96E-02	1.24E-02	1.39E-04	9.87E-05	6.23E-05
MAHs										
benzene	0.029		3.45E-04		3.00E-04	1.78E-04	9.84E-05	1.56E-06	9.09E-07	4.97E-07
toluene		0.11		0.11	2.89E-04	1.75E-04	9.82E-05	1.50E-06	8.94E-07	4.95E-07
ethylbenzene		0.029		0.029	2.92E-04	1.80E-04	1.02E-04	1.50E-06	9.15E-07	5.13E-07
xylene		0.09		0.09	2.68E-04	1.63E-04	9.15E-05	1.38E-06	8.30E-07	4.61E-07
PAHs										
naphthalene		0.004		0.004	1.36E-04	7.41E-05	3.88E-05	7.61E-07	3.92E-07	1.99E-07
pyrene		0.03		0.03	3.71E-06	3.55E-06	3.28E-06	4.45E-07	2.16E-07	1.06E-07
benzo (a) pyrene	7.3		1.37E-06		4.99E-07	4.95E-07	4.88E-07	3.56E-07	1.73E-07	8.50E-08

Contaminant	Risk Based Screening Level (mg/L-H_2O) Carcinogenic Outdoors			Carcinogenic Indoors			Non-carcinogenic Outdoors			Non-carcinogenic Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							8.09E+04	1.14E+05	1.81E+05	5.47E+02	7.68E+02	1.21E+03
C_{10} - C_{14}							5.21E+03	7.35E+03	1.16E+04	3.52E+01	4.94E+01	7.79E+01
C_{15} - C_{36}							3.93E+04	5.54E+04	8.78E+04	2.65E+02	3.73E+02	5.88E+02
MAHs												
benzene	1.89E+03	3.23E+03	5.91E+03	1.31E+01	2.20E+01	3.98E+01						
toluene							2.68E+05	4.49E+05	8.11E+05	1.85E+03	3.05E+03	5.45E+03
ethylbenzene							7.04E+04	1.16E+05	2.06E+05	4.84E+02	7.84E+02	1.39E+03
xylene							2.37E+05	3.96E+05	7.12E+05	1.63E+03	2.69E+03	4.79E+03
PAHs												
naphthalene							1.92E+04	3.72E+04	7.32E+04	1.43E+02	2.63E+02	5.02E+02
pyrene							2.46E+05	5.07E+05	1.03E+06	3.93E+04	4.11E+04	4.46E+04
benzo (a) pyrene	3.27E+01	6.76E+01	1.37E+02	3.12E+01	3.14E+01	3.19E+01						

Table 5B3c Preliminary Health Risk Based Acceptance Criteria - Groundwater - *Commercial/Industrial Site use* SILTY CLAY Soil Type

Site Use:	Commercial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Workers	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Volatilisation factor ($mg/m^3/mg/L-H_2O$) Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	2.97E-02	2.11E-02	1.34E-02	2.25E-04	1.60E-04	1.01E-04
C_{10} - C_{14}		0.3		0.3	2.77E-02	1.97E-02	1.25E-02	2.10E-04	1.49E-04	9.40E-05
C_{15} - C_{36}		1.5		1.5	1.83E-02	1.31E-02	8.28E-03	1.39E-04	9.87E-05	6.23E-05
MAHs										
benzene	0.029		3.45E-04		2.00E-04	1.19E-04	6.56E-05	1.56E-06	9.09E-07	4.97E-07
toluene		0.11		0.11	1.93E-04	1.17E-04	6.55E-05	1.50E-06	8.94E-07	4.95E-07
ethylbenzene		0.029		0.029	1.95E-04	1.20E-04	6.79E-05	1.50E-06	9.15E-07	5.13E-07
xylene		0.09		0.09	1.79E-04	1.09E-04	6.10E-05	1.38E-06	8.30E-07	4.61E-07
PAHs										
naphthalene		0.004		0.004	9.06E-05	4.94E-05	2.59E-05	7.61E-07	3.92E-07	1.99E-07
pyrene		0.03		0.03	2.47E-06	2.37E-06	2.18E-06	4.45E-07	2.16E-07	1.06E-07
benzo (a) pyrene	7.3		1.37E-06		3.33E-07	3.30E-07	3.25E-07	3.56E-07	1.73E-07	8.50E-08

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							2.36E+05	3.33E+05	5.28E+05	1.79E+03	2.52E+03	3.98E+03
C_{10} - C_{14}							1.52E+04	2.15E+04	3.40E+04	1.15E+02	1.62E+02	2.56E+02
C_{15} - C_{36}							1.15E+05	1.62E+05	2.56E+05	8.70E+02	1.22E+03	1.93E+03
MAHs												
benzene	8.25E+03	1.41E+04	2.59E+04	6.43E+01	1.08E+02	1.96E+02						
toluene							7.83E+05	1.31E+06	2.37E+06	6.07E+03	1.00E+04	1.79E+04
ethylbenzene							2.05E+05	3.37E+05	6.02E+05	1.59E+03	2.57E+03	4.55E+03
xylene							6.92E+05	1.15E+06	2.08E+06	5.36E+03	8.81E+03	1.57E+04
Aromatics												
							5.60E+04	1.08E+05	2.14E+05	4.70E+02	8.62E+02	1.65E+03
naphthalene												
pyrene							7.17E+05	1.48E+06	3.00E+06	1.29E+05	1.35E+05	1.46E+05
benzo (a) pyrene	1.43E+02	2.96E+02	6.00E+02	1.53E+02	1.55E+02	1.57E+02						

Table 5B1d Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces, CLAY Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20^{o}C L-H$_2$0/L-air	Koc	Deff cm^2/s	ks cm^{3}H$_2$O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	5.5E-07	30	4.68E-03	4.49E-06	9.78E-07	7.03E-07	6.16E-07
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	3.8E-07	3776.775	3.28E-03	3.14E-06	6.78E-07	4.87E-07	4.27E-07
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	3.0E-07	1503561.699	2.58E-03	2.47E-06	5.35E-07	3.85E-07	3.37E-07
benzene	0.093	1.1E-05	2.2E-01	83	1.8E-05	0.249	7.26E-03	2.22E-05	2.00E-05	1.90E-05	1.86E-05
toluene	0.085	9.40E-06	2.6E-01	302	1.3E-05	0.906	6.63E-03	1.74E-05	1.51E-05	1.41E-05	1.37E-05
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	9.9E-06	3.288	5.93E-03	1.38E-05	1.15E-05	1.06E-05	1.03E-05
xylene	0.072	8.50E-06	2.9E-01	240	1.1E-05	0.72	5.62E-03	1.43E-05	1.23E-05	1.15E-05	1.12E-05
naphthalene	0.072	9.40E-06	4.9E-02	1288	6.7E-05	3.864	5.62E-03	6.40E-05	6.56E-05	6.64E-05	6.68E-05
pyrene	0.048	7.24E-06	2.2E-04	38019	1.1E-02	114.057	3.94E-03	1.01E-02	1.07E-02	1.11E-02	1.12E-02
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.0E-01	1167.135	5.63E-03	8.87E-02	9.43E-02	9.74E-02	9.90E-02

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	6.54E-06	7.25E-05	9.14E-07	7.25E-05	2.31E-07	7.25E-05
C_{10} - C_{14}	5.75E-07	7.25E-05	7.15E-09	7.25E-05	1.79E-09	7.25E-05
C_{15} - C_{36}	2.35E-08	7.25E-05	1.20E-11	7.25E-05	2.99E-12	7.25E-05
toluene	7.77E-06	7.25E-05	1.28E-06	7.25E-05	3.27E-07	7.25E-05
ethylbenzene	4.27E-06	7.25E-05	3.93E-07	7.25E-05	9.88E-08	7.25E-05
xylene	8.06E-06	7.25E-05	1.38E-06	7.25E-05	3.51E-07	7.25E-05
naphthalene	4.05E-06	7.25E-05	3.53E-07	7.25E-05	8.86E-08	7.25E-05
pyrene	6.72E-07	7.25E-05	9.77E-09	7.25E-05	2.44E-09	7.25E-05
20 Year Average - Carcinogenic						
benzene	7.45E-06	2.54E-05	3.06E-06	2.54E-05	8.51E-07	2.54E-05
benzo(a)pyrene	1.11E-07	2.54E-05	7.67E-10	2.54E-05	1.92E-10	2.54E-05
30 Year Average - Carcinogenic						
benzene	6.08E-06	1.69E-05	2.92E-06	1.69E-05	8.47E-07	1.69E-05
benzo(a)pyrene	9.09E-08	1.69E-05	7.67E-10	1.69E-05	1.92E-10	1.69E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	1.06E-03	1.46E-02	1.83E-04	1.46E-02	4.64E-05	1.46E-02
C_{10} - C_{14}	1.39E-05	1.46E-02	1.43E-06	1.46E-02	3.59E-07	1.46E-02
C_{15} - C_{36}	2.35E-08	1.46E-02	2.40E-09	1.46E-02	6.01E-10	1.46E-02
toluene	1.19E-03	1.46E-02	2.48E-04	1.46E-02	6.49E-05	1.46E-02
ethylbenzene	4.78E-04	1.46E-02	7.65E-05	1.46E-02	1.97E-05	1.46E-02
xylene	1.26E-03	1.46E-02	2.68E-04	1.46E-02	6.99E-05	1.46E-02
naphthalene	2.02E-04	1.46E-02	5.73E-05	1.46E-02	1.68E-05	1.46E-02
pyrene	3.38E-08	1.46E-02	3.33E-08	1.46E-02	3.17E-08	1.46E-02
20 Year Average - Carcinogenic						
benzene	1.53E-03	5.10E-03	5.91E-04	5.10E-03	1.69E-04	5.10E-03
benzo(a)pyrene	4.30E-10	5.10E-03	4.29E-10	5.10E-03	4.26E-10	5.10E-03
30 Year Average - Carcinogenic						
benzene	1.30E-03	3.40E-03	5.66E-04	3.40E-03	1.68E-04	3.40E-03
benzo(a)pyrene	4.30E-10	3.40E-03	4.29E-10	3.40E-03	4.26E-10	3.40E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-H$_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	2.61E-05	9.37E-06	4.11E-06
C_{10} - C_{14}	2.41E-05	8.66E-06	3.79E-06
C_{15} - C_{36}	1.61E-05	5.77E-06	2.53E-06
toluene	8.71E-07	4.08E-07	1.98E-07
ethylbenzene	8.19E-07	3.78E-07	1.82E-07
xylene	7.94E-07	3.71E-07	1.80E-07
naphthalene	7.14E-07	3.62E-07	1.82E-07
pyrene	5.23E-07	2.70E-07	1.37E-07
Carcinogenic			
benzene	9.78E-07	4.66E-07	2.27E-07
benzo(a)pyrene	4.19E-07	2.16E-07	1.10E-07

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-H$_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	5.23E-03	1.88E-03	8.25E-04
C_{10} - C_{14}	4.83E-03	1.74E-03	7.62E-04
C_{15} - C_{36}	3.22E-03	1.16E-03	5.08E-04
toluene	1.71E-04	8.12E-05	3.96E-05
ethylbenzene	1.61E-04	7.54E-05	3.65E-05
xylene	1.56E-04	7.38E-05	3.59E-05
naphthalene	1.28E-04	6.86E-05	3.55E-05
pyrene	3.73E-06	3.61E-06	3.39E-06
Carcinogenic			
benzene	1.91E-04	9.23E-05	4.54E-05
benzo(a)pyrene	4.99E-07	4.97E-07	4.91E-07

Table 5B2d Preliminary Health Risk Based Acceptance Criteria - Groundwater
Residential and Agricultural Site Use CLAY Soil Type

Site Use:	Residential	Exposure Frequency:	350	d/yr	Inhalation rate indoor:	15	m^3/d
Receptor:	Adults	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	20	m^3/d
		(non carc):	30	yr			
Target Risk:	0.00001	Exposure Dur:	30	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/L-H_2O$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
$C_7 - C_9$		5		5	5.23E-03	1.88E-03	8.25E-04	2.61E-05	9.37E-06	4.11E-06
$C_{10} - C_{14}$		0.3		0.3	4.83E-03	1.74E-03	7.62E-04	2.41E-05	8.66E-06	3.79E-06
$C_{15} - C_{36}$		1.5		1.5	3.22E-03	1.16E-03	5.08E-04	1.61E-05	5.77E-06	2.53E-06
MAHs										
benzene	0.029		3.45E-04		1.91E-04	9.23E-05	4.54E-05	9.78E-07	4.66E-07	2.27E-07
toluene		0.11		0.11	1.71E-04	8.12E-05	3.96E-05	8.71E-07	4.08E-07	1.98E-07
ethylbenzene		0.029		0.029	1.61E-04	7.54E-05	3.65E-05	8.19E-07	3.78E-07	1.82E-07
xylene		0.09		0.09	1.56E-04	7.38E-05	3.59E-05	7.94E-07	3.71E-07	1.80E-07
PAHs										
naphthalene		0.004		0.004	1.28E-04	6.86E-05	3.55E-05	7.14E-07	3.62E-07	1.82E-07
pyrene		0.03		0.03	3.73E-06	3.61E-06	3.39E-06	5.23E-07	2.70E-07	1.37E-07
benzo (a) pyrene	7.3		1.37E-06		4.99E-07	4.97E-07	4.91E-07	4.19E-07	2.16E-07	1.10E-07

	Risk Based Screening Level ($mg/L-H_2O$)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
$C_7 - C_9$							7.00E+05	1.95E+06	4.44E+06	4.66E+03	1.29E+04	2.95E+04
$C_{10} - C_{14}$							4.54E+04	1.26E+05	2.89E+05	3.02E+02	8.40E+02	1.92E+03
$C_{15} - C_{36}$							3.41E+05	9.49E+05	2.16E+06	2.27E+03	6.30E+03	1.44E+04
MAHs												
benzene	3.00E+03	6.31E+03	1.29E+04	2.05E+01	4.24E+01	8.63E+01						
toluene							4.61E+05	9.83E+05	2.03E+06	3.13E+03	6.60E+03	1.35E+04
ethylbenzene							1.29E+05	2.80E+05	5.81E+05	8.74E+02	1.87E+03	3.87E+03
xylene							4.14E+05	8.85E+05	1.83E+06	2.81E+03	5.93E+03	1.22E+04
PAHs												
naphthalene							2.04E+04	4.04E+04	8.03E+04	1.52E+02	2.84E+02	5.49E+02
pyrene							2.09E+05	4.05E+05	7.97E+05	3.91E+04	4.04E+04	4.30E+04
benzo (a) pyrene	2.78E+01	5.39E+01	1.06E+02	3.12E+01	3.13E+01	3.17E+01						

Table 5B3d Preliminary Health Risk Based Acceptance Criteria - Groundwater - *Commercial/Industrial Site use* CLAY Soil Type

Site Use:	Commercial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Workers	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	3.48E-03	1.25E-03	5.50E-04	2.61E-05	9.37E-06	4.11E-06
C_{10} - C_{14}		0.3		0.3	3.22E-03	1.16E-03	5.08E-04	2.41E-05	8.66E-06	3.79E-06
C_{15} - C_{36}		1.5		1.5	2.15E-03	7.72E-04	3.39E-04	1.61E-05	5.77E-06	2.53E-06
MAHs										
benzene	0.029		3.45E-04		1.27E-04	6.15E-05	3.03E-05	9.78E-07	4.66E-07	2.27E-07
toluene		0.11		0.11	1.14E-04	5.41E-05	2.64E-05	8.71E-07	4.08E-07	1.98E-07
ethylbenzene		0.029		0.029	1.08E-04	5.02E-05	2.43E-05	8.19E-07	3.78E-07	1.82E-07
xylene		0.09		0.09	1.04E-04	4.92E-05	2.39E-05	7.94E-07	3.71E-07	1.80E-07
PAHs										
naphthalene		0.004		0.004	8.57E-05	4.57E-05	2.37E-05	7.14E-07	3.62E-07	1.82E-07
pyrene		0.03		0.03	2.49E-06	2.41E-06	2.26E-06	5.23E-07	2.70E-07	1.37E-07
benzo (a) pyrene	7.3		1.37E-06		3.33E-07	3.31E-07	3.27E-07	4.19E-07	2.16E-07	1.10E-07

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							2.04E+06	5.68E+06	1.30E+07	1.53E+04	4.24E+04	9.68E+04
C_{10} - C_{14}							1.32E+05	3.69E+05	8.42E+05	9.91E+02	2.76E+03	6.29E+03
C_{15} - C_{36}							9.94E+05	2.77E+06	6.31E+06	7.44E+03	2.07E+04	4.72E+04
MAHs												
benzene	1.31E+04	2.76E+04	5.65E+04	1.01E+02	2.09E+02	4.25E+02						
toluene							1.34E+06	2.87E+06	5.92E+06	1.03E+04	2.16E+04	4.44E+04
ethylbenzene							3.77E+05	8.16E+05	1.69E+06	2.87E+03	6.15E+03	1.27E+04
xylene							1.21E+06	2.58E+06	5.33E+06	9.20E+03	1.95E+04	4.00E+04
PAHs												
naphthalene							5.96E+04	1.18E+05	2.34E+05	4.97E+02	9.31E+02	1.80E+03
pyrene							6.10E+05	1.18E+06	2.33E+06	1.28E+05	1.33E+05	1.41E+05
benzo (a) pyrene	1.22E+02	2.36E+02	4.64E+02	1.53E+02	1.54E+02	1.56E+02						

Table 5B1e Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces PUMICE Soil Type

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20°C L-H_20/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	9.3E-04	50	4.68E-03	3.72E-06	1.47E-05	2.90E-05	5.62E-05
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	6.5E-04	6294.625	3.28E-03	2.60E-06	1.03E-05	2.02E-05	3.93E-05
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	5.1E-04	2505936.165	2.58E-03	2.04E-06	8.08E-06	1.59E-05	3.09E-05
benzene	0.093	1.1E-05	2.2E-01	83	1.5E-03	0.415	7.26E-03	2.35E-05	8.97E-05	1.69E-04	3.03E-04
toluene	0.085	9.40E-06	2.6E-01	302	1.3E-03	1.51	6.63E-03	1.81E-05	6.96E-05	1.32E-04	2.40E-04
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.2E-03	5.48	5.93E-03	1.41E-05	5.46E-05	1.04E-04	1.92E-04
xylene	0.072	8.50E-06	2.9E-01	240	1.1E-03	1.2	5.62E-03	1.49E-05	5.72E-05	1.09E-04	1.98E-04
naphthalene	0.072	9.40E-06	4.9E-02	1288	1.1E-03	6.44	5.62E-03	7.27E-05	2.44E-04	4.02E-04	5.94E-04
pyrene	0.048	7.24E-06	2.2E-04	38019	4.0E-03	190.095	3.94E-03	1.17E-02	4.84E-03	4.41E-03	4.22E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	3.0E-02	1945.225	5.63E-03	1.03E-01	3.63E-02	3.28E-02	3.12E-02

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	1.84E-04	6.85E-05	1.98E-04	6.85E-05	1.31E-04	6.85E-05
C_{10} - C_{14}	1.79E-05	6.85E-05	6.70E-06	6.85E-05	1.83E-06	6.85E-05
C_{15} - C_{36}	7.32E-07	6.85E-05	1.23E-08	6.85E-05	3.07E-09	6.85E-05
toluene	6.18E-05	6.85E-05	5.05E-05	6.85E-05	2.04E-05	6.85E-05
ethylbenzene	3.58E-05	6.85E-05	2.22E-05	6.85E-05	7.17E-06	6.85E-05
xylene	6.62E-05	6.85E-05	5.55E-05	6.85E-05	2.32E-05	6.85E-05
naphthalene	1.27E-05	6.85E-05	3.54E-06	6.85E-05	9.29E-07	6.85E-05
pyrene	3.01E-07	6.85E-05	2.08E-09	6.85E-05	5.20E-10	6.85E-05
20 Year Average - Carcinogenic						
benzene	5.79E-05	2.40E-05	6.15E-05	2.40E-05	3.90E-05	2.40E-05
benzo(a)pyrene	4.56E-08	2.40E-05	1.36E-10	2.40E-05	3.41E-11	2.40E-05
30 Year Average - Carcinogenic						
benzene	4.72E-05	1.60E-05	5.17E-05	1.60E-05	3.53E-05	1.60E-05
benzo(a)pyrene	3.72E-08	1.60E-05	1.36E-10	1.60E-05	3.41E-11	1.60E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	2.60E-02	1.38E-02	2.33E-02	1.38E-02	1.69E-02	1.38E-02
C_{10} - C_{14}	3.59E-04	1.38E-02	2.95E-04	1.38E-02	1.85E-04	1.38E-02
C_{15} - C_{36}	6.04E-07	1.38E-02	4.95E-07	1.38E-02	3.09E-07	1.38E-02
toluene	4.01E-03	1.38E-02	3.36E-03	1.38E-02	2.16E-03	1.38E-02
ethylbenzene	1.41E-03	1.38E-02	1.16E-03	1.38E-02	7.35E-04	1.38E-02
xylene	4.56E-03	1.38E-02	3.83E-03	1.38E-02	2.47E-03	1.38E-02
naphthalene	1.80E-04	1.38E-02	1.48E-04	1.38E-02	9.29E-05	1.38E-02
pyrene	2.02E-08	1.38E-02	1.94E-08	1.38E-02	1.70E-08	1.38E-02
20 Year Average - Carcinogenic						
benzene	7.73E-03	4.81E-03	6.86E-03	4.81E-03	4.89E-03	4.81E-03
benzo(a)pyrene	2.58E-10	4.81E-03	2.56E-10	4.81E-03	2.49E-10	4.81E-03
30 Year Average - Carcinogenic						
benzene	7.01E-03	3.21E-03	6.32E-03	3.21E-03	4.66E-03	3.21E-03
benzo(a)pyrene	2.58E-10	3.21E-03	2.56E-10	3.21E-03	2.49E-10	3.21E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-H_20/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	3.92E-04	3.86E-04	3.74E-04
C_{10} - C_{14}	3.65E-04	3.60E-04	3.49E-04
C_{15} - C_{36}	2.42E-04	2.39E-04	2.32E-04
toluene	4.02E-06	3.82E-06	3.47E-06
ethylbenzene	3.88E-06	3.71E-06	3.41E-06
xylene	3.69E-06	3.51E-06	3.20E-06
naphthalene	2.66E-06	2.19E-06	1.62E-06
pyrene	2.36E-07	1.08E-07	5.15E-08
Carcinogenic			
benzene	4.39E-06	4.13E-06	3.70E-06
benzo(a)pyrene	1.61E-07	7.28E-08	3.47E-08

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-H_20/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	7.64E-02	7.52E-02	7.30E-02
C_{10} - C_{14}	7.12E-02	7.01E-02	6.81E-02
C_{15} - C_{36}	4.72E-02	4.65E-02	4.52E-02
toluene	7.31E-04	6.98E-04	6.40E-04
ethylbenzene	7.14E-04	6.85E-04	6.34E-04
xylene	6.72E-04	6.42E-04	5.90E-04
naphthalene	3.72E-04	3.24E-04	2.57E-04
pyrene	3.58E-06	3.28E-06	2.82E-06
Carcinogenic			
benzene	7.84E-04	7.43E-04	6.73E-04
benzo(a)pyrene	4.95E-07	4.86E-07	4.69E-07

Table 5B2e Preliminary Health Risk Based Acceptance Criteria - Groundwater
Residential and Agricultural Site Use PUMICE Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30 yr		
Target Risk:	0.00001	Exposure Dur:	30 yr		
Target HI:	1	Body Weight:	70 kg		

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/L-H_2O$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	7.64E-02	7.52E-02	7.30E-02	3.92E-04	3.86E-04	3.74E-04
C_{10} - C_{14}		0.3		0.3	7.12E-02	7.01E-02	6.81E-02	3.65E-04	3.60E-04	3.49E-04
C_{15} - C_{36}		1.5		1.5	4.72E-02	4.65E-02	4.52E-02	2.42E-04	2.39E-04	2.32E-04
MAHs										
benzene	0.029		3.45E-04		7.84E-04	7.43E-04	6.73E-04	4.39E-06	4.13E-06	3.70E-06
toluene		0.11		0.11	7.31E-04	6.98E-04	6.40E-04	4.02E-06	3.82E-06	3.47E-06
ethylbenzene		0.029		0.029	7.14E-04	6.85E-04	6.34E-04	3.88E-06	3.71E-06	3.41E-06
xylene		0.09		0.09	6.72E-04	6.42E-04	5.90E-04	3.69E-06	3.51E-06	3.20E-06
PAHs										
naphthalene		0.004		0.004	3.72E-04	3.24E-04	2.57E-04	2.66E-06	2.19E-06	1.62E-06
pyrene		0.03		0.03	3.58E-06	3.28E-06	2.82E-06	2.36E-07	1.08E-07	5.15E-08
benzo (a) pyrene	7.3		1.37E-06		4.95E-07	4.86E-07	4.69E-07	1.61E-07	7.28E-08	3.47E-08

	Risk Based Screening Level ($mg/L-H_2O$)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
Alkanes												
C_7 - C_9							4.65E+04	4.73E+04	4.87E+04	3.19E+02	3.23E+02	3.33E+02
C_{10} - C_{14}							3.00E+03	3.04E+03	3.14E+03	2.05E+01	2.08E+01	2.15E+01
C_{15} - C_{36}							2.26E+04	2.29E+04	2.36E+04	1.55E+02	1.57E+02	1.62E+02
MAHs												
benzene	6.70E+02	7.11E+02	7.94E+02	4.99E+00	5.27E+00	5.82E+00						
toluene							9.99E+04	1.05E+05	1.16E+05	7.33E+02	7.67E+02	8.37E+02
ethylbenzene							2.73E+04	2.85E+04	3.10E+04	1.98E+02	2.06E+02	2.23E+02
xylene							8.91E+04	9.37E+04	1.03E+05	6.52E+02	6.82E+02	7.42E+02
PAHs												
naphthalene							5.49E+03	6.67E+03	9.03E+03	5.23E+01	6.01E+01	7.57E+01
pyrene							4.63E+05	1.02E+06	2.12E+06	4.08E+04	4.45E+04	5.18E+04
benzo (a) pyrene	7.23E+01	1.60E+02	3.36E+02	3.15E+01	3.20E+01	3.32E+01						

Table 5B3e Preliminary Health Risk Based Acceptance Criteria - Groundwater

Commercial/Industrial Site use PUMICE Soil Type

Site Use:	Commercial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Workers	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/L-H_2O$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	5.09E-02	5.02E-02	4.87E-02	3.92E-04	3.86E-04	3.74E-04
C_{10} - C_{14}		0.3		0.3	4.75E-02	4.67E-02	4.54E-02	3.65E-04	3.60E-04	3.49E-04
C_{15} - C_{36}		1.5		1.5	3.15E-02	3.10E-02	3.01E-02	2.42E-04	2.39E-04	2.32E-04
MAHs										
benzene	0.029		3.45E-04		5.23E-04	4.96E-04	4.49E-04	4.39E-06	4.13E-06	3.70E-06
toluene		0.11		0.11	4.87E-04	4.65E-04	4.26E-04	4.02E-06	3.82E-06	3.47E-06
ethylbenzene		0.029		0.029	4.76E-04	4.57E-04	4.23E-04	3.88E-06	3.71E-06	3.41E-06
xylene		0.09		0.09	4.48E-04	4.28E-04	3.93E-04	3.69E-06	3.51E-06	3.20E-06
PAHs										
naphthalene		0.004		0.004	2.48E-04	2.16E-04	1.71E-04	2.66E-06	2.19E-06	1.62E-06
pyrene		0.03		0.03	2.39E-06	2.19E-06	1.88E-06	2.36E-07	1.08E-07	5.15E-08
benzo (a) pyrene	7.3		1.37E-06		3.30E-07	3.24E-07	3.12E-07	1.61E-07	7.28E-08	3.47E-08

	Risk Based Screening Level ($mg/L-H_2O$)											
Contaminant	Carcinogenic						Non-carcinogenic					
	Outdoors			Indoors			Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							1.36E+05	1.38E+05	1.42E+05	1.05E+03	1.06E+03	1.09E+03
C_{10} - C_{14}							8.74E+03	8.88E+03	9.15E+03	6.73E+01	6.83E+01	7.04E+01
C_{15} - C_{36}							6.59E+04	6.69E+04	6.90E+04	5.07E+02	5.15E+02	5.30E+02
MAHs												
benzene	2.93E+03	3.11E+03	3.47E+03	2.46E+01	2.59E+01	2.86E+01						
toluene							2.91E+05	3.07E+05	3.37E+05	2.40E+03	2.52E+03	2.75E+03
ethylbenzene							7.95E+04	8.32E+04	9.05E+04	6.49E+02	6.76E+02	7.31E+02
xylene							2.60E+05	2.73E+05	3.00E+05	2.14E+03	2.24E+03	2.44E+03
PAHs												
naphthalene							1.60E+04	1.95E+04	2.63E+04	1.72E+02	1.97E+02	2.49E+02
pyrene							1.35E+06	2.97E+06	6.20E+06	1.34E+05	1.46E+05	1.70E+05
benzo (a) pyrene	3.16E+02	7.01E+02	1.47E+03	1.55E+02	1.58E+02	1.63E+02						

Table 5B1f Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces,PEATS AND HIGH ORGANIC Soil Type,

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20^{o}C L-$H_2$0/L-air	Koc	Deff cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	2.1E-03	1200	4.68E-03	5.30E-06	3.49E-05	6.86E-05	1.33E-04
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	1.5E-03	151071	3.28E-03	3.71E-06	2.44E-05	4.80E-05	9.30E-05
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	1.2E-03	60142467.96	2.58E-03	2.92E-06	1.92E-05	3.77E-05	7.31E-05
benzene	0.093	1.1E-05	2.2E-01	83	3.3E-03	9.96	7.26E-03	2.16E-05	1.39E-04	2.66E-04	4.92E-04
toluene	0.085	9.40E-06	2.6E-01	302	3.0E-03	36.24	6.63E-03	1.72E-05	1.11E-04	2.14E-04	3.99E-04
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	2.7E-03	131.52	5.93E-03	1.38E-05	8.94E-05	1.73E-04	3.25E-04
xylene	0.072	8.50E-06	2.9E-01	240	2.6E-03	28.8	5.62E-03	1.42E-05	9.16E-05	1.77E-04	3.31E-04
naphthalene	0.072	9.40E-06	4.9E-02	1288	2.6E-03	154.56	5.62E-03	5.76E-05	3.40E-04	6.01E-04	9.73E-04
pyrene	0.048	7.24E-06	2.2E-04	38019	2.9E-03	4562.28	3.94E-03	8.80E-03	3.19E-03	3.02E-03	2.94E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.2E-02	46685.4	5.63E-03	7.75E-02	1.38E-02	1.29E-02	1.24E-02

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	6.18E-05	6.44E-05	5.17E-05	6.44E-05	2.15E-05	6.44E-05
C_{10} - C_{14}	5.36E-06	6.44E-05	6.92E-07	6.44E-05	1.75E-07	6.44E-05
C_{15} - C_{36}	2.19E-07	6.44E-05	1.17E-09	6.44E-05	2.91E-10	6.44E-05
toluene	1.98E-05	6.44E-05	8.44E-06	6.44E-05	2.37E-06	6.44E-05
ethylbenzene	1.09E-05	6.44E-05	2.79E-06	6.44E-05	7.25E-07	6.44E-05
xylene	2.16E-05	6.44E-05	9.84E-06	6.44E-05	2.80E-06	6.44E-05
naphthalene	3.84E-06	6.44E-05	3.58E-07	6.44E-05	8.99E-08	6.44E-05
pyrene	5.02E-08	6.44E-05	6.14E-11	6.44E-05	1.53E-11	6.44E-05
20 Year Average - Carcinogenic						
benzene	2.14E-05	2.25E-05	1.78E-05	2.25E-05	7.35E-06	2.25E-05
benzo(a)pyrene	5.74E-09	2.25E-05	2.29E-12	2.25E-05	5.73E-13	2.25E-05
30 Year Average - Carcinogenic						
benzene	1.74E-05	1.50E-05	1.56E-05	1.50E-05	7.11E-06	1.50E-05
benzo(a)pyrene	4.68E-09	1.50E-05	2.29E-12	1.50E-05	5.73E-13	1.50E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	2.00E-03	1.29E-02	1.83E-03	1.29E-02	1.42E-03	1.29E-02
C_{10} - C_{14}	1.53E-05	1.29E-02	1.40E-05	1.29E-02	1.08E-05	1.29E-02
C_{15} - C_{36}	2.55E-08	1.29E-02	2.32E-08	1.29E-02	1.79E-08	1.29E-02
toluene	2.09E-04	1.29E-02	1.90E-04	1.29E-02	1.47E-04	1.29E-02
ethylbenzene	6.36E-05	1.29E-02	5.79E-05	1.29E-02	4.46E-05	1.29E-02
xylene	2.48E-04	1.29E-02	2.26E-04	1.29E-02	1.74E-04	1.29E-02
naphthalene	7.86E-06	1.29E-02	7.16E-06	1.29E-02	5.52E-06	1.29E-02
pyrene	8.43E-10	1.29E-02	7.94E-10	1.29E-02	6.65E-10	1.29E-02
20 Year Average - Carcinogenic						
benzene	6.84E-04	4.53E-03	6.25E-04	4.53E-03	4.84E-04	4.53E-03
benzo(a)pyrene	1.07E-11	4.53E-03	1.05E-11	4.53E-03	9.84E-12	4.53E-03
30 Year Average - Carcinogenic						
benzene	6.79E-04	3.02E-03	6.21E-04	3.02E-03	4.82E-04	3.02E-03
benzo(a)pyrene	1.07E-11	3.02E-03	1.05E-11	3.02E-03	9.84E-12	3.02E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	9.30E-04	9.15E-04	8.86E-04
C_{10} - C_{14}	8.67E-04	8.53E-04	8.26E-04
C_{15} - C_{36}	5.75E-04	5.66E-04	5.48E-04
toluene	6.40E-06	6.17E-06	5.76E-06
ethylbenzene	6.36E-06	6.15E-06	5.78E-06
xylene	5.90E-06	5.70E-06	5.33E-06
naphthalene	3.71E-06	3.27E-06	2.65E-06
pyrene	1.56E-07	7.37E-08	3.59E-08
Carcinogenic			
benzene	6.77E-06	6.50E-06	6.02E-06
benzo(a)pyrene	6.13E-08	2.86E-08	1.38E-08

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	1.74E-01	1.71E-01	1.66E-01
C_{10} - C_{14}	1.62E-01	1.60E-01	1.55E-01
C_{15} - C_{36}	1.08E-01	1.06E-01	1.03E-01
toluene	1.10E-03	1.07E-03	1.01E-03
ethylbenzene	1.11E-03	1.08E-03	1.02E-03
xylene	1.02E-03	9.89E-04	9.33E-04
naphthalene	4.64E-04	4.28E-04	3.71E-04
pyrene	3.44E-06	3.07E-06	2.52E-06
Carcinogenic			
benzene	1.14E-03	1.10E-03	1.03E-03
benzo(a)pyrene	4.83E-07	4.62E-07	4.25E-07

Table 5B2f Preliminary Health Risk Based Acceptance Criteria - Groundwater
Residential and Agricultural Site Use PEATS AND HIGH ORGANIC Soil Type

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30 yr		
Target Risk:	0.00001	Exposure Dur:	30 yr		
Target HI:	1	Body Weight:	70 kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	1.74E-01	1.71E-01	1.66E-01	9.30E-04	9.15E-04	8.86E-04
C_{10} - C_{14}		0.3		0.3	1.62E-01	1.60E-01	1.55E-01	8.67E-04	8.53E-04	8.26E-04
C_{15} - C_{36}		1.5		1.5	1.08E-01	1.06E-01	1.03E-01	5.75E-04	5.66E-04	5.48E-04
MAHs										
benzene	0.029		3.45E-04		1.14E-03	1.10E-03	1.03E-03	6.77E-06	6.50E-06	6.02E-06
toluene		0.11		0.11	1.10E-03	1.07E-03	1.01E-03	6.40E-06	6.17E-06	5.76E-06
ethylbenzene		0.029		0.029	1.11E-03	1.08E-03	1.02E-03	6.36E-06	6.15E-06	5.78E-06
xylene		0.09		0.09	1.02E-03	9.89E-04	9.33E-04	5.90E-06	5.70E-06	5.33E-06
PAHs										
naphthalene		0.004		0.004	4.64E-04	4.28E-04	3.71E-04	3.71E-06	3.27E-06	2.65E-06
pyrene		0.03		0.03	3.44E-06	3.07E-06	2.52E-06	1.56E-07	7.37E-08	3.59E-08
benzo (a) pyrene	7.3		1.37E-06		4.83E-07	4.62E-07	4.25E-07	6.13E-08	2.86E-08	1.38E-08

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							1.96E+04	2.00E+04	2.06E+04	1.40E+02	1.42E+02	1.46E+02
C_{10} - C_{14}							1.26E+03	1.28E+03	1.32E+03	9.01E+00	9.14E+00	9.42E+00
C_{15} - C_{36}							9.52E+03	9.68E+03	9.99E+03	6.79E+01	6.89E+01	7.10E+01
MAHs												
benzene	4.34E+02	4.52E+02	4.88E+02	3.43E+00	3.55E+00	3.79E+00						
toluene							6.27E+04	6.50E+04	6.97E+04	4.86E+02	5.01E+02	5.32E+02
ethylbenzene							1.67E+04	1.72E+04	1.83E+04	1.27E+02	1.31E+02	1.38E+02
xylene							5.56E+04	5.76E+04	6.16E+04	4.29E+02	4.43E+02	4.69E+02
PAHs												
naphthalene							3.94E+03	4.46E+03	5.51E+03	4.20E+01	4.55E+01	5.24E+01
pyrene							7.03E+05	1.48E+06	3.05E+06	4.24E+04	4.76E+04	5.80E+04
benzo (a) pyrene	1.90E+02	4.09E+02	8.45E+02	3.22E+01	3.37E+01	3.66E+01						

Table 5B3f Preliminary Health Risk Based Acceptance Criteria - Groundwater, *Commercial/Industrial Site use* PEATS AND HIGH ORGANIC Soil Type

Site Use:	Commercial	Exposure Frequency:	240 d/yr	Inhalation rate indoor:	10 m^3/d
Receptor:	Workers	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	10 m^3/d
		(non carc):	20 yr		
Target Risk:	0.00001	Exposure Dur:	20 yr		
Target HI:	1	Body Weight:	70 kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	1.16E-01	1.14E-01	1.11E-01	9.30E-04	9.15E-04	8.86E-04
C_{10} - C_{14}		0.3		0.3	1.08E-01	1.06E-01	1.03E-01	8.67E-04	8.53E-04	8.26E-04
C_{15} - C_{36}		1.5		1.5	7.17E-02	7.06E-02	6.85E-02	5.75E-04	5.66E-04	5.48E-04
MAHs										
benzene	0.029		3.45E-04		7.62E-04	7.36E-04	6.89E-04	6.77E-06	6.50E-06	6.02E-06
toluene		0.11		0.11	7.34E-04	7.12E-04	6.71E-04	6.40E-06	6.17E-06	5.76E-06
ethylbenzene		0.029		0.029	7.40E-04	7.19E-04	6.81E-04	6.36E-06	6.15E-06	5.78E-06
xylene		0.09		0.09	6.80E-04	6.60E-04	6.22E-04	5.90E-06	5.70E-06	5.33E-06
PAHs										
naphthalene		0.004		0.004	3.09E-04	2.86E-04	2.48E-04	3.71E-06	3.27E-06	2.65E-06
pyrene		0.03		0.03	2.30E-06	2.05E-06	1.68E-06	1.56E-07	7.37E-08	3.59E-08
benzo (a) pyrene	7.3		1.37E-06		3.22E-07	3.08E-07	2.84E-07	6.13E-08	2.86E-08	1.38E-08

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
Alkanes												
C_7 - C_9							5.72E+04	5.82E+04	6.01E+04	4.59E+02	4.66E+02	4.80E+02
C_{10} - C_{14}							3.68E+03	3.74E+03	3.86E+03	2.95E+01	3.00E+01	3.09E+01
C_{15} - C_{36}							2.78E+04	2.82E+04	2.91E+04	2.23E+02	2.26E+02	2.33E+02
MAHs												
benzene	1.90E+03	1.98E+03	2.14E+03	1.69E+01	1.75E+01	1.87E+01						
toluene							1.83E+05	1.90E+05	2.03E+05	1.59E+03	1.64E+03	1.75E+03
ethylbenzene							4.86E+04	5.02E+04	5.34E+04	4.17E+02	4.29E+02	4.54E+02
xylene							1.62E+05	1.68E+05	1.80E+05	1.41E+03	1.45E+03	1.54E+03
PAHs												
naphthalene							1.15E+04	1.30E+04	1.61E+04	1.38E+02	1.49E+02	1.72E+02
pyrene							2.05E+06	4.33E+06	8.89E+06	1.39E+05	1.56E+05	1.90E+05
benzo (a) pyrene	8.33E+02	1.79E+03	3.70E+03	1.59E+02	1.66E+02	1.80E+02						

Table 5B1g Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces FRACTURED BASALTS with Shallow Overlaying Soil

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20°C L-H_20/L-air	Koc	Deff cm^2/s	Deff-over cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	1.1E-03	2.1E-05	10	4.68E-03	9.25E-05	3.99E-05	7.69E-05	1.44E-04
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	7.7E-04	1.4E-05	1258.925	3.28E-03	6.47E-05	2.79E-05	5.38E-05	1.01E-04
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	6.1E-04	1.1E-05	501187.233	2.58E-03	5.09E-05	2.19E-05	4.23E-05	7.91E-05
benzene	0.093	1.1E-05	2.2E-01	83	1.7E-03	4.5E-05	0.083	7.26E-03	1.44E-04	8.60E-05	1.64E-04	2.99E-04
toluene	0.085	9.40E-06	2.6E-01	302	1.6E-03	3.8E-05	0.302	6.63E-03	1.31E-04	7.40E-05	1.41E-04	2.59E-04
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	1.4E-03	3.3E-05	1.096	5.93E-03	1.17E-04	6.34E-05	1.21E-04	2.23E-04
xylene	0.072	8.50E-06	2.9E-01	240	1.3E-03	3.2E-05	0.24	5.62E-03	1.11E-04	6.21E-05	1.19E-04	2.18E-04
naphthalene	0.072	9.40E-06	4.9E-02	1288	1.3E-03	7.4E-05	1.288	5.62E-03	1.13E-04	1.37E-04	2.48E-04	4.18E-04
pyrene	0.048	7.24E-06	2.2E-04	38019	9.1E-04	8.6E-03	38.019	3.94E-03	5.00E-04	1.58E-03	1.15E-03	1.01E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	1.1E-03	7.5E-02	389.045	5.63E-03	3.83E-03	2.29E-03	1.51E-03	1.29E-03

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	5.08E-04	9.66E-05	5.91E-04	9.66E-05	4.72E-04	9.66E-05
C_{10} - C_{14}	5.17E-05	9.66E-05	3.25E-05	9.66E-05	1.06E-05	9.66E-05
C_{15} - C_{36}	2.11E-06	9.66E-05	7.26E-08	9.66E-05	1.82E-08	9.66E-05
toluene	1.85E-04	9.66E-05	1.89E-04	9.66E-05	1.09E-04	9.66E-05
ethylbenzene	1.05E-04	9.66E-05	9.13E-05	9.66E-05	4.02E-05	9.66E-05
xylene	2.00E-04	9.66E-05	2.07E-04	9.66E-05	1.23E-04	9.66E-05
naphthalene	3.69E-05	9.66E-05	1.86E-05	9.66E-05	5.46E-06	9.66E-05
pyrene	3.79E-07	9.66E-05	2.33E-09	9.66E-05	5.82E-10	9.66E-05
20 Year Average - Carcinogenic						
benzene	1.87E-04	3.38E-05	2.18E-04	3.38E-05	1.76E-04	3.38E-05
benzo(a)pyrene	2.35E-08	3.38E-05	2.57E-11	3.38E-05	6.41E-12	3.38E-05
30 Year Average - Carcinogenic						
benzene	1.53E-04	2.25E-05	1.81E-04	2.25E-05	1.52E-04	2.25E-05
benzo(a)pyrene	1.92E-08	2.25E-05	2.57E-11	2.25E-05	6.41E-12	2.25E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	8.95E-02	1.94E-02	8.40E-02	1.94E-02	6.88E-02	1.94E-02
C_{10} - C_{14}	1.78E-03	1.94E-02	1.51E-03	1.94E-02	9.96E-04	1.94E-02
C_{15} - C_{36}	3.03E-06	1.94E-02	2.55E-06	1.94E-02	1.67E-06	1.94E-02
toluene	1.93E-02	1.94E-02	1.70E-02	1.94E-02	1.20E-02	1.94E-02
ethylbenzene	6.90E-03	1.94E-02	5.93E-03	1.94E-02	4.00E-03	1.94E-02
xylene	2.20E-02	1.94E-02	1.95E-02	1.94E-02	1.39E-02	1.94E-02
naphthalene	9.15E-04	1.94E-02	7.73E-04	1.94E-02	5.09E-04	1.94E-02
pyrene	9.96E-08	1.94E-02	8.36E-08	1.94E-02	5.44E-08	1.94E-02
20 Year Average - Carcinogenic						
benzene	3.35E-02	6.79E-03	3.15E-02	6.79E-03	2.60E-02	6.79E-03
benzo(a)pyrene	1.26E-09	6.79E-03	1.03E-09	6.79E-03	6.45E-10	6.79E-03
30 Year Average - Carcinogenic						
benzene	2.91E-02	4.53E-03	2.76E-02	4.53E-03	2.35E-02	4.53E-03
benzo(a)pyrene	1.26E-09	4.53E-03	1.03E-09	4.53E-03	6.45E-10	4.53E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-H_20/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	1.06E-03	1.03E-03	9.59E-04
C_{10} - C_{14}	9.92E-04	9.57E-04	8.95E-04
C_{15} - C_{36}	6.58E-04	6.35E-04	5.93E-04
toluene	4.28E-06	4.08E-06	3.74E-06
ethylbenzene	4.51E-06	4.31E-06	3.97E-06
xylene	4.00E-06	3.82E-06	3.51E-06
naphthalene	1.49E-06	1.35E-06	1.14E-06
pyrene	7.73E-08	2.81E-08	1.24E-08
Carcinogenic			
benzene	4.21E-06	4.00E-06	3.65E-06
benzo(a)pyrene	1.02E-08	3.35E-09	1.43E-09

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-H_20/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	1.97E-01	1.90E-01	1.79E-01
C_{10} - C_{14}	1.84E-01	1.78E-01	1.67E-01
C_{15} - C_{36}	1.22E-01	1.18E-01	1.11E-01
toluene	7.73E-04	7.41E-04	6.85E-04
ethylbenzene	8.18E-04	7.86E-04	7.29E-04
xylene	7.24E-04	6.94E-04	6.42E-04
naphthalene	2.41E-04	2.23E-04	1.93E-04
pyrene	3.10E-06	2.30E-06	1.52E-06
Carcinogenic			
benzene	7.55E-04	7.23E-04	6.66E-04
benzo(a)pyrene	4.03E-07	2.88E-07	1.83E-07

Table 5B2g Preliminary Health Risk Based Acceptance Criteria - Groundwater *Residential and Agricultural Site Use* FRACTURED BASALTS with Shallow Overlaying Soil

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor:	15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor:	20 m^3/d
		(non carc):	30 yr		
Target Risk:	0.00001	Exposure Dur:	30 yr		
Target HI:	1	Body Weight:	70 kg		

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	1.97E-01	1.90E-01	1.79E-01	1.06E-03	1.03E-03	9.59E-04
C_{10} - C_{14}		0.3		0.3	1.84E-01	1.78E-01	1.67E-01	9.92E-04	9.57E-04	8.95E-04
C_{15} - C_{36}		1.5		1.5	1.22E-01	1.18E-01	1.11E-01	6.58E-04	6.35E-04	5.93E-04
MAHs										
benzene	0.029		3.45E-04		7.55E-04	7.23E-04	6.66E-04	4.21E-06	4.00E-06	3.65E-06
toluene		0.11		0.11	7.73E-04	7.41E-04	6.85E-04	4.28E-06	4.08E-06	3.74E-06
ethylbenzene		0.029		0.029	8.18E-04	7.86E-04	7.29E-04	4.51E-06	4.31E-06	3.97E-06
xylene		0.09		0.09	7.24E-04	6.94E-04	6.42E-04	4.00E-06	3.82E-06	3.51E-06
PAHs										
naphthalene		0.004		0.004	2.41E-04	2.23E-04	1.93E-04	1.49E-06	1.35E-06	1.14E-06
pyrene		0.03		0.03	3.10E-06	2.30E-06	1.52E-06	7.73E-08	2.81E-08	1.24E-08
benzo (a) pyrene	7.3		1.37E-06		4.03E-07	2.88E-07	1.83E-07	1.02E-08	3.35E-09	1.43E-09

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							1.72E+04	1.78E+04	1.90E+04	1.24E+02	1.28E+02	1.36E+02
C_{10} - C_{14}							1.10E+03	1.14E+03	1.22E+03	7.95E+00	8.22E+00	8.75E+00
C_{15} - C_{36}							8.33E+03	8.63E+03	9.23E+03	6.00E+01	6.20E+01	6.60E+01
MAHs												
benzene	6.98E+02	7.33E+02	8.04E+02	5.18E+00	5.42E+00	5.88E+00						
toluene							9.39E+04	9.83E+04	1.07E+05	6.93E+02	7.22E+02	7.81E+02
ethylbenzene							2.35E+04	2.45E+04	2.67E+04	1.72E+02	1.80E+02	1.94E+02
xylene							8.21E+04	8.60E+04	9.37E+04	6.05E+02	6.31E+02	6.82E+02
PAHs												
naphthalene							9.78E+03	1.08E+04	1.28E+04	8.08E+01	8.75E+01	1.01E+02
pyrene							1.42E+06	3.89E+06	8.84E+06	4.71E+04	6.35E+04	9.64E+04
benzo (a) pyrene	1.15E+03	3.48E+03	8.16E+03	3.86E+01	5.41E+01	8.51E+01						

Table 5B3g Preliminary Health Risk Based Acceptance Criteria - Groundwater *Commercial/Industrial Site use* FRACTURED BASALTS with Shallow Overlaying Soil

Site Use: Commercial
Receptor: Workers

Target Risk: 0.00001
Target HI: 1

Exposure Frequency: 240 d/yr
Averaging Time (carc): 70 yr
(non carc): 20 yr
Exposure Dur: 20 yr
Body Weight: 70 kg

Inhalation rate indoor: 10 m^3/d
Inhalation rate outdoor: 10 m^3/d

			Acceptable CDI		Volatilisation factor ($mg/m^3/mg/L\text{-}H_2O$)					
Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Carcinogenic	Non-car.	Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	1.31E-01	1.27E-01	1.19E-01	1.06E-03	1.03E-03	9.59E-04
C_{10} - C_{14}		0.3		0.3	1.22E-01	1.18E-01	1.11E-01	9.92E-04	9.57E-04	8.95E-04
C_{15} - C_{36}		1.5		1.5	8.12E-02	7.85E-02	7.38E-02	6.58E-04	6.35E-04	5.93E-04
MAHs										
benzene	0.029		3.45E-04		5.04E-04	4.82E-04	4.44E-04	4.21E-06	4.00E-06	3.65E-06
toluene		0.11		0.11	5.15E-04	4.94E-04	4.57E-04	4.28E-06	4.08E-06	3.74E-06
ethylbenzene		0.029		0.029	5.46E-04	5.24E-04	4.86E-04	4.51E-06	4.31E-06	3.97E-06
xylene		0.09		0.09	4.82E-04	4.63E-04	4.28E-04	4.00E-06	3.82E-06	3.51E-06
PAHs										
naphthalene		0.004		0.004	1.61E-04	1.48E-04	1.29E-04	1.49E-06	1.35E-06	1.14E-06
pyrene		0.03		0.03	2.07E-06	1.53E-06	1.01E-06	7.73E-08	2.81E-08	1.24E-08
benzo (a) pyrene	7.3		1.37E-06		2.69E-07	1.92E-07	1.22E-07	1.02E-08	3.35E-09	1.43E-09

Table 5B1h Volatilisation from surface and sub-surface soils, and groundwater to outdoor air and enclosed spaces GRAVEL with Overlaying Soil

Chemical	Dair cm^2/s	Dwat cm^2/s	H @ 20^{o}C L-$H_2$0/L-air	Koc	Deff cm^2/s	Deff-over cm^2/s	ks cm^3H_2O/g-soil	Defcrack cm^2/s	Defcap cm^2/s	Deffws (2m) cm^2/s	Deffws (4m) cm^2/s	Deffws (8m) cm^2/s
C_7 - C_9	0.06	7.10E-06	1.2E+02	10000	7.6E-03	9.8E-04	10	4.68E-03	1.43E-05	4.30E-04	8.15E-04	1.47E-03
C_{10} - C_{14}	0.042	4.80E-06	1.6E+02	1258925	5.3E-03	6.9E-04	1258.925	3.28E-03	9.99E-06	3.01E-04	5.70E-04	1.03E-03
C_{15} - C_{34}	0.033	3.80E-06	1.4E+02	501187233	4.2E-03	5.4E-04	501187.233	2.58E-03	7.85E-06	2.37E-04	4.48E-04	8.09E-04
benzene	0.093	1.1E-05	2.2E-01	83	1.2E-02	1.5E-03	0.083	7.26E-03	2.78E-05	7.88E-04	1.48E-03	2.62E-03
toluene	0.085	9.40E-06	2.6E-01	302	1.1E-02	1.4E-03	0.302	6.63E-03	2.43E-05	6.98E-04	1.31E-03	2.34E-03
ethylbenzene	0.076	8.50E-06	3.2E-01	1096	9.6E-03	1.2E-03	1.096	5.93E-03	2.11E-05	6.11E-04	1.15E-03	2.05E-03
xylene	0.072	8.50E-06	2.9E-01	240	9.1E-03	1.2E-03	0.24	5.62E-03	2.04E-05	5.89E-04	1.11E-03	1.97E-03
naphthalene	0.072	9.40E-06	4.9E-02	1288	9.1E-03	1.2E-03	1.288	5.62E-03	3.88E-05	8.96E-04	1.63E-03	2.77E-03
pyrene	0.048	7.24E-06	2.2E-04	38019	6.1E-03	2.9E-03	38.019	3.94E-03	3.74E-03	3.85E-03	4.71E-03	5.30E-03
benzo(a)pyrene	0.05	5.80E-06	2.0E-05	389045	6.3E-03	1.9E-02	389.045	5.63E-03	3.28E-02	9.82E-03	7.70E-03	6.95E-03

Volatilisation Factor - Soil to Outdoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Year Average - Non Carcinogenic						
C_7 - C_9	9.10E-04	8.05E-05	1.10E-03	8.05E-05	9.90E-04	8.05E-05
C_{10} - C_{14}	1.23E-04	8.05E-05	1.19E-04	8.05E-05	6.18E-05	8.05E-05
C_{15} - C_{36}	5.06E-06	8.05E-05	4.95E-07	8.05E-05	1.25E-07	8.05E-05
toluene	4.26E-04	8.05E-05	4.96E-04	8.05E-05	3.97E-04	8.05E-05
ethylbenzene	2.46E-04	8.05E-05	2.71E-04	8.05E-05	1.87E-04	8.05E-05
xylene	4.54E-04	8.05E-05	5.30E-04	8.05E-05	4.30E-04	8.05E-05
naphthalene	8.80E-05	8.05E-05	7.72E-05	8.05E-05	3.41E-05	8.05E-05
pyrene	8.94E-07	8.05E-05	1.56E-08	8.05E-05	3.89E-09	8.05E-05
20 Year Average - Carcinogenic						
benzene	4.05E-04	2.82E-05	4.94E-04	2.82E-05	4.54E-04	2.82E-05
benzo(a)pyrene	5.10E-08	2.82E-05	1.45E-10	2.82E-05	3.62E-11	2.82E-05
30 Year Average - Carcinogenic						
benzene	3.31E-04	1.88E-05	4.05E-04	1.88E-05	3.79E-04	1.88E-05
benzo(a)pyrene	4.16E-08	1.88E-05	1.45E-10	1.88E-05	3.62E-11	1.88E-05

Volatilisation Factor - Soil to Indoor Air (Johnson-Ettinger)

Chemical	Soil Volatilisation Factor (kg-soil/m^3-air)					
	Surface Soil		>1 m		>4m	
	(1)	(2)	(1)	(2)	(1)	(2)
Yearly Average - Non Carcinogenic						
C_7 - C_9	8.59E-02	1.62E-02	8.41E-02	1.62E-02	7.87E-02	1.62E-02
C_{10} - C_{14}	1.82E-03	1.62E-02	1.77E-03	1.62E-02	1.62E-03	1.62E-02
C_{15} - C_{36}	3.09E-06	1.62E-02	3.00E-06	1.62E-02	2.76E-06	1.62E-02
toluene	2.11E-02	1.62E-02	2.06E-02	1.62E-02	1.90E-02	1.62E-02
ethylbenzene	7.24E-03	1.62E-02	7.05E-03	1.62E-02	6.48E-03	1.62E-02
xylene	2.38E-02	1.62E-02	2.32E-02	1.62E-02	2.14E-02	1.62E-02
naphthalene	9.34E-04	1.62E-02	9.09E-04	1.62E-02	8.34E-04	1.62E-02
pyrene	1.01E-07	1.62E-02	9.86E-08	1.62E-02	9.01E-08	1.62E-02
20 Year Average - Carcinogenic						
benzene	4.54E-02	5.66E-03	4.46E-02	5.66E-03	4.20E-02	5.66E-03
benzo(a)pyrene	1.29E-09	5.66E-03	1.24E-09	5.66E-03	1.10E-09	5.66E-03
30 Year Average - Carcinogenic						
benzene	4.21E-02	3.77E-03	4.14E-02	3.77E-03	3.93E-02	3.77E-03
benzo(a)pyrene	1.29E-09	3.77E-03	1.24E-09	3.77E-03	1.10E-09	3.77E-03

Volatilisation Factor - Groundwater to Outdoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	1.15E-02	1.09E-02	9.81E-03
C_{10} - C_{14}	1.07E-02	1.01E-02	9.15E-03
C_{15} - C_{36}	7.10E-03	6.72E-03	6.07E-03
toluene	4.04E-05	3.79E-05	3.38E-05
ethylbenzene	4.34E-05	4.08E-05	3.65E-05
xylene	3.79E-05	3.56E-05	3.18E-05
naphthalene	9.75E-06	8.88E-06	7.53E-06
pyrene	1.88E-07	1.15E-07	6.47E-08
Carcinogenic			
benzene	3.85E-05	3.61E-05	3.21E-05
benzo(a)pyrene	4.36E-08	1.71E-08	7.73E-09

Volatilisation Factor - Groundwater to Indoor Air

Chemical	GW Volatilisation Factor (L-$H_2$0/m^3-air)		
	2 m	4 m	8 m
Non-Carcinogenic			
C_7 - C_9	1.20E+00	1.17E+00	1.10E+00
C_{10} - C_{14}	1.12E+00	1.09E+00	1.03E+00
C_{15} - C_{36}	7.43E-01	7.22E-01	6.83E-01
toluene	3.95E-03	3.83E-03	3.61E-03
ethylbenzene	4.30E-03	4.17E-03	3.93E-03
xylene	3.72E-03	3.61E-03	3.40E-03
naphthalene	7.55E-04	7.28E-04	6.78E-04
pyrene	3.51E-06	3.32E-06	2.98E-06
Carcinogenic			
benzene	3.71E-03	3.60E-03	3.38E-03
benzo(a)pyrene	4.75E-07	4.38E-07	3.79E-07

Table 5B2h Preliminary Health Risk Based Acceptance Criteria - Groundwater *Residential and Agricultural Site Use* Gravel with Overlaying Soil

Site Use:	Residential	Exposure Frequency:	350 d/yr	Inhalation rate indoor: 15 m^3/d
Receptor:	Adults	Averaging Time (carc):	70 yr	Inhalation rate outdoor: 20 m^3/d
		(non carc):	30 yr	
Target Risk:	0.00001	Exposure Dur:	30 yr	
Target HI:	1	Body Weight:	70 kg	

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	1.20E+00	1.17E+00	1.10E+00	1.15E-02	1.09E-02	9.81E-03
C_{10} - C_{14}		0.3		0.3	1.12E+00	1.09E+00	1.03E+00	1.07E-02	1.01E-02	9.15E-03
C_{15} - C_{36}		1.5		1.5	7.43E-01	7.22E-01	6.83E-01	7.10E-03	6.72E-03	6.07E-03
MAHs										
benzene	0.029		3.45E-04		3.71E-03	3.60E-03	3.38E-03	3.85E-05	3.61E-05	3.21E-05
toluene		0.11		0.11	3.95E-03	3.83E-03	3.61E-03	4.04E-05	3.79E-05	3.38E-05
ethylbenzene		0.029		0.029	4.30E-03	4.17E-03	3.93E-03	4.34E-05	4.08E-05	3.65E-05
xylene		0.09		0.09	3.72E-03	3.61E-03	3.40E-03	3.79E-05	3.56E-05	3.18E-05
PAHs										
naphthalene		0.004		0.004	7.55E-04	7.28E-04	6.78E-04	9.75E-06	8.88E-06	7.53E-06
pyrene		0.03		0.03	3.51E-06	3.32E-06	2.98E-06	1.88E-07	1.15E-07	6.47E-08
benzo (a) pyrene	7.3		1.37E-06		4.75E-07	4.38E-07	3.79E-07	4.36E-08	1.71E-08	7.73E-09

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							1.59E+03	1.68E+03	1.86E+03	2.03E+01	2.09E+01	2.21E+01
C_{10} - C_{14}							1.02E+02	1.08E+02	1.20E+02	1.30E+00	1.34E+00	1.42E+00
C_{15} - C_{36}							7.71E+02	8.15E+02	9.02E+02	9.82E+00	1.01E+01	1.07E+01
MAHs												
benzene	7.62E+01	8.13E+01	9.16E+01	1.06E+00	1.09E+00	1.16E+00						
toluene							9.95E+03	1.06E+04	1.19E+04	1.36E+02	1.40E+02	1.48E+02
ethylbenzene							2.44E+03	2.59E+03	2.90E+03	3.28E+01	3.39E+01	3.59E+01
xylene							8.66E+03	9.22E+03	1.03E+04	1.18E+02	1.21E+02	1.29E+02
PAHs												
naphthalene							1.50E+03	1.64E+03	1.94E+03	2.58E+01	2.67E+01	2.87E+01
pyrene							5.82E+05	9.52E+05	1.69E+06	4.16E+04	4.40E+04	4.89E+04
benzo (a) pyrene	2.67E+02	6.82E+02	1.51E+03	3.27E+01	3.55E+01	4.10E+01						

Table 5B3h Preliminary Health Risk Based Acceptance Criteria - Groundwater *Commercial/Industrial Site use* GRAVEL with Overlaying Soil

Site Use:	Commercial	Exposure Frequency:	240	d/yr	Inhalation rate indoor:	10	m^3/d
Receptor:	Workers	Averaging Time (carc):	70	yr	Inhalation rate outdoor:	10	m^3/d
		(non carc):	20	yr			
Target Risk:	0.00001	Exposure Dur:	20	yr			
Target HI:	1	Body Weight:	70	kg			

Contaminant	SF (1/mg/kg/d)	RfD (mg/kg/d)	Acceptable CDI Carcinogenic	Acceptable CDI Non-car.	Volatilisation factor ($mg/m^3/mg/L-H_2O$) Indoors			Outdoors		
	Inhalation	Inhalation	Inhalation	Inhalation	2m	4m	8m	2m	4m	8m
Alkanes										
C_7 - C_9		5		5	8.01E-01	7.78E-01	7.36E-01	1.15E-02	1.09E-02	9.81E-03
C_{10} - C_{14}		0.3		0.3	7.48E-01	7.26E-01	6.87E-01	1.07E-02	1.01E-02	9.15E-03
C_{15} - C_{36}		1.5		1.5	4.96E-01	4.81E-01	4.55E-01	7.10E-03	6.72E-03	6.07E-03
MAHs										
benzene	0.029		3.45E-04		2.47E-03	2.40E-03	2.26E-03	3.85E-05	3.61E-05	3.21E-05
toluene		0.11		0.11	2.63E-03	2.55E-03	2.40E-03	4.04E-05	3.79E-05	3.38E-05
ethylbenzene		0.029		0.029	2.87E-03	2.78E-03	2.62E-03	4.34E-05	4.08E-05	3.65E-05
xylene		0.09		0.09	2.48E-03	2.40E-03	2.27E-03	3.79E-05	3.56E-05	3.18E-05
PAHs										
naphthalene		0.004		0.004	5.04E-04	4.85E-04	4.52E-04	9.75E-06	8.88E-06	7.53E-06
pyrene		0.03		0.03	2.34E-06	2.21E-06	1.99E-06	1.88E-07	1.15E-07	6.47E-08
benzo (a) pyrene	7.3		1.37E-06		3.17E-07	2.92E-07	2.53E-07	4.36E-08	1.71E-08	7.73E-09

Contaminant	Risk Based Screening Level ($mg/L-H_2O$) Carcinogenic Outdoors			Indoors			Non-carcinogenic Outdoors			Indoors		
Alkanes	2m	4m	8m	2m	4m	8m	2m	4m	8m	2m	4m	8m
C_7 - C_9							4.64E+03	4.90E+03	5.43E+03	6.65E+01	6.84E+01	7.24E+01
C_{10} - C_{14}							2.98E+02	3.15E+02	3.49E+02	4.27E+00	4.40E+00	4.65E+00
C_{15} - C_{36}							2.25E+03	2.38E+03	2.63E+03	3.22E+01	3.32E+01	3.51E+01
MAHs												
benzene	3.33E+02	3.56E+02	4.01E+02	5.19E+00	5.36E+00	5.69E+00						
toluene							2.90E+04	3.09E+04	3.47E+04	4.45E+02	4.59E+02	4.87E+02
ethylbenzene							7.11E+03	7.56E+03	8.47E+03	1.08E+02	1.11E+02	1.18E+02
xylene							2.53E+04	2.69E+04	3.02E+04	3.86E+02	3.98E+02	4.23E+02
PAHs												
naphthalene							4.37E+03	4.80E+03	5.66E+03	8.46E+01	8.78E+01	9.42E+01
pyrene							1.70E+06	2.78E+06	4.93E+06	1.36E+05	1.44E+05	1.61E+05
benzo (a) pyrene	1.17E+03	2.98E+03	6.61E+03	1.61E+02	1.75E+02	2.02E+02						

Appendix 5C
Stock water criteria

1.1 Overview

The uptake of contaminants by stock is unlikely to be a limiting consideration compared to potable use of groundwater, however, it is an important consideration when the salinity is such that potable use is limited. Where the salinity of the groundwater limits use of groundwater to less sensitive uses, the impact of contaminated groundwater on stock health and human health may be an important consideration.

In deriving Tier 1 groundwater acceptance criteria for the protection of stockwater use consideration has been given to:

- protection of stock health
- protection of human health where livestock products (e.g. milk and meat) are consumed
- aesthetic considerations (e.g. palatability of the water).

The derivation of stockwater criteria is highly uncertain due to inadequate information regarding the accumulation of contaminants in stock and relevant thresholds for the palatability of water for stock. Due to limited information, consideration of palatability and other aesthetic considerations have not been included in the derivation of the Tier 1 groundwater acceptance criteria for stockwater use.

The basis for the derivation of stockwater criteria is presented in Section 5.4 of Module 5. This appendix focuses on the derivation of criteria based on the protection of human health where livestock products are consumed. Consideration of livestock health and aesthetic impact is presented in Section 5.4. In practice the uptake and accumulation of petroleum hydrocarbons by livestock and the associated impact on human health is not limiting compared to the impact on stock health (refer Section 5.4).

1.2 Uptake model

1.2.1 Summary

The uptake and accumulation of contaminants by stock is dependent on a range of complex biological processes affecting absorption, distribution, metabolism and elimination of contaminants. Simplified empirical formulae are available which provide an indication of the uptake of contaminants by stock. These formulae are presented in numerous research papers. The equations used for the derivation of the Tier 1 groundwater acceptance criteria can be found in Travis and Arms (1988).

The Travis and Arms model has been widely used however it is limited in that most of the data on which the correlations are based is for chlorinated pesticides. Chlorinated pesticides are generally resistant to metabolism in mammals whereas hydrocarbon compounds including PAHs are readily metabolised. Metabolism of PAHs and other hydrocarbons is expected to reduce accumulation in livestock and hence the Travis and Arms model is expected to overestimate uptake and accumulation.

1.2.2 Pathways

Contaminants are taken up by stock through ingestion of stock water. Contaminants may accumulate within animal tissue or fat reservoirs (e.g. milk) and through the consumption of animal products humans may be exposed to these contaminants. For the purposes of deriving criteria two main pathways, by which humans may ingest contaminants, have been assumed:

- ingestion of meat: beef, pork, etc
- ingestion of milk and dairy products

Travis and Arms present equations relating the uptake and accumulation of contamination in beef to the intake of contaminants, which for the purposes of deriving Tier 1 criteria have been assumed to apply to a range of livestock. Equations relating uptake to intake of contaminants are also presented for milk.

1.2.3 Equations

The biotransfer factors for beef (Bb) and milk (Bm) are defined as:

$$\mathrm{Bb} = \frac{\text{concentration in beef (mg / kg)}}{\text{daily intake of organic (mg / d)}} \qquad \text{(C1)}$$

$$\mathrm{Bm} = \frac{\text{concentration in milk (mg / kg)}}{\text{daily intake of organic (mg / d)}} \qquad \text{(C2)}$$

The calculation of the biotransfer factors are calculated as follows:

$$\log \mathrm{Bb} = -7.6 + \log \mathrm{Kow} \qquad \text{(C3)}$$

$$\log \mathrm{Bm} = -8.1 + \log \mathrm{Kow} \qquad \text{(C4)}$$

where:

Kow = Octanol Water Partition Coefficient.

1.3 Groundwater criteria calculation

1.3.1 Exposure parameters

Screening criteria calculations are made for both meat and milk pathways. The exposure parameters are presented in Table 5C1.

Table 5C1 Exposure parameters

Parameter	Value	Reference
Stock		
Stock water ingestion rate	55 L/d	Shell, 1994
Human		
Exposure frequency	365 d/y	
Exposure duration	70 yrs	
Averaging time	70 yrs	
Body weight	70 kg	ANZECC, 1992
Meat ingestion rate	152 g/d	Langley, 1993
Milk ingestion rate	269 g/d	Langley, 1993

1.3.2 Meat and milk concentrations

The contaminant concentrations in the meat and milk corresponding to the acceptable daily intake (e.g. RfD) are calculated using the following equations

$$\mathrm{Ci} = \frac{\mathrm{ADI} \times \mathrm{AT} \times 365 \times \mathrm{BW}}{\mathrm{EF} \times \mathrm{IR} \times \mathrm{ED}} \qquad \text{(C5)}$$

where:

Ci = Concentration of beef or milk (mg/kg)

ADI = Average daily intake (mg/kg/d)

IR = Ingestion rate of beef or milk (kg/d)

ED = Exposure duration (years)

AT = Averaging time (70 years for carc., ED for non-carc)

BW = Body weight (kg)

For carcinogenic contaminants:

ADI = Target Risk / SF (C6)

For non-carcinogenic contaminants:

ADI = Target Hazard Index x RfD (C7)

where: SF = Slope factor $(\mathrm{mg/kg/d})^{-1}$

RfD = Reference dose factor (mg/kg/d)

1.3.3 Groundwater concentration

The contaminated concentrations in beef and milk corresponding to the acceptable intake are used to calculate the groundwater acceptance criteria. The beef and milk concentrations are substituted into equations C1 and C2 to calculate the allowable daily intake of contaminants by stock. From this the groundwater concentration is calculated from the equation:

$$\text{Groundwater Concentration (mg / L)} = \frac{\text{Daily intake of contaminants by stock (mg / d)}}{\text{Ingestion rate of stock water (L / d)}}$$

(C8)

Groundwater concentrations are calculated for both exposure pathways (i.e. beef and milk consumption). However, risk calculations should combine both sources to determine the groundwater concentration. The combined pathway groundwater acceptance criteria is calculated by:

$$\text{Groundwater Acceptance Criterion (mg / L)} = \frac{1}{\frac{1}{\mathrm{Cb}} + \frac{1}{\mathrm{Cm}}} \qquad \text{(C9)}$$

1.4 References

ANZECC/NHMRC. 1992. **Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites**.

Langley A. 1993. **Refining Exposure Assessment.** Proc 2nd Nat Workshop on the Health Risk Assessment and Management of Contaminated Land.

Shell, 1994.

Travis C.C., and A.D. Arms. 1988. **Bioaccumulation of Organics in Beef, Milk and Vegetation**, Environ Sci Technl. Vol 22, No 3.

Table 5C2
Stock water calculations
Risk to human health - meat

Water Conc	1	mg/L	Meat cons.	152	g/d	Exp. Freq.	365	d/y
Stock Ing Rate:	55	L/d	BW	70	kg	ED	70	
Daily Intake:	55	mg/d				AT	70	

Chemical	Kow	log Bb	Bb	beef conc mg/kg	LADD mg/kg.d	CDI mg/kg.d	Screening mg/L
C_7-C_9	1.41E+05	-2.4500	3.55E-03	1.95E-01	4.24E-04	5.00E+00	11799.51309
C_{10}-C_{14}	3.72E+07	-0.0300	9.33E-01	5.13E+01	1.11E-01	1.00E-01	0.897205158
C_{15}-C_{36}	2.09E+09	1.7200	5.25E+01	2.89E+03	6.27E+00	1.50E+00	0.239322219
benzene	132	-5.4794	3.32E-06	1.82E-04	3.96E-07	3.45E-04	870.8028334
toluene	537	-4.8700	1.35E-05	7.42E-04	1.61E-06	2.00E-01	124150.214
ethylbenzene	1413	-4.4499	3.55E-05	1.95E-03	4.24E-06	1.00E-01	23591.17655
xylene	1820	-4.3399	4.57E-05	2.51E-03	5.46E-06	1.80E-01	32968.02112
naphthalene	2344	-4.2300	5.89E-05	3.24E-03	7.03E-06	4.00E-03	568.7897401
pyrene	151356	-2.4200	3.80E-03	2.09E-01	4.54E-04	3.00E-02	66.07132516
benzo(a)pyrene	1096478	-1.5600	2.75E-02	1.51E+00	3.29E-03	1.37E-06	0.000416497

Table 5C3
Stock water calculations
Risk to human health - milk

Water Conc	1	mg/L	Milk Cons.	269	g/d	Exp. Freq.	365	d/y
Stock Ing Rate:	55	L/d	BW	70	kg	ED	70	
Daily Intake:	55	mg/d				AT	70	

Chemical	Kow	log Bm	Bm	beef conc mg/kg	LADD mg/kg.d	CDI mg/kg.d	Screening mg/L
C_7-C_9	1.41E+05	-2.9500	1.12E-03	6.17E-02	2.37E-04	5.00E+00	21084.11588
C_{10}-C_{14}	3.72E+07	-0.5300	2.95E-01	1.62E+01	6.24E-02	1.00E-01	1.603182891
C_{15}-C_{36}	2.09E+09	1.2200	1.66E+01	9.13E+02	3.51E+00	1.50E+00	0.42763607
benzene	132	-5.9794	1.05E-06	5.77E-05	2.22E-07	3.45E-04	1556.005549
toluene	537	-5.3700	4.27E-06	2.35E-04	9.02E-07	2.00E-01	221839.4503
ethylbenzene	1413	-4.9499	1.12E-05	6.17E-04	2.37E-06	1.00E-01	42154.20553
xylene	1820	-4.8399	1.45E-05	7.95E-04	3.06E-06	1.80E-01	58909.34415
naphthalene	2344	-4.7300	1.86E-05	1.02E-03	3.94E-06	4.00E-03	1016.349463
pyrene	151356	-2.9200	1.20E-03	6.61E-02	2.54E-04	3.00E-02	118.0604204
benzo(a)pyrene	1096478	-2.0600	8.71E-03	4.79E-01	1.84E-03	1.37E-06	0.000744224

Ministry for the
Environment
Manatū Mō Te Taiao

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

MODULE 6
Development of site-specific acceptance criteria

August 1999

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6 Development of site-specific acceptance criteria

Module 6 provides general guidance for the development of risk-based site-specific soil and groundwater acceptance criteria as part of Tier 2 and Tier 3 site assessments.

6.1 Introduction

This module is designed to provide additional guidance for the development of site-specific soil and groundwater acceptance criteria in the context of Tier 2 and Tier 3 assessments. In particular, the following items are addressed:

- the development of Tier 2 site-specific acceptance criteria, based on the risk assessment methodology used for the development of Tier 1 acceptance criteria (outlined in Module 4) and a range of other risk assessment models;
- key requirements for the development of Tier 3 site-specific acceptance criteria. Given the highly site-specific nature of detailed risk assessment, it is not possible to fully define procedures for the development of Tier 3 criteria. Rather, the general requirements for such detailed site-specific risk assessment are outlined, together with an indication of the level of detail and site-specific input required as part of a Tier 3 assessment.

The objective of this module is not to provide detailed or definitive guidance regarding the conduct of Tier 2 and 3 assessments, but rather to provide a general indication of the issues that may require consideration and the level of detail required as part of Tier 2 and 3 assessments. The complexity of the Tier 2 and 3 assessments mean that the scope of work should be determined by appropriately qualified and experienced hydrogeologists, environmental engineers and risk assessment professionals on a site by site basis.

6.2 Developing Tier 2 acceptance criteria

The philosophy and general approach for deriving Tier 2 soil and groundwater acceptance criteria are discussed. Consideration is given to site-specific information requirements and options for more detailed fate and transport modelling.

6.2.1 Overview

A Tier 2 assessment is initiated where:

- the measured contaminant concentrations exceed the Tier 1 acceptance criteria (or the Tier 1 acceptance criteria are regarded as inappropriate)
- the likely savings in remediation costs resulting from this less conservative acceptance criteria compensates for the additional cost associated with a Tier 2 assessment.

The development of Tier 2 acceptance criteria is based on:

- the procedures outlined in Module 4 for the development of Tier 1 generic acceptance criteria or alternative risk assessment models, as outlined in Section 6.2.3

- replacement of generic data used in developing Tier 1 criteria with site-specific data.

Based on the results of the Tier 1 assessment, site conditions and receptor locations, a critical review of the completeness and relevance of exposure pathways should be conducted. The identification of relevant and complete exposure pathways is a critical element of any Tier 2 assessment.

The development of Tier 2 acceptance criteria can be based largely on screening level fate and transport models with incorporation of site-specific data to reduce the level of conservatism inherent in the criteria development. Alternatively, simple two-dimensional fate and transport modules may be used to refine risk estimates and site-specific acceptance criteria[1].

6.2.2 Information requirements

Examples of site-specific information that can be included in the derivation of Tier 2 criteria include:

- the depth to contamination
- soil type and properties (e.g. moisture content, porosity, density, organic carbon content), including variability in soil properties through the soil profile
- local climatic conditions (e.g. temperature and wind speed)
- building construction details and ventilation rates
- quantity of home-grown fruit and vegetables likely to be consumed (based on site use and physical constraints
- current and potential site use and activity patterns (e.g. duration of indoor and outdoor exposure, distance from the contamination to the receptor)
- nature and diversity of ecosystems, including the occurrence of specific species which have been identified as sensitive and likely to control the derivation of ecologically-based acceptance criteria
- physical setting of the site and the relevance of beneficial uses considered in the derivation of the Tier 1 acceptance criteria.

In some cases direct measurement of parameters noted above is not possible, however, improved estimates may be made based on the available site information.

Prior to collecting additional information, the review of exposure pathways should be completed such that the information gathering can be focussed toward addressing the exposure pathways identified as relevant and complete.

As part of a Tier 2 assessment, it is generally inappropriate to vary parameters used in the development of acceptance criteria that do not vary on a site-specific basis, e.g. toxicity and physical/chemical properties of the chemicals, unless specific new information becomes available. If parameters that are not site-specific are to be varied, detailed justification should be provided.

It is anticipated that the documentation associated with a Tier 2 assessment may include:

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[1] The scope of a Tier 2 assessment undertaken in the context of these guidelines is more detailed and complex than that undertaken in accordance with the ASTM RBCA standard, reflecting the greater level of flexibility and detail inherent in the Tier 1 assessment as presented in these guidelines. The use of simple two-dimensional models as part of the Tier 2 assessment differs from the ASTM RBCA standard which has been configured to use simple analytical models which provide a unique output for a unique input.

- an overview of the setting of the site and the site-specific considerations
- justification for the adoption of site-specific values for parameters of relevance to the derivation of Tier 2 criteria
- details of the calculation of acceptance criteria using the procedures outlined in Module 4
- an assessment of the uncertainty associated with the adopted acceptance criteria and the likely impact of use of default values for some parameters where site-specific data is not available.

The Tier 2 assessment focuses on the refinement and validation of input parameters for the risk assessment (including fate and transport modelling), based on site-specific information. A Tier 2 assessment would normally include limited validation of fate and transport predictions (e.g. based on information gathered as part of the site assessment).

6.2.3 Alternative risk assessment models

A range of computer-based models have been developed for use in risk assessment, some specific to the assessment of petroleum contamination. The development of Tier 2 site-specific acceptance criteria may be streamlined by the use of such models, although the assumptions underlying such models should be carefully reviewed and documented as part of any derivation of Tier 2 acceptance criteria.

Therefore, two options exist for derivation of Tier 2 site-specific acceptance criteria:

- use of the equations set out in Module 4 for derivation of Tier 1 generic acceptance criteria, together with site-specific information
- use of one of a range of alternative, computer-based models together with site-specific information.

The derivation of Tier 2 acceptance criteria based on the equations used for derivation of the Tier 1 criteria has the advantage of streamlining the regulatory acceptance, given that the equations used for the Tier 1 analyses have undergone extensive peer review and that regulators will be familiar with the basis for the derivations. Additional information may be required to support alternative approaches, although these may be equally valid. Some of the alternative risk assessment models that may be considered for use in deriving Tier 2 acceptance criteria include:

- RISC, developed by BP Oil. The RISC model incorporates the VADSAT and Johnson and Ettinger volatilisation sub-models.
- Decision Support System (DSS), developed on behalf of the API
- HESP, developed by Shell (The Netherlands)
- RBCA Implementation Tools, developed by Groundwater Services Inc, incorporating the Johnson and Jury sub-models
- Fate 2, developed by Shell (US).

A range of other risk assessment models are also available, some of which may be useful in the derivation of Tier 2 site-specific acceptance criteria. Some of the models listed above require a considerable amount of site-specific information and effort, and may be more appropriately applied at a Tier 3 level.

Some of the alternative risk assessment models incorporate different assumptions regarding the fate and transport of contamination compared to those used to derive the Tier 1 generic acceptance criteria. Where assumptions regarding fate and transport differ, careful documentation is required. It is important that key assumptions and limitations underlying each model are carefully reviewed in selecting a model for use in the Tier 2 assessment.

In some cases, research is continuing with the aim of refining the risk assessment models. When such information becomes available, it may be incorporated in the derivation of Tier 2 acceptance criteria, and used to refine the existing risk assessment models. For example, opportunity exists for further refinement and validation of approaches to account for biodegradation in volatilisation.

If groundwater contamination is of particular concern, modelling of groundwater fate and transport using dedicated groundwater fate and transport models may be warranted. Some of the groundwater flow and fate and transport models that may be used in Tier 2 assessment are listed in Section 6.4.3.

Many of the same models may be used in Tier 2 and Tier 3 assessments, the difference being in the level of detail incorporated in setting up the models and the amount of effort spent on calibration and verification of the models (refer Section 6.4.3).

In addition, the RISC and DSS models incorporate groundwater fate and transport modelling capabilities, based on the VADSAT and AT123D sub-models respectively. BP Oil is upgrading RISC to include a surface water mixing model and a sediment partitioning model for use in situations where a groundwater plume intercepts a surface water body. The updated model will also include food chain pathways for ecological receptors RISC v4.0 will also include a modified Johnson model which incorporates vapour degradation and models to account for exposure via ingestion of vegetables and by use of contaminated water for irrigation .

Each of the risk assessment models listed above incorporates some consideration of leaching of contaminants from the unsaturated zone, thus predicting the impact of soil contamination on groundwater quality. Other stand-alone one-dimensional leaching models for use in Tier 2 assessments include VLEACH and CHEMFLOW, both developed by and available from the USEPA.

6.3 Developing Tier 3 acceptance criteria

A Tier 3 assessment is designed to reflect site-specific conditions and incorporate state-of-the-art risk assessment. Therefore, only the general requirements and level of detail necessary as part of a Tier 3 assessment and the derivation of Tier 3 site-specific acceptance criteria, are discussed.

Site-specific acceptance criteria developed in the context of a Tier 3 investigation incorporate a high degree of site-specific information, and state-of-the-art-risk assessment. The development of Tier 3 acceptance criteria may involve considerable expenditure and therefore the benefit gained from reduced conservatism is only able to be realised on a relatively small number of complex sites. The decision to proceed with Tier 3 assessment requires judging whether the remediation savings likely to result from less conservative criteria outweigh the cost associated with the Tier 3 assessment.

The Tier 3 assessment and the development of Tier 3 site-specific acceptance criteria may involve:

- detailed consideration of the distribution and spatial variability of the contamination
- incorporation of site-specific exposure assumptions, as per the Tier 2 investigations

- detailed site measurements and investigations to refine exposure parameters (e.g. activity patterns for site users), parameters of importance in fate and transport modelling or calibrated/validated fate and transport predictions
- a detailed review of the toxicology of each chemical of concern in order to confirm or refine the dose response factors, including consideration of site-specific factors that may influence the absorption and distribution of contaminants within the body (e.g. form of contaminant)
- detailed fate and transport modelling, particularly in relation to groundwater contamination, in order to improve predictions of contaminant concentrations at the point of exposure
- quantitative uncertainty and sensitivity analysis, incorporating techniques such as probabilistic risk assessment (Monte Carlo).

6.4 Refining site-specific acceptance criteria

Key issues in refining site-specific acceptance criteria relevant to the derivation of both Tier 2 and Tier 3 site-specific acceptance criteria, are discussed. Consideration is given to site-specific measurements, probabilistic risk assessment and detailed fate and transport modelling.

6.4.1 Site-specific measurements

Predicting contaminant concentrations at the point of exposure is an important element of risk assessment. Where the primary exposure route involves direct contact with contaminated soil (e.g. ingestion of contaminated soil) the exposure concentration may be taken directly from the measured soil concentrations. However, where exposure involves cross-media transfer or where the point of exposure is remote from the point of measurement of contaminant concentrations, it is often necessary to predict contaminant concentrations at the point of exposure, based on measurements at other locations. This is a particularly important issue when considering exposure to volatile chemicals, such as those present in gasoline and other hydrocarbon fuels, for which inhalation is the primary exposure route.

The development of Tier 1 and Tier 2 acceptance criteria is largely based on screening level fate and transport models. Such models incorporate a significant degree of uncertainty and conservatism, reflecting the simplifications inherent in the models. Refining fate and transport modelling used in the risk assessment, can have a major impact on the acceptance criteria. Fate and transport modelling incorporated in the development of the Tier 1 acceptance criteria includes:

- emissions from contaminated soil and groundwater to outdoor air
- emissions from contaminated soil and groundwater to indoor air
- uptake of contaminants by plants.

While it is possible to refine fate and transport modelling, the ideal data on which to base risk estimates are measured contaminant concentrations at the point of exposure (e.g. in indoor air). Unfortunately, direct measurement of contaminant concentrations at the point of exposure is often either not possible or not reliable (e.g. measurement of indoor air concentrations may be confounded by other sources). Alternatively, measurement of contaminant concentrations or fluxes at other points along the exposure pathway, may reduce the uncertainty associated with risk estimates.

When the risk assessment is looking forward to possible site redevelopment, it is not always possible to measure contaminant concentrations at the point of exposure. In such circumstances, intermediate measurements and measurement of input parameters may be used to refine or partially validate the fate and transport models. For example if a site is currently used as a service station, it is not possible to measure contaminant concentrations in basements associated with future residential development or in fruit and vegetables grown at the site.

6.4.1.1 Soil properties

Soil and aquifer properties are important input parameters for fate and transport modelling. Fate and transport modelling may be undertaken using default values, as for derivation of Tier 1 criteria, or using typical values for the soil types encountered on site. However, direct measurement of soil and aquifer properties on a site-specific basis provides the most accurate information for use in fate and transport modelling.

Soil and groundwater properties that may be measured on a site-specific basis include:

- bulk density
- particle density
- particle size distribution
- moisture content
- air and water filled porosity
- organic carbon content
- partitioning coefficient chemical specific, (involves trials conducted on a laboratory scale)
- hydraulic conductivity of the aquifer (requires pump tests, slug tests or similar aquifer tests conducted in the field)
- hydraulic gradient
- dissolved oxygen.

In practice, air-filled porosity and organic carbon content are the most important soil parameters relating to volatilisation and dissolved oxygen content; hydraulic conductivity and hydraulic gradient are important in assessing the fate of groundwater contamination. However, the reliable measurement of air filled porosity at a site, in order to obtain a representative value for modelling purposes, is not straightforward.

A level of uncertainty will be associated with each of the above measurements. It is important that a sufficient number of tests be conducted to ensure estimates are representative of the conditions at the site. Further consideration should be given to possible variation in each of the parameters spatially and with depth.

The requirement for site-specific measurement of soil and groundwater properties should be carefully evaluated on a site-specific basis. In some cases prudent use of published information may help, particularly where decision-making is not sensitive to the particular value assumed for a given parameter.

6.4.1.2 Soil gas profiles and emission flux measurements

Inhalation of volatile compounds following diffusion into indoor air is one of the dominant exposure routes for soil contaminated by gasoline and some other petroleum products. Measurements that enable validation of emission modelling are useful in refining risk estimates and reducing the conservatism inherent in the acceptance criteria. Two techniques that could assist in partial validation of the volatilisation models (where direct measurement of, say, indoor air concentrations is not possible) are:

- measurement of emission flux
- measurement of contaminant concentrations in soil gas at a range of depths.

In practice reliable protocols for the measurement of emission flux are yet to be developed and hence such techniques require further development before they can be routinely applied. The measurement of emission flux is most likely to be considered as part of a Tier 3 assessment.

Measurement of soil gas concentrations within the contaminated zone and comparison with the total contaminant concentrations in the soil (as measured by laboratory analysis) can be used to validate the partitioning sub-models used. Further, the profile of soil gas concentrations with depth can be used, in conjunction with detailed lithological data, to examine the extent to which a quasi-steady state has been achieved (assumed in many emission models) and whether loss processes other than volatilisation (e.g. degradation) are likely to be significant. Particular care must be exercised to ensure short-circuiting and infiltration of surface air is minimised when sampling shallow soil gas. Acceptance criteria for use in evaluating soil gas measurements are presented in Appendix 4J.

6.4.1.3 Plant uptake

Where preliminary fate and transport modelling indicates plant uptake and consumption of home-grown fruit and vegetables are potentially significant exposure pathways, consideration may be given to site-specific measurement of contaminant concentrations in plants. The available correlations between soil concentration and contaminant concentrations in edible portions of plants are highly uncertain and may significantly over-predict the uptake of contaminants by plants, particularly in edible portions of the plant.

Where exposure via the consumption of home-grown produce is dominant, then site-specific trials to measure the uptake of contaminants by plants may be considered, depending on the cost of conducting the trials and the likely savings resulting from less conservative acceptance criteria. In practice. specific plant uptake trials are difficult to conduct and there are limitations getting information suitable for use in a quantitative manner.

While plant uptake trials may be considered as part of a Tier 3 assessment, in most cases remediation of surface soils may be more cost-effective (given the cost and uncertainty associated with plant uptake trials).

6.4.2 Probabilistic risk assessment

Probabilistic risk assessment is a tool that can be used to assist in quantifying uncertainty and variability. Historically, risk assessment has been undertaken using conservative point estimates for each of the input parameters, with a single risk estimate resulting. In some cases a range of values may be used for each input parameter, providing a range of risk estimates, reflecting, for example, typical and reasonable maximum exposure. This approach can provide some understanding of the sensitivity of the final risk estimates to various input parameters.

The use of point estimates is a simplification as many of the input parameters used in risk assessment are either:

- uncertain, due to a lack of information

- or variable, that is the parameters vary between each of the individuals that may be exposed, e.g. body weight.

The use of point estimates has an important role in the development of conservative, generic criteria. However, it has been criticised as the combined effect of a series of conservative assumptions can result in an unrealistically conservative final risk estimate. Further, the use of point estimates means that the risk assessor and risk manager may not be able to determine how conservative the final risk estimate is, limiting the consideration of uncertainty in risk management.

Probabilistic risk assessment techniques provide a tool to account for uncertainty and variably in input parameters, allowing understanding of the level of conservatism associated with the final risk estimate.

Probabilistic risk assessment techniques, such as Monte Carlo analysis, involve:

- assigning a probability distribution to each of the input variables (where possible), such as body weight, inhalation rate, soil ingestion rate. The probability distribution may reflect the actual distribution of a parameter, say, through the community (e.g. body weight) or may reflect the range of possible values of a parameter for which there is a lack of reliable information (e.g. adult soil ingestion rate)
- combining each of the input distributions, in accordance with the normal risk assessment equations, by selecting values at random from each of the input distributions, determining the risk estimate for that combination, then repeating the process sufficient times for a reliable output distribution to be established.

The output, or risk estimate distribution, can be used to assist in risk management decisions. The presentation of risk estimates as a probability distribution allows risk managers to consider the proportion of the population that may be exposed to a given level of risk.

6.4.3 Detailed fate and transport modelling

Fate and transport modelling is an essential element of risk assessment, where consideration is given to:

- cross-media transfer of contaminants
- exposure at points remote from the source or point at which measurements have been taken
- future migration of contaminants and exposure of people not currently exposed.

The derivation of the Tier 1 acceptance criteria incorporates screening level fate and transport modelling. More complex, and potentially realistic, modelling can be undertaken in many circumstances, but detailed, site-specific information is required in order to realise the benefits of the additional complexity. In particular, many detailed fate and transport models require careful calibration which can only be undertaken on a site-specific basis.

Fate and transport modelling conducted in support of Tier 2 and Tier 3 assessments should give particular consideration to the presence and impact of preferential pathways for transport of contaminants. Preferential pathways have a major impact on the transport of contaminants, and where significant, must be incorporated in the adopted fate and transport model. The presence of preferential pathways can affect the selection of fate and transport modelling software; more complex models being required to assess the impact of such pathways.

6.4.3.1 Groundwater fate and transport

Groundwater fate and transport modelling can be undertaken on a wide range of levels, from screening level one-dimensional modelling, as used for the derivation of Tier 1 generic acceptance criteria, to simple two-dimensional modelling possibly incorporated as part of a Tier 2 assessment, and complex two- or three-dimensional modelling as part of a Tier 3 assessment.

The level of groundwater fate and transport modelling warranted at a particular site depends heavily on the quality of the data available to describe conditions at the site.

The groundwater fate and transport modelling process may be outlined as follows:

1. Define the objectives of the model.
2. Build a conceptual model of the hydrogeological system at the site.
3. Select an appropriate model type based on the conceptual model, the boundary conditions, soil and groundwater contaminant concentrations, the size of the source and the quality of the data available to support the model.
4. Design the quantitative model.
5. Calibrate the model (required for Tier 2 and 3 assessments).
6. Complete a sensitivity analysis to define the important input parameters and determine the robustness of the model predictions. (Experience indicates biodegradation rates are important and related to DO levels and the hydraulic conductivity, two significant parameters).
7. Use the model to predict the contaminant fate and transport.
8. Verify the model predictions regarding contaminant transport with time by comparison with further monitoring results (likely to be confined to Tier 3 assessments).
9. Report the results.

Most groundwater fate and transport modelling incorporates conventional hydrogeological flow modelling, while modelling of other fate and transport process can be overlain on the basic flow prediction. Justification of the model may range from provision of supporting information for the selection of input parameters, through to calibration and verification of the model against the piezometric surface and measured contaminant concentrations.

Consideration of groundwater contamination as part of the Tier 1 assessment is based on comparison of measured contaminant concentrations with generic criteria developed using screening level, one-dimensional fate and transport modelling.

A Tier 2 assessment may include the assessment of the groundwater impacts using site-specific information to carry out either, one-dimensional analytical evaluations or simple two-dimensional numerical modelling.

One-dimensional analytical evaluations would include consideration of the following dissolved phase, fate and transport processes:

- advection
- dispersion
- adsorption

- diffusion
- biodegradation (if reliable data are available to substantiate its inclusion).

The Air Force Centre for Environmental Excellence, Brooks AFB, Texas, has developed BIOSCREEN, a screening tool for simulating natural attenuation of dissolved hydrocarbons at petroleum sites. The analytical model is based on the Domenico analytical solute transport model which simulates the following processes:

- advection
- dispersion
- adsorption
- aerobic degradation
- anaerobic degradation.

The model will predict the maximum extent of plume migration which can then be compared to the distance to potential points of exposure.

Apart from the use of analytical solutions, numerical two- and three- dimensional models available for use, include:

- **MODFLOW coupled with MT3D**

  MODFLOW is a finite difference, porous media, groundwater flow model that is able to account for flow in two and three dimensions, under both steady state and transient conditions. MODFLOW has been developed by the US Geological Survey. MT3D, developed by S.S. Papadopulos, is used with any block-centred finite difference flow model and is often linked with MODFLOW for the evaluation of the fate and transport of the contaminant of concern. MT3D is a three-dimensional, finite difference model, based on the Eulerian-Lagrangian solution of the advective-dispersive-reactive transport. The model accounts for advection, dispersion and some simple chemical reactions.

- **BIOPLUME (Rice University)**

  BIOPLUME is a two-dimensional, finite difference model for flow and transport of dissolved hydrocarbons. The model considers convection, dispersion, mixing, and oxygen-limited biodegradation.

- **ARMOS (ES&T)**

  ARMOS is a two-dimensional, finite element model for flow and light separate phase hydrocarbons.

- **ASM (University of Kassel)**

  ASM is a two-dimensional, finite difference, flow and transport model. Flow processes considered include, steady state and transient considerations, unconfined, confined and leaky aquifer systems and the inclusion of sources and sinks. The solute is considered on a simplified manner using pathlines.

Each of the models listed above has differing capabilities, particularly with respect to the definition of the physical system (both groundwater and solute). The level of sophistication warranted in modelling is directly proportional to the quality of data available at a particular site, for space and for time.

The groundwater fate and transport models listed above can also incorporate the results of the unsaturated zone models, such as VLEACH (USEPA) and CHEMFLOW (USEPA), which can be used to predict the leaching of contaminants from soil.

In addition, a number of risk assessment software packages, for example the American Petroleum Institute's Decision Support System (DSS, incorporating AT123D) and BP Oil's, RISC model (incorporating VADSAT), include groundwater fate and transport sub-models that may be of use in a Tier 2 assessment.

Whether one-dimensional or two-dimensional modelling is used as the basis for the Tier 2 assessment, some model calibration is required.

A Tier 3 assessment may be based on use of a two-dimensional fate and transport model, such as those listed above, or one of a range of highly complex two- and three-dimensional fate and transport models. The level of modelling undertaken as part of a Tier 3 assessment depends on the complexity of the system to be modelled, the quality of the available data and the objectives of the overall modelling exercise (e.g. the level of accuracy required).

Normally a Tier 3 assessment would involve both calibration and verification of the model.

6.4.3.2 Volatilisation

Relatively few detailed, unsaturated zone, fate and transport models able to predict volatilisation of contaminants under a range of conditions e.g. from groundwater and soil, through various soil types and to outdoor or indoor air, are available.

Some examples are as follows:

- The RISC model developed by BP Oil (US) incorporates some fate and transport modelling, and accounts for some processes not considered in the simplified models used for derivation of the Tier 1 criteria. In particular, RISC incorporates a fully-transient volatilisation model which accounts for the attenuation provided by overlying soil, and the delay between release of the contaminant and establishment of the peak indoor and outdoor air concentrations.
- RBCA implementation tools developed by Groundwater Services International (GSI).
- MEPAS developed by Battelle.
- The Decision Support System (DSS) developed by the American Petroleum Institute.
- VADSAT (also incorporated in RISC), developed by EST Inc.

In addition, a number of models have been published in the scientific literature; some of which are incorporated in the computer-based models listed above. Examples include:

- Jury, Spencer and Farmer 1983,
- Hwang and Falco 1986,
- Johnson and Ettinger 1991.

To date, little work has been completed with the aim of validating the predictions of the volatilisation models. Considerable research aimed at refining the models continues, particularly in relation to methods for considering biological degradation in the unsaturated zone and its impact on emission fluxes. In general, volatilisation models are regarded as conservative, i.e. likely to over-predict emission rates, resulting in relatively low soil acceptance criteria in some circumstances.

6.5 Developing ecologically-based acceptance criteria

The requirements and general approach for the development of ecologically-based acceptance criteria are discussed. The assessment of ecological impact is complex and therefore the methodology to be used should be selected on a site- and project-specific basis.

6.5.1 General

Soil and groundwater contamination may result in adverse health and environmental effects. Where significant contamination occurs, the potential exists for off-site environmental impacts, particularly for large sites or where a site is located within or adjacent to a sensitive ecosystem (e.g. wetlands).

Most petroleum contaminated sites are located within an urban or developed environment, and so the generic Tier 1 soil acceptance criteria include only limited consideration of ecological concerns. This approach is consistent with protection of likely future use of petroleum sites, e.g. the primary ecological concern in a residential context is the support of plant life for domestic gardens.

Due to uncertainty of the impact of petroleum contamination on the terrestrial environment, Tier 1 soil acceptance criteria based on ecological protection have not been nominated. Rather the Tier 1 ecological assessment is based on the identification of:

- sensitive ecological receptors
- complete exposure pathways.

A checklist to assist in this process is presented in Appendix 4I. Tier 1 soil acceptance criteria based on the soil to groundwater pathway and the Tier 1 groundwater acceptance criteria for the protection of aquatic ecosystems may be useful as part of the Tier 1 ecological assessment.

Where off site ecological effects may be significant, more detailed consideration may be warranted.

Agreed approaches for the assessment of ecological risk are yet to be established in New Zealand although information is available from a range of international approaches. As with the health risk assessment of soil contamination, a tiered approach is proposed. No distinction is made between different land uses. Land use may influence the selection of ecological receptors to be protected (e.g. protection of on site terrestrial receptors may not be required in an industrial context), however the approach for assessing impact on the selected receptors is independent of land use.

The proposed approach to ecological risk assessment is outlined as follows:

Tier 1

Identification of possible sensitive ecological receptors and review of exposure pathways to determine relevance and completeness. A checklist has been prepared to assist with this process (refer Appendix 4I). Where sensitive ecological receptors are identified and exposure pathways may be complete, a Tier 2 assessment may be warranted.

Tier 2

A Tier 2 assessment of ecological risk may, in the first instance, involve comparison of contaminant concentrations (estimated or measured) at or near the likely point of impact with soil screening criteria based on a standard methodology and No Observable Adverse Effect Level/Concentration (NOAEL/NOAEC) or similar data. Three approaches for deriving such criteria may be considered; the modified USEPA method, the Canadian approach and the Dutch methodology. These approaches are:

- simplified and based on conservative assumptions
- largely descriptive and qualitative
- based on look-up tables for soil screening criteria
- draw on published information
- assess at a species level.

However, the assessment of ecological risk based on generic screening level criteria has been criticised as being overly conservative.

The development of site-specific ecological soil screening criteria may be considered as an extension of the above approach where the species and media of concern are selected based on site-specific information. This particular approach is:

- semi-quantitative
- uses standard ecological risk assessment methods and models
- has greater emphasis on data collection, focussing on the key issues raised by the Tier 1 assessment
- still assesses largely at a species level.

Tier 3

A Tier 3 assessment involves a fully detailed, site-specific assessment of ecological impact, including:

- considering detailed site-specific data
- predictive fate, transport and exposure modelling
- quantitative information on complex ecosystem responses
- considering complex assessment issues such as chronic effects, interaction between chemicals, interaction between ecosystem levels, and food chain impacts.

An important distinction between the health and ecological risk assessment methodologies is that the health risk assessment focuses on the protection of the individual, whereas the ecological risk assessment focuses on the assessment of impacts in populations.

Further, when assessing possible ecological effects of a given contaminant, consideration must be given to background soil concentrations. It is assumed that the local ecosystem is sustainable at the natural background levels of contaminants in soil and therefore clean-up below background concentrations is not required.

The development of site-specific ecologically based acceptance criteria requires detailed consideration of the affected ecosystem, the value assigned to the ecosystem, and the point at which a given level of protection is to be achieved.

The first step in an ecological risk assessment involves establishment of the project objectives in order that the assessment may be properly focussed. These could be:

- definition of the ecosystem to be considered
- the value and function of the ecosystem (e.g. harbour area allowing passage of fish, or pristine ecosystem preserved as a nation resource)

- the level of protection to be afforded (high level of protection consistent with maintenance of a pristine ecosystem, or minor impacts are tolerable).

The definition of the project objectives allows the direction and level of detail of the ecological risk assessment to be appropriately focussed.

For example, at most sites sufficiently contaminated to warrant a Tier 3 ecological assessment, the on-site ecosystem will be highly modified as a result of general development, rather than simply as a result of the contamination. In such circumstances, it may be appropriate to afford a relatively low level of protection to the on-site ecosystem, consistent with the proposed use (e.g. survival of plants would be required in a residential context), while providing a much higher level of protection to the off-site environment. In particular, specific consideration should be given to possible impacts on nearby surface water bodies.

Deriving Tier 3 ecologically-based criteria must involve:

- detailed site-specific consideration of nature, extent and distribution of contaminants
- detailed predictive fate and transport modelling, to understand possible transport of contaminants, the ecosystems that may be impacted and the likely contaminant concentrations within the impacted ecosystems
- site-specific assessment of the ecosystems impacted, including consideration of the species present and the interaction between various species
- consideration of possible food-chain effects
- detailed consideration of the levels at which onset of chronic effects, particularly sub-lethal effects occur. This may involve some site-specific test work
- assessment of background contaminant concentration and other stresses on the ecosystem.

6.5.2 Fate and transport modelling

As outlined in Section 6.4.3, fate and transport modelling is an essential element of risk assessment, including ecological risk assessment, given that the ecosystem requiring protection is frequently located off-site, remote from the point of contaminant release.

Some important considerations in fate and transport modelling for ecological risk assessment include:

- the nature, extent, level and spatial distribution of contamination
- background contaminant concentrations
- soil type and physicochemical properties that may affect attenuation of contaminants, or other processes such as erosion
- contaminant plume movement (whether the dissolved phase hydrocarbon plume is increasing, decreasing or stable)
- microbiological activity, and likely degradation rates
- aquifer properties and discharge points
- potential for erosion of contaminated soil.

The fate and transport modelling can also be extended (following the assessment of the ecosystem) to account for accumulation and transfer of contaminants through the ecosystem, including consideration of food chain effects.

6.5.3 Assessment of the ecosystem

For each of the ecosystems potentially affected, it is important to develop an understanding of the composition and functioning of the ecosystem on a number of levels. Important considerations include:

- identification of key species for a range of taxonomic groups e.g. earthworms, terrestrial plants, birds
- interaction between the species in the ecosystem, both in terms of food chain and other system functions.

It is important to build a conceptual model of the ecosystem, enabling the impact of stresses on any one part of the ecosystem to be evaluated in terms of its impact on the wider ecosystem. For example, in an aquatic environment a particular species may perform a physical support function, which if compromised could result in an impact on the physical structure of the ecosystem.

6.5.4 Assessment of impact of contaminants

Depending on the species impacted and the cost-benefit relationship, it may be appropriate to undertake controlled sensitivity and uptake trials using key species identified as part of a Tier 3 assessment.

Such information may then be used to undertake predictive modelling of population and community changes at an ecosystem level, with the aim of developing a quantitative understanding of the impact of contaminants on the overall ecosystem.

6.6 References and further reading

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Ministry for the
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Manatū Mō Te Taiao

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

MODULE 7
Site management

August 1999

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7 Site management

This module provides an overview of the options available for site control, management and remediation of petroleum hydrocarbon contaminated sites and the basis for choosing various options. The module also presents guidance on managing environmental issues during underground storage tank (UST) and underground petroleum equipment removal and replacement. A discussion of the current legislation that governs the management of contaminated sites and potential future changes to relevant legislation is provided. In addition, various readily available remedial technologies are described. Advantages and disadvantages of each technology are presented.

Section 7.1 discusses the goals of site management and presents the factors that govern the decision process in determining the level of management required at a site. The current legislation governing contaminated sites is summarised in Section 7.2. The remaining subsections outline specific actions, management practices and technologies available to mitigate a site. Site management techniques such as natural attenuation, land use restrictions, access restrictions, and monitoring are discussed in Section 7.3. Management of environmental issues during UST and underground petroleum equipment removal and replacement are also discussed in Section 7.3. Containment options are discussed in Section 7.4. Both in situ and above ground technologies for remediating contaminated soils are discussed in Section 7.5. Groundwater remediation technologies, including product recovery, are discussed in Section 7.6. Disposal options for contaminated soil and groundwater are discussed in Section 7.7. References for this module are provided in Section 7.8. Comment on issues associated with the management of liquid phase hydrocarbons is given in Section 4.1.1.

7.1 Introduction

This section discusses the goal of site management, the options available for achieving the goals and the basis for choosing various options.

The fundamental goal of a site management strategy must be to render the site acceptable and safe for the long term. This is the approach embodied in the Australian and New Zealand Environment and Conservation Council (ANZECC) and National Health Medical Research Council (NHMRC) contaminated sites guidelines (ANZECC/NHMRC, 1992). Where human health is deemed to be at risk, or the off-site environment is likely to suffer significant adverse impact, a site should be cleaned up to the extent necessary to minimise such risks in both the short and long terms.

However, in cases where there is no threat, or an acceptable threat, to human health or the environment, it may well be acceptable to devise a strategy whereby the contaminants are contained on site, or planning controls are used to limit the use of the site. There are a large number of options potentially available to manage contaminated sites to achieve these goals.

Once the site investigations and Tier 1 or Tier 2 assessments have been carried out (see Modules 3-6) there will be a body of data available on which to make decisions regarding the level of management, if any, required at the site. The site investigation and risk assessment data will also be used to determine the type of technology that would be the most cost-effective in achieving the management goals. The decision on which approach to take will be governed by multiple factors, including:

- the nature and degree of the contamination

- the intended future use of the site
- the proximity of receptors and the potential pathways to them
- the site characteristics, including geology and soil type, depth to groundwater
- size of the contaminated area
- potential for off site migration
- costs of management or control
- community concern considerations.

Site management options include:

- land use controls
- access restrictions
- management controls
- containment
- remedial treatment systems
- disposal
- monitoring.

In all cases, it will be necessary to ensure that the required consents and approvals are held prior to implementing the management scheme. A discussion of the current legislation governing contaminated sites in New Zealand is given in Section 7.2, and possible resource consent requirements can be found in the discussion of each site management option.

7.2 Legislation

This section provides an overview of the legislation governing the management of contaminated sites in New Zealand.

7.2.1 The Resource Management Act 1991

The purpose of the Resource Management Act 1991(RMA) is to promote the sustainable management of natural and physical resources. The RMA is the principal statute for the management of land, air, water, soil resources, subdivision of land, the coast, and pollution control. It clearly sets out the resource management responsibilities of individuals, territorial authorities, regional councils and the Government. It sets up a system of policy and plan preparation and administration, including the granting of resource consents which allows the balancing of a wide range of interests and values.

The provisions of the RMA relating to discharges to land, air and water, and the control of the use of land, are of most relevance in managing contaminated sites. Section 30 of the RMA requires regional councils to control discharges of contaminants into or onto land, air or water. They must also control the use of land in order to prevent, or mitigate the adverse effects of the storage, use, disposal, or transportation of hazardous substances.

Section 31 of the RMA requires territorial authorities to control any actual or potential effects of the use, development, or protection of land, which includes preventing or mitigating of any adverse effects of the storage, use, disposal, or transportation of hazardous substances.

7.2.1.1 Resource consent requirements

A number of resource consents may be required for the management of a contaminated site. They include:

- a discharge consent from the regional council for discharges into or onto land, air or water
- a land use consent from the territorial authority.

Resource consents may be necessary to undertake various steps in the site assessment and management process. It is important to contact the regional council and the territorial authority to determine what their particular requirements are, as these may vary throughout the country.

7.2.2 The Health Act 1956

Sections 29 to 35 of the Health Act 1956provide that in certain cases where a nuisance is being caused within the meaning of the Act, an owner or occupier of the premises can be required to abate the nuisance. The primary responsibility for enforcing these provisions rests with the territorial local authority. In the event that the person creating the nuisance fails to comply with an abatement request there are legal remedies available.

A prosecution may be taken for a failure to abate a nuisance. The prosecution may result in an order from a District Court judge requiring an owner or occupier of the premises to abate the nuisance effectively; prohibit the recurrence of the nuisance; both abate and prohibit the recurrence of the nuisance; or to carry out specified works to abate or prevent a recurrence of the nuisance.

If there is default in complying with an order, the territorial local authority, or the Medical Officer of Health on behalf of the territorial local authority and the Ministry of Health, may carry out any works at the expense of the owner and occupier. The costs are deemed to be a charge on the land.

In instances where immediate action for the abatement of a nuisance is necessary in the opinion of the Engineer or Environmental Health Officer of a territorial local authority, those officers may, without notice to the occupier, enter the premises and abate the nuisance. Any costs incurred are recoverable as a debt from the owner or occupier.

7.2.3 The Building Act 1991

The Building Act also addresses site contamination but only where there is an intention to carry out building work. The purpose of the Act is to provide controls relating to the building work and the use of buildings to ensure that buildings are safe and sanitary. Under the associated Building Code F1 *Hazardous Agents on Site*, the objective is to safeguard people from injury or illness caused by hazardous agents or contaminants on a site. There is a requirement that buildings shall be constructed to avoid the likelihood of people within being adversely affected by hazardous agents or contaminants on site. Code F1 requires that sites shall be assessed to determine the presence and potential threat of any hazardous agents or contaminants. The likely effect of these is to be determined taking account of:

- the intended use of the building
- the nature, potency or toxicity of the hazardous agent or contaminant, and
- the protection provided by the building envelope and building systems.

7.2.4 The Health and Safety in Employment Act 1992

The purpose of this Act is to prevent harm to employees and other people (e.g. visitors, contractors) while they are on a work site. All organisations are required to comply with the minimum standards outlined in the Act. To do this, employers need to take all practicable steps to maintain a safe working environment. This includes:

- minimisation, isolation or elimination of hazards (or potential hazards)
- training of staff in safe work practices
- ensuring employees are not exposed to hazards in the course of their work
- informing staff of what to do in an emergency.

Employees are also encouraged to be responsible and look after their own and others safety and health at work. Ways of doing this include:

- observing safe work practices in carrying out their duties
- following instructions given to them by their managers
- being responsible for their own and others' safety and health at work.

7.2.5 Hazardous Substances and New Organisms Act

The Hazardous Substances and New Organisms Act 1996 (HSNO) pulls together the management of hazardous substances into one law that focuses on all of their hazards - to both humans and the environment. HSNO establishes a consistent process for assessing the risk posed by hazardous substances and setting national controls to manage their environmental effects and risks.

The Environmental Protection Authority (EPA) is an independent body established under the Environmental Protection Authority Act 2011, and is responsible for regulating hazardous substances and chemicals under the HSNO Act. The EPA replaces the Environmental Management Risk Authority that was originally established under HSNO.

Both HSNO and the RMA work together to protect human health and the environment from the effects of hazardous substances. Where HSNO sets controls on a national level in recognition of the inherent hazard of certain substances, the RMA controls are set through the local planning process so differences in the sensitivity of the local environment and community needs can be taken into account.

7.3 Site management

The primary goal of site management is to control site operations and use until such time as an acceptable risk level is reached. Long-term site management options include natural attenuation, access and land use restrictions and/or monitoring. During UST and underground equipment removal and replacement, site operations need to be controlled to mitigate potential impacts from contamination and other on-site activities.

Where a risk management approach is adopted, it may be necessary to prepare a site management plan designed to control site operations and use until such time as an acceptable risk level is reached. The timeframe depends on the type of technology used to remediate the site. The primary purpose of the plan is to ensure that exposure pathways are minimised in the short and long term. A site management plan should include the following elements:

- description of the site characteristics
- description of the contaminant source and characteristics
- description of the potential adverse impact, receptors and pathways
- details of the risk management scheme to be implemented (or in place)
- methods of monitoring the performance of the management technique
- methods for ensuring the management technique is enforced for the period required
- details of an emergency response action plan (including parties to be notified and up-to-date phone numbers) to be implemented if system failure is detected
- consultation procedures with the regulatory authorities
- safety measures required if site works are to be undertaken.

Where a site management plan is in place, or some form of long-term risk management process has been implemented, it is important to ensure that the site is not disturbed or used inappropriately in the future such that the site user, or the environment, is put at risk.

During UST and underground equipment removal and replacement risk management processes and procedures may need to be implemented to manage potential environmental and health and safety risks that may arise during these works. Management options are discussed in Section 7.3.1.

The methods for achieving long-term control of a site can include natural attenuation, land use controls, access restrictions, and monitoring. These options are discussed in Sections 7.3.2 - 7.3.5.

7.3.1 UST and underground petroleum equipment removal and replacement

During the removal and replacement of petroleum storage and dispensing equipment it may, depending on the scale and nature of the works, be necessary to develop an environmental management plan (EMP) to manage potential environmental effects. This section presents typical management practices that should be followed during petroleum storage and dispensing equipment removal and replacement works and that can be incorporated into a site specific EMP, if required.

For the purpose of this guidance petroleum storage and dispensing equipment is considered to comprise:

1. underground petroleum storage system (UPSS) equipment (USTs, below ground lines and fill points) on service stations, commercial sites and production land
2. above ground petroleum storage tanks (typically less than 100m^3 capacity) and below ground lines on service stations, commercial sites and production land.

The guidance presented could be applied to tank removal and replacement works undertaken on bulk storage facilities; however, given the larger scale and nature of these facilities additional controls may be required.

UPSS equipment and above ground tank and line removal and replacement works typically comprises:

- removal of above ground dispensing equipment
- concrete breaking, excavation, exposure and removal of the below ground equipment (USTs lines, fill points)
- removal of above ground tanks
- removal of petroleum equipment from site for off-site disposal
- excavation of line trench and UST pit bedding materials and possibly natural soils (some of which may be impacted with petroleum hydrocarbons)
- possible removal of perched groundwater and LNAPL from excavations
- soil contamination benchmarking within UST pits, line trench excavations and other excavations
- installation of new UPSS and above ground equipment (if replacement work is being undertaken)
- backfilling excavated voids, re-surfacing and recommissioning (if replacement work is being undertaken).

All works should be undertaken to minimise impacts on the environment and comply with relevant legislative requirements, licences, approvals and notices.

The following sections outline key environmental management practices that should be adopted during petroleum equipment removal and replacement.

7.3.1.1 Petroleum storage and dispensing equipment removal and replacement

The petroleum equipment elements must be removed by an appropriately licensed contractor and in accordance with the Code of Practice for the Design, Installation and Operation of Underground Petroleum Storage Systems (Department of Labour 1992), HSNO, Health and Safety in Employment Act 1992, and any other regional/local rules and regulations.

Following removal of the petroleum equipment, the environmental consultant (or similar) should visually inspect tanks, pipework etc. for any defects which may indicate potential loss of containment and record this information.

The petroleum equipment, particularly the USTs, must be removed and transported off-site as soon as practical for disposal/destruction by an appropriately licensed contractor. Off-site transport and disposal must be undertaken in accordance with the Code of Practice for the Transport and Disposal of Petroleum Tanks and Related Wastes (Department of Labour, 1995) and HSNO.

7.3.1.2 Soil removal and management

During removal of the petroleum equipment it may be necessary to excavate and remove bedding material and hydrocarbon impacted soils from the site. Significantly impacted soil should, wherever possible, be removed from the site, particularly where these soils are likely to exceed the Tier 1 soil guideline values given in Module 4.

Typical soil removal volumes at service stations and commercial sites range between 5m3 to 100m3. Larger volumes sometimes require removal where there has been some form of significant fuel loss at the site or where the soils cannot be placed back in excavated voids because of their poor engineering characteristics.

Soils and bedding materials removed from site must be disposed of to a facility consented to receive such wastes. Each disposal facility is likely to have different rules controlling the disposal of uncontaminated and contaminated soils and these should be established before beginning the removal works. Controls may include:

- sampling and laboratory analyses of representative samples of soil to be disposed
- comparison of analytical results with relevant facility limits
- completion of waste manifest forms to document the soil chain of custody and final disposal location.

It is not anticipated that any excavated materials would be re-used on site; however, should non-impacted soil or bedding material be re-used as backfill this should be benchmarked before being placed in any excavation by the environmental consultant.

During the petroleum equipment removal works, it may be necessary for excavated soil to be temporarily stockpiled on-site before off-site removal. In the event material is temporarily stockpiled on-site, stockpiles should be:

- managed in a manner protective of on-site workers, the public and off-site migration pathways (such as stormwater drains)
- located on concrete hard standing or if necessary sheeted/covered
- kept tidy, less than 4 m in height and with a stable slope.

Stockpiles are generally short term and tend to be removed off-site on the same day or the day following excavation. Where necessary (e.g. for long term stockpiles) hay bales or similar forms of silt containment should be placed around the stockpiled soil and stormwater drains/grates to help prevent surface run-off. The stockpile area should be fenced to prevent public or unauthorised access. Where stockpiled material is odorous, it should be covered with an impermeable material or other form of odour suppression (e.g. application of odour suppressant compounds) to limit the potential release of odours/vapours.

Soils and fill imported to site to backfill excavated voids should comprise clean/uncontaminated materials. The source of imported materials and the volume imported should be documented.

All trucks transporting soils materials to and from site should be covered and vehicles adequately cleaned.

7.3.1.3 Soil benchmarking

Site contamination condition should be benchmarked at the completion of the petroleum equipment removal by sampling from the excavations and the soil results compared to the Tier 1 values presented in Module 4 to determine if further investigation or remedial works are required. The work should be performed by a suitably qualified person, such as an environmental consultant.

The soil sampling exercise should be undertaken in accordance with Module 3 and in particular (and as a minimum) the sampling regime given in Table 3.2. The soil testing should be undertaken in accordance with the Draft Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water (Oil Industry Environmental Working Group, 1999).

The results of the soil benchmarking work and oversight of the petroleum equipment removal by the environmental consultant (or similar) should be documented in accordance with Contaminated Land Management Guideline No. 1 – Reporting on Contaminated Sites in New Zealand (MfE, 2003), in particular the MfE Checklist for the Removal of Petroleum Underground Storage Tanks.

7.3.1.4 Liquid management

During the petroleum equipment removal and replacement works surface water (i.e. stormwater) should be diverted away from excavations and soil stockpiles.

Where groundwater is encountered in excavations during UPSS removal this groundwater is generally not removed. If the UPSS is being replaced and a high groundwater table exists then specific measures and controls should be used to manage excavation stability and pit dewatering. Dewatering may require a resource consent.

Shallow perched groundwater and stormwater may collect in open excavations. If this water is potentially impacted with petroleum hydrocarbons (or other contaminants) and needs to be removed from site, then care needs to be exercised to remove the water and the water should be disposed of to a licensed waste disposal facility. If LNAPL is encountered during petroleum equipment removal then every effort should be made to remove the LNAPL and this should be disposed of to an approved licensed waste disposal facility. The presence of perched water and LNAPL should be recorded by the environmental consultant. Records on the quantity of water and LNAPL removed from site should be documented in the UST removal/environmental benchmark report (see above).

7.3.1.5 Air quality management

The primary sources of potential hydrocarbon odour may be associated with hydrocarbon vapours released from any on-site degassing of petrol USTs, the walls and floors of open excavations and from soil stockpiles where potentially hydrocarbon impacted soil is exposed. Actual vapour concentrations are dependent on site conditions and activities. Air emission and odour controls can be used to limit the potential flammability/explosion risks and mitigate odour nuisance. Vapour levels should be monitored by on-site contractors to identify and manage any potential hazards.

If considered necessary, the following vapour/odour management procedures could be used:

- undertaking excavation works in a staged manner to limit the exposed surface area of potentially odorous material
- wetting-down of excavations
- application of odour suppressants
- covering any portion of the site that is generating odour

- covering stockpiled soil with sheeting to suppress the potential release of odours
- routinely backfilling excavations.

Petroleum equipment removal and replacement work is generally short duration work and any odour effects will be in temporary.

7.3.1.6 Dust management

Excavation and stockpiling of soils and on-site vehicle movements may generate dust and where appropriate, the generation and impact of dust on the surrounding environment can be minimised by:

- suspending or limiting dust generating activities during periods of high wind
- using water on exposed soils to suppress dust, ensuring that any water used is not allowed to migrate off-site by the stormwater, sewer, or any other means
- covering areas of exposed soil with sheeting
- ensuring trucks transporting soils material to and from site and removing soils are covered and that vehicles are adequately cleaned.

7.3.2 Natural attenuation

Natural attenuation, also referred to as intrinsic bioattenuation, relies on the natural processes of biological degradation, volatilisation, adsorption, and dispersion, which naturally occur at a site, to reduce the level of contamination in the soil and groundwater. In the absence of human intervention, many contaminant plumes will develop until they reach a quasi-steady-state. At steady-state, the contaminant plume is no longer growing and may shrink somewhat over time. Major processes controlling the size of the steady-state plume include:

- release of dissolved contaminants from the source area
- downgradient transport of the contaminants and mixing with uncontaminated groundwater
- volatilisation
- abiotic and biologically mediated transformation of the contaminants of concern.

Soluble components of petroleum products are easily attenuated in most aquifer systems. Benzene, one of the more mobile and carcinogenic components in petrol and diesel, is easily biodegraded in a well-oxygenated groundwater. Typically, dissolved oxygen concentrations of greater than 1 mg/l are required to allow bioremediation of benzene and other petroleum compounds.

Periodic monitoring is recommended to assess the continued effectiveness of natural attenuation. Refer to American Petroleum Institute document on natural attenuation (No. 1628) and ASTM Standard E1739.

Possible resource consent requirements:

- air discharge consent for vapours and odours
- consent for discharges to stormwater and groundwater.

Advantages	Cost-effective. Substantial scientific information available to allow well-founded assessment of viability of natural attenuation.
Disadvantages	May require long-term monitoring. Future land use and use of underlying groundwater may be constrained.
Suitability	No limitations on soil types or hydrocarbons, provided the exposure potential is shown to be acceptable.

7.3.3 Land use controls

Controlling the future use of a site to permit only less sensitive uses is a way of avoiding or reducing exposure to contaminants, and therefore allows higher contaminant concentrations to remain on site, e.g. redevelopment of a site for commercial use rather than residential use. If significant contamination is allowed to remain on site, it must be shown that the contamination will not cause an unacceptable risk to human health and the environment. The land use controls mechanisms available include:

Land Information Memoranda & Project Information Memoranda	Land Information Memoranda, issued under the Local Government Official Information and Meetings Act 1987, and Project Information Memoranda, issued under the Building Act 1991, can be used to release information on site contamination to interested parties.
District plan	Structures or activities such as basements or pools, or their construction, can be controlled using the district plan.
Memorandum of encumbrance	The memorandum creates a nominal mortgage in favour of the local authority and can be made binding on successors in title. It acts as a notification to those searching the title prior to purchase. The memorandum can be used as a condition of a resource consent.
Notation on a district plan	A notation can be placed on the district plan identifying a site as being contaminated. This can be initiated by an individual, company or council.

Another mechanism which is being considered is the use of notation on title, where a notation could be placed against the land title to identify the presence of contamination or to restrict the land use. No decision had been made by the government on this issue at the time this document was completed.

7.3.4 Access restrictions

Access restrictions such as fencing and restrictions on groundwater use are used to minimise potential exposure to a contaminated media. Fencing is used to limit exposure to soil or surface water by sensitive populations such as children and animals. Restrictions on groundwater could be used if a contaminated plume is migrating off site and affecting off-site potable supply wells. Another option for restricting access to impacted groundwater is to provide an alternative water supply to groundwater users. Providing an alternative water supply could involve periodic delivery of bottled or tankered water to be stored on site or constructing a water supply line from an uncontaminated supply well.

7.3.5 Groundwater monitoring

Groundwater monitoring, as part of a management strategy, is recommended if groundwater is or has the potential to be impacted. The objectives of the monitoring programme are to monitor the effectiveness of the management scheme, whether it is natural attenuation or active remediation, and provide assurance that the predictions regarding the fate and transport of the contamination are accurate.

It is recommended that a groundwater monitoring programme include a monitoring well installed upgradient of the site and two or three monitoring wells installed downgradient of the potential source(s) of groundwater contamination. At least one downgradient well can be located outside the contaminant plume to detect migration of the plume. See Section 3.4.6 of Module 3 for descriptions of monitoring wells.

It is suggested that monitoring wells should be sampled quarterly for the first year if contamination is present or groundwater elevations are expected to vary seasonally by more than 0.5 metre. If groundwater elevations are relatively stable, then semi-annual sampling for the first year is recommended. Yearly sampling after the first year is recommended until contaminant levels on the site reach acceptable levels. Note, however, that the monitoring frequency may be amended on the basis of site-specific factors.

The groundwater samples should be analysed for AVOCs if the source of contamination is petrol or diesel as discussed in Section 3.3 of Module 3. If the potential source of the contamination is suspected to be diesel, fuel oil, lubricating oils, bunker fuels, residential fuels, or crude oil, then the groundwater samples should be analysed for TPH. A percentage of the samples, say 10%, could also be analysed for PAHs. The compounds of key interest include BTEX, naphthalene, pyrene and benzo(a)pyrene as discussed in Module 4.

7.4 Containment

Containment at contaminated sites is used to minimise the vertical and horizontal migration of constituents of concern and can be used to isolate the contamination from potential receptors. Containment can be an effective and acceptable site management option but may require long-term monitoring.

In theory, there is no limit to the contaminant concentrations which can be contained on a site provided the integrity of the containment technology can be maintained until contaminant concentrations are reduced to acceptable levels. Containment options for soil at petroleum sites can include dust control, vertical barriers, and asphalt or concrete capping. Containment options for groundwater can include maintaining hydraulic control at the site through groundwater extraction.

7.4.1 Dust control

Dust control measures are used to limit the potential for fugitive dust to migrate off site. Most often, this technology applies to stock piles of excavated material waiting treatment and/or disposal. Dust control can include spraying a contaminated area with water, covering with a high density plastic sheet, or applying a dust suppressant.

7.4.2 Vertical barriers

Vertical barriers, also referred to as cut-off walls, are used to prevent horizontal migration of contamination in either soil or groundwater. They are often used if a sensitive environment such as a stream, used for recreational purposes, is located downstream from a site. Vertical barriers are either comprised of a slurry wall, grout curtain or steel shoring and are most effective when an impermeable layer below the water table is available to key in to. A slurry wall consists of a trench downgradient or around the area of contamination that is filled with a soil (or cement) and bentonite slurry. To form a grout curtain, grout is injected into holes that are drilled in a regular pattern around the contamination (or just on the downstream side). A cut-off wall can also be comprised of interlocking steel shoring that is vibrated into place.

Possible resource consent requirements:

- earthworks consent
- consent to discharge contaminants to groundwater.

Advantages	A moderate cost option if the impermeable layer is at depths less than 10 - 15 metres from the ground surface. Can be used as an interim measure until land use changes.
Disadvantages	Future land use is severely constrained as any containment system must be maintained intact. Liability is not discharged but simply managed. Hydrocarbons are not destroyed but merely prevented from migrating. The long-term integrity of the containment materials is not proven.
Suitability	Not suitable at sites with impermeable layers deeper than 30 metres, or at sites with fractured impermeable layers, such as fractured bedrock or fractured greywacke.

7.4.3 Capping

Capping at petroleum contaminated sites is typically used to isolate the contaminated soil from potential receptors and limit infiltration of rainfall. Limiting infiltration reduces the potential for downward migration of the petroleum hydrocarbons in the soil to the groundwater. Capping also limits upwards migration of vapours.

The most cost-effective caps at petroleum sites are typically comprised of concrete or asphalt. These caps are easily implemented but can be susceptible to weathering and cracking. Other capping materials can include clay and high density polyethylene (HDPE) liners.

Capping can also trap vapours and direct them to areas such as basements. For this reason it may be necessary to consider putting in a venting system.

Possible resource consent requirements:

- consent to discharge contaminants to groundwater.

Advantages	A low-cost option for isolating contaminants and limiting vertical migration.
Disadvantages	Liability is not discharged but simply managed. Caps restrict future land uses. Hydrocarbons are not destroyed. Long-term maintenance required.
Suitability	Suitable at most sites that can be managed long-term. May not be suitable if the site is to be sold and redeveloped.

7.4.4 Hydraulic control

Containment options for groundwater are designed to prevent further migration of the contaminated plume. Plume containment options typically consist of numerous extraction wells strategically placed either within the plume or near the leading edge. The number of wells and spacing between wells needed to maintain capture are a function of the hydrologic properties of the aquifer. Aquifer testing should be performed to obtain site-specific hydrogeologic data prior to designing a well network. See Section 3.4.6 of Module 3 for brief descriptions of aquifer tests and the type of information obtained from each type of test. Hydraulic control is typically combined with an ex situ groundwater treatment option. Several groundwater treatment options for petroleum contaminated sites are discussed in Section 7.6.

7.5 Soil remediation

Soil remediation technologies are used to reduce the concentration of petroleum hydrocarbons in the subsurface to acceptable levels. Technologies can be implemented either in situ or ex situ. Five cost-effective technologies for remediating petroleum hydrocarbons in soils are described. In addition, their advantages and disadvantages, and suitability are discussed.

Cost-effective in situ technologies for remediating petroleum hydrocarbons in soils include soil vapour extraction (SVE), and bioventing. Cost-effective ex situ technologies for remediating petroleum hydrocarbons in soils include land farming, biopiles, and low-temperature thermal desorption. The five technologies discussed above are the most commonly used treatment technologies for petroleum contaminated sites. Other technologies, not discussed here, are available for remediating sites that have metals and/or chlorinated hydrocarbon contamination in addition to petroleum.

7.5.1 Soil vapour extraction

SVE is used to extract volatile and some semi-volatile organic compounds from unsaturated soils. This process is accomplished by reducing the pressure in the soil vapour space and mechanically drawing large volumes of air through the pores in the soil, which volatilises and strips the volatile and semi-volatile compounds from the soil matrix into the air stream. In this process, hydrocarbon vapours are removed from the soil through horizontal or vertical wells installed in the impacted area. The wells are perforated above the water table and a vacuum is applied to the wellhead to draw the hydrocarbon-laden vapours to the surface where they are discharged. The discharged air may require treatment prior to discharge depending on local regulations. One form of soil vapour extraction is shown in Figure 7.1.

SVE can also be used to volatilise free product from the water table. A vacuum is often applied to an existing groundwater monitoring well by connecting the well to a vacuum pump or blower. A moisture separator, also referred to as a knock-out drum, is installed before the blower to collect moisture that may damage the pump.

A low permeability cover (e.g. asphalt, concrete, or plastic sheeting covered with soil) may be installed to prevent short circuiting of air directly from the surface if the SVE wells are screened within 3 to 10 metres of the surface. Preventing short circuiting results in a larger radius of influence for each well, which decreases the number of wells needed to remediate the site.

There are many factors that influence the effectiveness of SVE systems, including vapour pressure and solubility of the contaminants present, soil moisture, temperature, air permeability of the soil, porosity, and stratigraphy. SVE is most effective with homogeneous, highly permeable soils contaminated with organic compounds that have vapour pressures greater than 1 mm mercury and Henry’s Law coefficient values greater than 0.01. Therefore, SVE is effective at sites with gasoline-contaminated soils. More polar compounds and higher molecular weight (greater than 16 carbons) hydrocarbons are not easily removed from the soil using SVE because they are less volatile and more readily sorbed by the soil. Therefore, SVE is generally not as effective at removing contaminants from sites impacted by diesel and fuel oil. However, the use of SVE usually leads to an increase in the oxygen concentrations in the subsurface; this in turn leads to a decrease in diesel and fuel oil concentrations through biological degradation mechanisms.

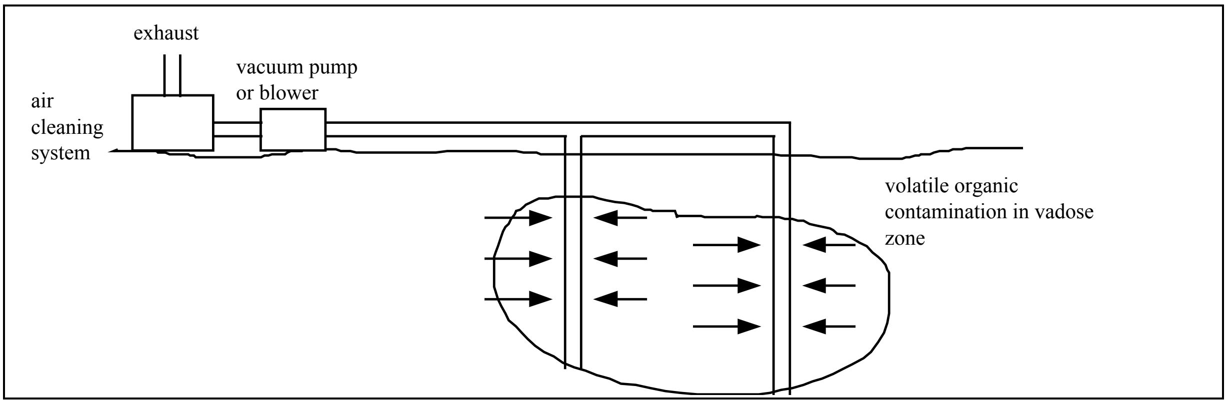

Figure 7.1 Soil vapour extraction

Possible resource consent requirements:

- air discharge consent for vapours and odours
- earthworks consent.

Advantages	Systems are generally easily installed and effective at petrol impacted sites. Can remediate petrol contamination in inaccessible locations (under building or roads). Can be used to remediate free product in existing monitoring wells. Some biodegradation of higher molecular weight hydrocarbons can occur during soil venting.
Disadvantages	Generates contaminated air which may require treatment.
Suitability	Best suited to moderate and high permeability soils contaminated with petrol.

7.5.2 Bioventing

Bioventing enhances natural biodegradation of petroleum hydrocarbons in the unsaturated zone by supplying oxygen to stimulate indigenous soil microorganisms. The micro-organisms aerobically metabolise middle and heavy distillate hydrocarbons into carbon dioxide and water. The stimulation is achieved by injecting air into horizontal or vertical vents installed in the contamination zone, as shown in Figure 7.2. It is usually not necessary to supply nutrients such as nitrogen because the availability of oxygen is typically the reaction rate limiting factor.

In general, bioventing has been found to result in some biodegradation at virtually all sites regardless of site conditions (Leeson et al, 1995). However, bioventing is most effective at sites with moderate to high permeability soils. Horizontal venting systems are effective where contamination is less than 4 metres deep. Typical degradation rates range from 5 to 20 mg/kg/day. Site clean-up averages 1 to 5 years (Miller et al, 1993). No secondary wastes or residuals are generated during the bioventing process.

Possible resource consent requirements:

- air discharge consent for vapours and odours
- earthworks consent.

Advantages	Easily installed, low-cost option that is effective for petrol, diesel and crude oils. Treatment can occur beneath buildings, roads and other surface features without disturbance.
Disadvantages	Timeframe for remediating moderately contaminated sites can take 1 to 5 years. Can result in increased emissions under buildings and into structures.
Suitability	Best suited to permeable soils such as sands and gravels.

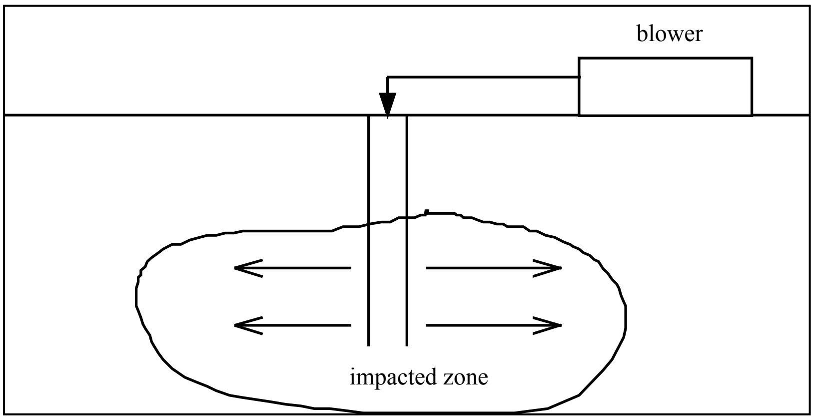

Figure 7.2 Bioventing

7.5.3 Land farming

Land farming is a biological treatment process that reduces the toxicity of organic constituents in soil by enhancing the natural microbial degradation process. For land farming, soil is excavated and place in 0.3 to 0.5 metre lifts on an engineered pad, as shown in Figure 7.3. The soil is periodically sprayed with a nutrient/water mixture, and tilled. Samples are taken to establish the success of the method until the concentrations of contaminants reach the desired clean-up level. Leachate from the spraying process and stormwater run-off are collected in a sump and reapplied over the soil lifts.

Land farming is typically an inexpensive option for remediating soils with petrol, diesel and waste oil, but requires a large area of land. Petrol is easily degraded and takes less time to achieve clean-up levels than diesel and waste oil. Typical clean-up times are three months to one year.

Possible resource consent requirements:

- land use consent
- consent to discharge contaminants to land
- earthworks consent
- air discharge consent for vapours and odours.

Advantages	Low-level technology. Relatively inexpensive depending on design of engineered pad. Proven effectiveness on a wide range of petroleum hydrocarbons.
Disadvantages	Requires a large land area. May need to consider managing odours.
Suitability	Works best on permeable soils, in moderate or warm temperatures.

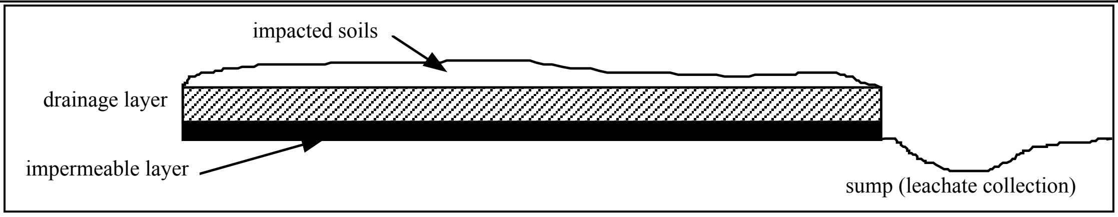

Figure 7.3 Land farming

7.5.4 Biopiles

Biotreatment cells (commonly referred to as biopiles) are designed to reduce the toxicity of organic constituents in soil through enhancing the natural microbial degradation process. Air is forced or pulled through a 2- to 3-metre high pile of impacted soil as shown in Figure 7.4. The biopile treatment process requires less land than land farming but is more capital intensive because perforated piping, a blower and possibly an air treatment system are required.

Possible resource consent requirements:

- land use consent
- consent for discharge of contaminants to land
- earthworks consent
- air discharge consent for vapours and odours.

Advantages	Low-level technology. Proven effectiveness on a wide range of petroleum hydrocarbons. Can be used in colder climates.
Disadvantages	Moderately costly.
Suitability	Suitable for wide range of petroleum hydrocarbons and soil types..

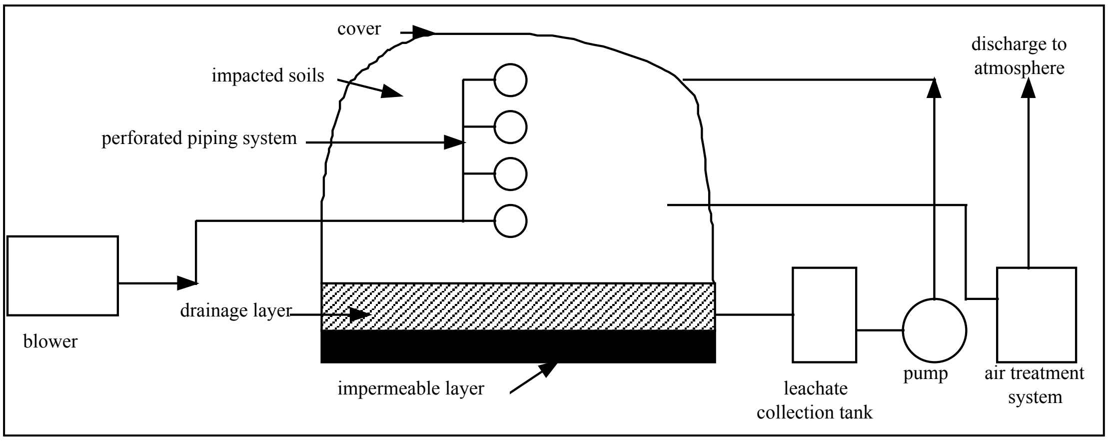

Figure 7.4 Biopiles

7.5.5 Low-temperature thermal desorption

Low-temperature thermal desorption (LTTD) units heat excavated soils contaminated with petroleum hydrocarbons to between 93°C and 315°C to volatilise water and organic constituents to separate them from the soil. The bed temperatures and residence times used in LTTD are sufficient to volatilise, or desorb, selected contaminants, but typically not to oxidise them.

Since the effectiveness of thermal desorption is dependent on the volatility of the organic contaminants, LTTD is generally more efficient for gasoline than diesel and fuel oil contaminated soils. The removal efficiency of LTTD does not depend on the input concentrations of contaminants, but on the residence time of the soil and the operating temperature of the unit. Numerous case studies have demonstrated that greater than 95% removal efficiencies can be achieved by LTTD; greater than 99% removal has been reported in some cases (USEPA, 1992). An LTTD unit can typically remediate a site with 15,000 cubic metres of material within two months.

Particle size distribution and available surface area affect the performance of the LTTD system. Smaller soil particles have a large surface area making more sites available for contamination sorption. Therefore contaminants tend to be adsorbed on smaller soil particles. In general, sandy soils are more effectively treated than clayey soils, which consist of small particles.

Possible resource consent requirements:

- earthworks consent
- land use consent
- air discharge consent.

Advantages	Can remediate large volumes of soils in a short timeframe. Systems are effective for most types of material and hydrocarbon contaminants.
Disadvantages	Transportable units are not yet readily available in New Zealand.
Suitability	Sites with large volumes of petrol and diesel contaminated soils.

7.6 Groundwater remediation

Groundwater remediation technologies are used to reduce the concentration of petroleum hydrocarbons in an aquifer beneath a site to acceptable levels. Acceptable levels are discussed in Module 4. Technologies can be implemented either in situ or ex situ. Six technologies for removing free product and technologies for remediating petroleum hydrocarbons in groundwater are described in this section. In addition, their advantages, disadvantages and suitability are discussed.

The most cost-effective approach for remediating groundwater is to remove the source of contamination before or during remediation. The most likely sources for groundwater contamination include soils saturated with petroleum hydrocarbons and free product floating on the surface of the water table. Technologies for remediating contaminated soils are discussed in Section 7.5. Technologies for remediating free product include recovery trenches, skimming, bailing, vacuum extraction, suction, and bioslurping. These technologies are discussed in Section 7.6.1.

Once the free product has been removed from the water table, remediation of the dissolved and adsorbed phases can begin, if required. In most cases, natural attenuation can adequately mitigate the contaminated groundwater. Contaminated groundwater can be treated either in situ or ex situ. The in situ technologies discussed in this section for remediating petroleum hydrocarbons in groundwater include air sparging and in situ bioremediation. The ex situ technologies discussed for remediating petroleum hydrocarbons in groundwater include air stripping, activated carbon adsorption, spray irrigation, and ex situ biological treatment. The in-situ groundwater treatment technologies are described in Section 7.6.2; the ex situ technologies are described in Section 7.6.3.

7.6.1 Free product removal

Technologies for remediating free product include recovery trenches, skimming, vacuum extraction, suction pumping, bailing, and bioslurping. These technologies are described in this section.

7.6.1.1 Recovery trenches

A trench is excavated on the downgradient side of a product plume to a level deeper than the water table and any expected fluctuations in the water table. Product migrates with the groundwater into the trench and can be removed by pumping from a low point or sump in the trench. Product recovery by trenches is shown in Figure 7.5. Where it is unsafe to leave the trench open (i.e. public access cannot be fully controlled, or the ground conditions are unstable) a perforated pipe drain can be installed and the trench backfilled.

Provided the trench is sufficiently long and correctly placed, complete capture of the plume can be effected by placing an impermeable barrier on the downstream side of the trench and pumping to lower the water table and induce flow into the trench. It is important to ensure that any natural barriers to vertical migration (e.g. an aquiclude or less permeable stratum) are not breached by the trench or this can result in an unwanted spreading of the contaminant.

Trenches are most cost effective where the plume is wide, the water table is shallow, and the product is relatively free flowing.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- earthworks consent
- consent for abstraction of groundwater.

Advantages	Simple to operate and requires no special equipment to install. Can be quick to install and cost effective. Complete plume interception if the trench is long enough.
Disadvantages	Can cause considerable ground disturbance and possible loss of operational land. Requires a collection system. There are health and safety considerations where the trench is open.
Suitability	Free product recovery where the permeability of the ground is high, the water table is near the surface (<4 metres) and groundwater flow velocities are high.

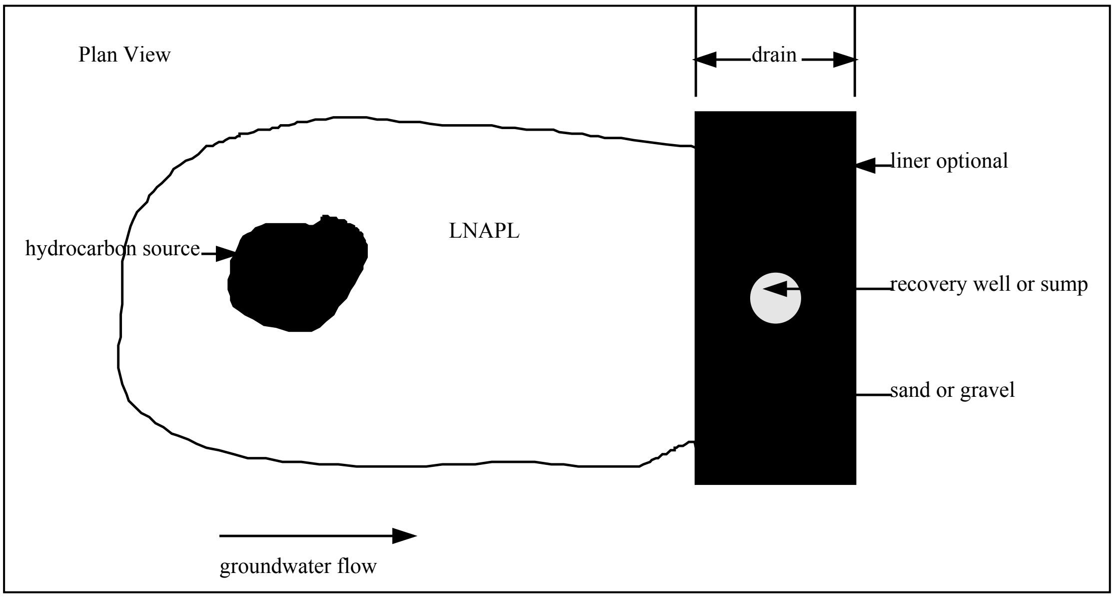

Figure 7.5 Recovery trench

7.6.1.2 Skimming

Passive and active product skimming devices are commercially available. A passive skimmer is a device designed to be installed in a groundwater well to collect small quantities of floating product. It comprises a sealed buoyant tube with a hydrophobic membrane which sits at the water level. The membrane allows petroleum hydrocarbons to pass through while preventing water passage. The hydrocarbon collects in the submerged section of the tube. The skimmer is lifted periodically and the product drained through a valve at the base of the tube.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Active skimming methods include a skimming pump, a one-pump system, and a two pump system. Active skimming requires a power source and a system at the surface for collecting the product or the product/water mix.

Skimming pumps are designed to remove floating product from a recovery well. A skimming pump is designed with a ballast to position the intake of the pump within the layer of floating product. A single-pump is designed to draw down the water table and remove both floating product and the water beneath. A dual-pump system is more sophisticated and comprises a water pump and a hydrocarbon pump. The water pump is used to lower the water table and encourage inflow of product. The hydrocarbon pump is normally fitted with a sensor which will trigger the pump once a sufficient depth of product is present.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, councils sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Passive skimming	
Advantages	Inexpensive and simple to operate. No surface intrusion. Little water, only product recovered. Can be installed in any well of 100 mm diameter or greater. No power needed. Will not cause smearing.
Disadvantages	Small area of influence. Does not enhance recovery rate. Labour intensive.
Suitability	Good for small volumes of free product in relatively low permeability soils, e.g. where product is confined to the backfill around a tank. May require staff on site to empty the skimmer.

Active skimming	
Advantages	Simple to operate once installed although careful setup is required. Pneumatic and single-pump skimming devices generate mostly product with little water. Can cope with fluctuating water tables. Continuous recovery.
Disadvantages	Pneumatic skimming pump has small area of influence. Single-pump system can recover both product and water which must be removed from the site and appropriately discharged. Two-pump system must be operated in conjunction with groundwater treatment. Can require a large diameter well. Requires a power source. Requires a system at the surface to contain the recovered product. Moderately expensive. Two-pump systems can

	smear hydrocarbons in the cone of depression zone.
Suitability	Pneumatic skimming pump suitable for relatively thick, free-flowing product layers. Single- and two-pump systems suitable where soil permeability is moderate and depression of the water table can be achieved.

7.6.1.3 Bailing

Product is removed from the well using a disposable Teflon or stainless steel bailer. If not done with care, this can mix the floating product through the water column.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Quick implementation. No capital cost. Immediate indication of recovery rates.
Disadvantages	High personnel costs. Not continuous. Limited zone of influence hence only small volumes recovered.
Suitability	Good for small volumes of free product where mechanisation is not warranted, i.e. low permeability/yield, low risk of contaminant impact on the environment and staff available on site or nearby.

7.6.1.4 Suction pump

Product is removed from an open trench using a pump with a suction hose. Both product and water are collected and stored in drums or a tank. Removal of the product is typically performed in discrete batches unless recharge of product into the trench is high. This method is most often used during removal of a leaking underground storage tank where the free product is localised around the tank pit.

Disposal of the product/water mixture can be difficult unless there is an oil/water separator and drain system currently operating at a site. If a disposal system is not available on site, then the product/water mixture is typically transported to a depot using an oil tanker where it is properly disposed. The tanker or truck used to transport the oil/water mixture must meet Hazardous Goods Transport requirements for flammable products and must be cleaned before and after use to avoid cross-contamination with other loads. Landfilling the product/water mixture can be difficult and costly because landfills will not generally accept the liquid, or may charge a premium for doing so.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent

- earthworks consent
- consent for abstraction of groundwater.

Advantages	Can be easily implemented during site investigation stage if test pits or tank pits are excavated to the water table.
Disadvantages	Not continuous. Disposal of the collected water and product can be difficult and costly. High removal rates may result in smearing of the product within the capillary fringe.
Suitability	Most often used during removal of a leaking underground storage tank where the product is localised around the tank pit. Can be used to remove all types of petroleum products.

7.6.1.5 Vacuum extraction

Vacuum extraction uses a blower or vacuum pump connected to a wellhead to volatilise the product in the well as well as strip petroleum hydrocarbons from the capillary fringe. The hydrocarbon-laden air is drawn to the surface where it is discharged with or without treatment. Vacuum extraction is most cost-effective at sites contaminated with petrol with existing monitoring wells screened across the capillary fringe. The sites can have low to high permeability soils contaminated with petrol. Low permeability soils may require the use of a liquid ring compressor (which has a higher suction capacity), which requires a water source.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council’s sewers, reinjection to groundwater
- air discharge consent
- earthworks consent
- consent for abstraction of groundwater.

Advantages	Systems are generally easily installed and effective at petrol-impacted sites. Can remediate free product in inaccessible locations (under buildings or roads) and will remediate capillary fringe as well. Some biodegradation of higher molecular weight hydrocarbons can occur during vacuum extraction.
Disadvantages	Generates contaminated air which may require treatment.
Suitability	Best suited to moderate and high permeability soils contaminated with petrol but can be effective at sites with low permeability soils. Some success in remediation of diesel has been achieved.

7.6.1.6 Bioslurping

Bioslurping is a combination of vacuum extraction and liquid hydrocarbon removal as shown in Figure 7.6. A slurper spear, positioned near the hydrostatic groundwater level, is connected to a liquid ring vacuum pump (LRVP) at ground level. The LRVP pumps the vapour, product and water emulsion to a liquid/air separator cyclone. The hydrocarbon-laden air can be passed through a biofilter for treatment or discharged to the atmosphere. The liquid phase is typically passed through a coalescing-plate oil/water separator where the bulk of the product is removed. The outlet water contains product in emulsion and must be treated prior to discharge.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- earthworks consent
- consent for abstraction of groundwater.

Advantages	Providing a vacuum at the wellhead will enhance migration of product to the well especially in medium- to fine-grained sediments. Also remediates capillary fringe. Very little disturbance of groundwater table thus reducing smearing. Can be used at sites with petrol, diesel and waste oil.
Disadvantages	High velocity pump systems tend to form emulsions. Generates vapour and water streams that require further treatment.
Suitability	Best suited for low to high permeability sites contaminated with petrol, diesel and/or waste oil.

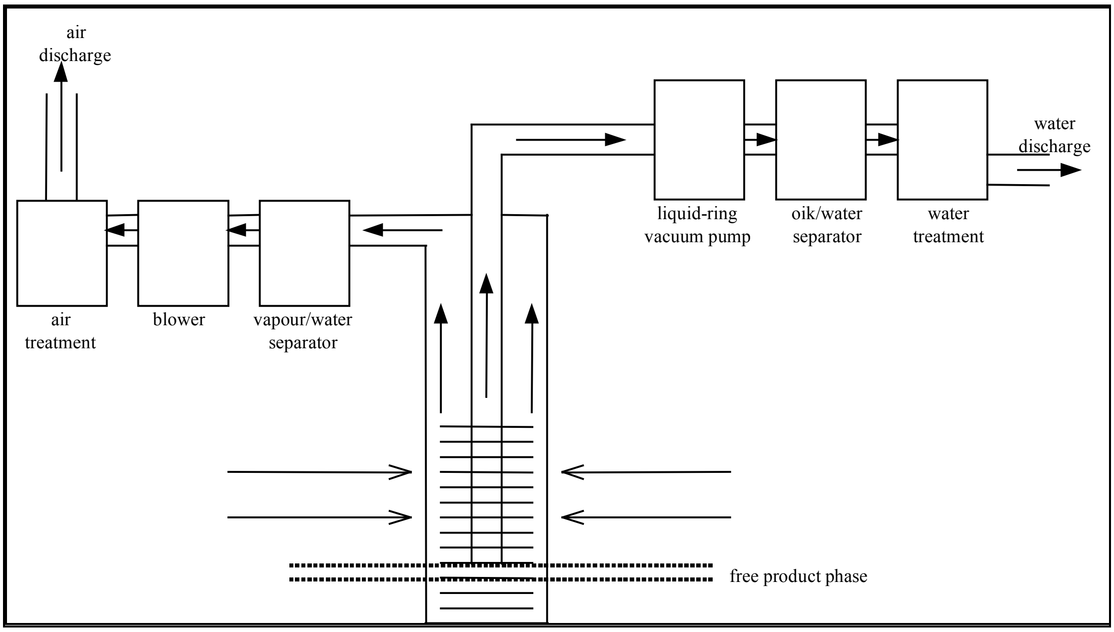

Figure 7.6 Bioslurping

7.6.2 In situ technology

Air sparging and in situ bioremediation technologies are discussed in this section.

7.6.2.1 Air sparging

Air sparging involves the injection of clean air into the saturated zone to strip out VOCs dissolved in groundwater and adsorbed to soils in the saturated zone. The vapour-phase contaminants transferred to the unsaturated zone may then be captured using a soil vapour extraction system or allowed to discharge through the unsaturated zone to the atmosphere. In addition to contaminant removal via mass transfer, the introduction of oxygen may also enhance subsurface biodegradation of contaminants.

The air sparging process creates turbulence and increases mixing in the saturated zone, which increases the contact between groundwater and soil. This results in higher concentrations of VOCs in the groundwater which can be recovered by pumping or can be further stripped by sparging. Air sparging systems are almost always coupled with an SVE system in order to control the subsurface air flow and prevent contaminated soil vapour from migrating to previously uncontaminated areas or entering basements of nearby buildings. The addition of air below the water table may also result in mounding and spreading of contaminated groundwater to uncontaminated areas. Therefore, proper hydraulic control is an important prerequisite for the implementation of this technology.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Generally low to moderate capital and operating costs. Typically remediates groundwater quicker than conventional pump-and-treat systems.
Disadvantages	Air flow may channel along preferential paths leading to incomplete remediation. Layers of fine-grained sediments may form barrier to upward airflow, diverting the flow laterally which can spread contamination.
Suitability	Adequately strips volatile compounds from groundwater and introduces oxygen into saturated zone which enhances natural biodegradation of less volatile compounds.

7.6.2.2 In situ bioremediation

In situ bioremediation is based on stimulating the natural breakdown of petroleum hydrocarbons within the subsurface by enhancing environmental conditions. Groundwater is extracted and treated in a surface mounted bioreactor. The effluent from the reactor, rich in micro organisms, nutrients and oxygen, is then reinjected into the aquifer upgradient of the extraction point. The treated groundwater can also be recirculated through the soil and allowed to percolate to groundwater to promote in situ biodegradation within the soil in addition to the groundwater.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Soil and groundwater treated with one technology. Typically remediates groundwater quicker than conventional pump-and-treat systems.
Disadvantages	Requires close monitoring. Not suitable for low permeability soils. Thorough knowledge of geology and hydrogeology required.
Suitability	Introduces nutrients and oxygen into saturated and unsaturated zone, which enhances natural biodegradation of less volatile compounds.

7.6.3 Ex situ technologies

Four above ground technologies for treating hydrocarbon-impacted groundwater are discussed in this section: air stripping, activated carbon adsorption, spray irrigation and biological treatment.

7.6.3.1 Air stripping

Air stripping uses air to strip volatile organic compounds from extracted groundwater. There are several types of air stripping systems including packed tower and cascading plate systems. The most common is the packed tower. In this type of system, water is released at the top of the tower and made to flow through a packed column against a current of air which is forced up from the bottom. The packed column ensures maximum air-water contact. Volatile organic compounds move into the air stream and are carried out the top of the column. The treated water leaves the bottom of the tower and is disposed. Disposal options for treated groundwater are discussed in Section 7.7. Depending on local authority requirements it may be necessary to treat the air stream prior to discharge to the atmosphere.

The performance of the tower can be affected by iron and manganese, as well as other dissolved compounds, which tend to precipitate out on the column causing clogging and biological slime growths. Other factors which affect performance are the temperature of the air and water, the achieved ratio of air to water, the concentration of the contaminant and the characteristics of the hydrocarbon contaminant. In properly designed and maintained towers, removal efficiencies of 99% have been achieved for BTEX. If necessary, activated carbon can be used just after the air stripping system as a polishing step to reduce organic concentrations to within required limits.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council’s sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Proven technology that is simple and easy to operate. Relatively low capital and operating cost.
Disadvantages	Fouling of the column may be caused by iron and other dissolved constituents in the groundwater. Stripped vapour may require a discharge to air consent and possible further treatment. Can be affected by low temperature.
Suitability	Volatile contaminants such as BTEX.

7.6.3.2 Activated carbon adsorption

Activated carbon treatment of organics-laden groundwater is a well proven, frequently used technology. It is based on the fact that many organic compounds will preferentially adsorb onto activated carbon. Treatment is effected by passing the groundwater over beds of activated carbon. A separator can be used before the bed if necessary to remove any floating product. Once the absorptive capacity of the carbon is exhausted, it is removed for disposal or regeneration using steam.

The adsorption capacity of the carbon media varies depending on the type of media used, the particle size, the nature of the compounds present, the level of naturally occurring organic matter that compete for adsorption sites, and other water quality parameters such as pH, temperature and total dissolved solids levels. Carbon adsorption favours compounds with low water solubility, high molecular weight, low polarity, and a low degree of ionisation. In general, carbon adsorption is economical at sites with low volume and low concentration waste streams, or as a polishing step for final treatment prior to discharge because of the cost of the carbon and the spent carbon disposal or regeneration costs.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- consent for abstraction of groundwater.

Advantages	Proven technology for removing aromatic compounds. Minimises problems with air emissions. Can cope with fluctuations in flow and contaminant concentrations.
Disadvantages	Fouling by high levels of suspended solids a problem. Carbon costs are high and spent carbon must be regenerated or disposed, of which is expensive. There is a lack of regeneration facilities in NZ. Pretreatment is necessary where oil and grease are present in high concentrations.
Suitability	Suitable for aromatics and organic compounds of low volatility where the oil and grease levels are low. Not suitable for oxygenated compounds such as alcohols. Generally used for polishing only due to high costs.

7.6.3.3 Spray irrigation

The natural processes of volatilisation, adsorption and biodegradation are utilised to remove contaminants from water when it is spray irrigated onto land. The water is sprayed from a nozzle to maximise air/water contact and hence volatilisation. Adsorption and biodegradation will occur as the water infiltrates the soils, reducing the contaminant levels still further.

The efficiency of initial removal can be affected by water and air temperature. It is important that the water infiltrates the ground rather than running off, to ensure the fullest possible treatment. Resource consents are likely to be required.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater

- air discharge consent
- consent for abstraction of groundwater
- consent to discharge contaminants to land.

Advantages	Cost effective if land available. Can enhance in situ biodegradation.
Disadvantages	Requires a land area with the capacity to accept the predicted hydraulic loading. Will generally require a consent with an assessment of environment showing impacts on groundwater and surface water quality.
Suitability	Suitable for low contaminant concentrations in low to moderate rainfall areas.

7.6.3.4 Ex situ biological treatment

Treatment systems and technology similar to that used in sewage treatment plants can be used in a scaled down version to facilitate aerobic biodegradation of petroleum hydrocarbons. The contaminated water is passed over or through a biological film in a trickling filter, biotower or rotating biological contactor. Oxygen for the bacteria is provided through contact with air. Activated sludge processes can also be used where the micro-organisms are suspended in liquid and oxygen is provided by aeration. The treated liquid is then passed to a settling chamber and the biological solids removed. A portion of the biological solids are returned to the aeration chamber to maintain the biological population. The sludge must be disposed of separately.

Biological systems are sensitive and must be frequently monitored and controlled to ensure the biological population has optimum conditions for growth. In the event that the microbial population is lost, the restarting process can be slow since the organisms must be acclimatised to the contaminant.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council’s sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Proven technology for a wide range of organic compounds. Fewer problems with air emissions.
Disadvantages	Expensive in terms of capital, operating and maintenance costs. Greater potential for malfunction. Sludge disposal required.
Suitability	Suitable for wide range of petroleum hydrocarbons. Best when hydrocarbon concentrations in groundwater are relatively stable.

7.7 Disposal

Disposal options for excavated soil and extracted groundwater are discussed in this section.

Two disposal options for excavated soils are available: landfilling and backfilling. Only treated soils are suitable for backfilling on site. If backfilled, contaminant levels in treated soils must meet appropriate clean-up levels as discussed in Module 4. Landfilling as a disposal option for untreated soils is discussed in Section 7.7.1.

Numerous options are available for disposing of extracted groundwater including disposal to land, reinjection, discharge to surface water bodies, and discharge to the sanitary sewer system. In most cases, extracted groundwater will require treatment prior to disposal. Groundwater disposal options are discussed in Sections 7.7.2 through 7.7.

7.7.1 Landfilling

Once approval is obtained from the landfill operator, the contaminated material is excavated and transported to the landfill. In some cities and towns a hazardous waste manifest is required to be completed before approval is given. It should be noted that the use of this method may become more limited in the future due to the increasing reluctance of territorial authorities to accept such waste at municipal soil waste landfills.

This technology is best suited for sites with contaminated soils at depths less than practical excavation depths. A larger volume of soil than is contaminated is typically excavated because of the need to slope the sides of the excavation. A method for separating uncontaminated soils from contaminated soils should be employed to reduce costs. The costs for the landfilling option will include excavation and transport, as well as the tipping fees at the landfill.

Possible resource consent requirements:

- discharge of contaminants to land.

Advantages	Removes contaminated soil from the site. Applicable to a wide range of contaminant types provided the landfill operator will accept the waste. Very quick.
Disadvantages	Expensive in some areas, especially if the volume to be removed is large. Some pretreatment may be required if contaminant levels high.
Suitability	Suitable for most petroleum-contaminated soils. Most cost effective at sites with contamination at depths shallower than 5 metres.

7.7.2 Reinjection

One option for disposing of treated groundwater is to reinject it back into the aquifer through reinjection wells or trenches. This option would require a fairly detailed evaluation of the hydrogeologic properties of the aquifer system and some modelling to design an effective reinjection system. Reinjection systems can require periodic maintenance, particularly at sites with high levels of iron or manganese in the groundwater, which can cause fouling.

Possible resource consent requirements:

- consent for discharge of contaminants by reinjection to groundwater
- consent for abstraction of groundwater.

Advantages	Can be designed to aid capture of plume. Water returned to aquifer for beneficial usage.
Disadvantages	Expensive. Requires detailed hydrogeologic information and modelling to properly design a system. Long-term maintenance required.
Suitability	Suitable for moderate to high permeability sites for a wide range of extraction rates.

7.7.3 Discharge to surface water bodies

Discharge of extracted groundwater to creeks, streams, or lakes typically requires treatment of the water to ANZECC aquatic standards. Water chemistry parameters should be monitored periodically to ensure minimal deleterious affects from discharge of treated groundwater.

Possible resource consent requirements:

- consent for discharge of contaminants to surface water bodies
- air discharge consent.

Advantages	Low-cost option if lake, stream or creek nearby.
Disadvantages	Monitoring of lake, stream, or creek required to ensure no long-term adverse effects from discharge of water.
Suitability	Suitable for sites with surface water bodies nearby that can withstand hydraulic loading.

7.7.4 Discharge to sanitary sewer or stormwater system

The feasibility of discharging treated or untreated groundwater to the sanitary sewer system or stormwater depends on the characteristics of the water and the capacity of the facility.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater or sewer
- consent for abstraction of groundwater.

Advantages	Groundwater may not require treatment prior to discharge.
Disadvantages	System may not have capacity.
Suitability	Suitable for sites with wastewater treatment facilities nearby that can withstand hydraulic and constituent loading.

7.8 References and further reading

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