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**The development of HSLs for petroleum hydrocarbons – an issues paper**

E. Friebe and P. Nadebaum



CRC for Contamination Assessment and Remediation of the Environment

Technical Report no. 4

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E. Friebel and P. Nadebaum

GHD Pty Ltd

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# **1. Introduction**

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## **1.1 Background**

In Australia, the normal approach for triggering further investigation during contaminated land investigations is to determine whether the concentration of contaminants of concern in soil and/or groundwater exceed published health screening levels (HSLs) or ecological investigation levels (EILs). These levels can also form the basis for clean-up criteria. In the case of petroleum hydrocarbons, a number of HSLs exist; however, these are limited and do not extend to a variety of soil types and aquifer situations, or to the assessment of volatile hydrocarbons. There is guidance on how the assessment of risk associated with such contaminants should be carried out, and it is common practice to undertake a risk assessment to determine whether the concentrations might pose a human health or ecological risk. As such, there is a basis for developing a set of HSLs and clean-up guidelines for petroleum hydrocarbons, but the detail of this has not yet been agreed and carried out.

The Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) research program includes Subprogram 1.4: Risk Characterisation and Communication, which includes the objective of preparing HSLs for hydrocarbons in soil and groundwater. This project forms part of this program, and has the objective of developing an accepted set of HSLs and clean-up guidelines for petroleum hydrocarbons in soil and groundwater, in the context of land uses and the beneficial use of groundwater typical of Australia.

## **1.2 Objectives of this issues paper**

The development of a set of HSLs and clean-up criteria for petroleum hydrocarbons will involve a staged program of work, and will be carried out under the guidance of a Project Advisory Group (PAG) involving various Australian industry representatives and regulatory agencies. It is expected that the program of work will include reviews and workshops as directed by the PAG to develop the detailed scope and basis for the development of the guidelines, and to review the work that is carried out.

This issues paper is the first stage in this program of work.

The objective of the issues paper is to identify issues and to provide a commentary on relevant literature and practices that will assist in preparing a detailed scope and basis for the development of a set of HSLs and clean-up criteria for petroleum hydrocarbons. A workshop with the PAG was held in Melbourne on 12 December 2006 to discuss the key issues. The minutes of the workshop are attached to this paper as Appendix A, and the key points of discussion are included in this paper.

As such, this paper includes summary information on:

- current practices and methods for developing and applying HSLs and clean-up guidelines
- information sources that are available and relevant to the development of HSLs and clean-up guidelines, and their relevance to the Australian environment and regulatory guidance and practices, and
- issues that need to be resolved before carrying out the development of the HSLs and clean-up guidelines.



### 1.3 Scope of this paper

This issues paper includes:

- a summary of the framework, methods and key assumptions that underlie the development of HSLs in Australia and internationally, and NEPM and enHealth guidance relevant to this
- a summary of the framework, methods and key assumptions made in documents which develop HSLs for other jurisdictions, and where they may differ from Australian guidelines and the implications of this
- the basis for selecting toxicity criteria and available information sources and databases for such criteria and their completeness
- the range of vapour models that are in common usage for health risk assessment and their relevance in Australia
- the basis for selection of exposure assumptions and pathways for various land uses
- the range of soil types and groundwater situations including depth that are present in Australia
- how it is intended that the HSLs and clean-up guidelines could be used, and
- the basis for nominating an acceptable risk.

In particular, this paper indicates how each of the issues are addressed in Australia and by international groups. Suggestions are provided as to how the issues might be best addressed in Australia. Where issues require further consideration to obtain consensus on the appropriate approach, this has been identified in the paper.

### 1.4 Referenced literature

There is a considerable volume of information available. Key documents that have formed the basis for the review include:

- NEPC, *The National Environment Protection (Assessment of Site Contamination) Measure*, December 1999
- enHealth, *Guidelines for assessing human health risks from environmental hazards*, June 2004
- papers from the Fifth National Workshop on the Assessment of Site Contamination and previous monographs
- Australia Oil Industry Environmental Guidelines Working Group *Guidelines for the Management of Petroleum Hydrocarbon Impacted Land*, final draft, April 1999
- New Zealand Ministry for Environment, *Guidelines for assessing and managing petroleum hydrocarbon contaminated sites in New Zealand*, June 1999
- CSIRO Land and Water, *Petroleum and Solvent Vapours: Quantifying their Behaviour, Assessment and Exposure*, G. Davis, M. Trefry, and B. Patterson, July 2004
- UK Environment Agency, *The UK approach for evaluating the human health risks from petroleum hydrocarbons in soils*, January 2005

- recent publications from US EPA, including development of Region 9 Preliminary Remediation Goals
- Canadian Soil Quality Guidelines (CCME) *Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (1999) and *Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale* (2000)
- Dutch Target and Intervention Values for Soil and Groundwater (2000).

## **2. General considerations and scope of the guideline document**

### **2.1 Introduction**

Typically, when assessing contaminated sites in Australia, a staged (or tiered) approach is adopted. Measured concentrations of chemicals in soil and groundwater may be compared to health-based criteria. These criteria are derived based on risk assessment principles, and are often referred to as health screening levels, health-based guideline levels, or Tier 1 criteria. In this paper these are referred to as 'Tier 1 criteria'.

If the assumptions used in the derivation of these criteria are not applicable or appropriate for the site, then a more detailed risk assessment (also known as a site-specific or Tier 2 risk assessment) may be carried out.

The derivation of investigation and clean-up criteria for petroleum hydrocarbons is a complex process and can require consideration of not only the requirements for protection of human health, but also the requirements for protecting aesthetic enjoyment of the site and ecological values. In general, a single set of criteria will not address all of these issues, because:

- there can be site-specific issues that cannot be addressed by generalised criteria
- the issues may be too complex to be addressed using a single set of criteria, or
- some situations may occur only rarely and may be better dealt with on an individual basis rather than as part of a larger group of more common situations.

When deriving criteria, assumptions must be made regarding the source and nature of the contamination, the receptors that need to be considered, the exposure pathways, and the exposure settings. In general, in order to focus the document, these assumptions should be confirmed and agreed as early as possible in the development of the guidelines.

### **2.2 Scope**

#### ***2.2.1 Range of effects that are to be considered***

The term 'health screening levels' (HSLs) specifically relates to protection of human health. However, clean-up of a site may involve additional considerations, and the following questions arise regarding the scope of the guidelines:

- Does odour need to be considered and, if so, for which situations (i.e. do we need Tier 1 criteria based on odour)?
- Do effects on plants need to be considered (i.e. phytotoxicity)? If so, under which situations do these need to be addressed (i.e. land use, depth below ground surface)? Do these need to be derived, or do we just present available literature values for the chemicals investigated?
- Do risks to terrestrial animals need to be considered? If so, under which situations do these need to be addressed (i.e. land use, depth below ground surface,

species)? Do guideline values need to be derived, or do we just present available literature values for the chemicals investigated?

- What sources should be considered – e.g. soil, groundwater, and non-aqueous phase liquid (NAPL) or phase separated hydrocarbon (PSH)?

The first PAG meeting considered these issues and advised that the constraints on the CRC project budgets and timeframes might not allow derivation of detailed ecological-based criteria.

### **2.2.2 Availability of related guidelines and their scope**

There are a number of existing guidelines that have been developed. A review of the scope of these guidelines indicates:

- The Australian Oil Industry Environmental Guideline Working Group (AOIEGWG) and New Zealand Ministry for the Environment (NZ MfE) have produced sets of Tier 1 criteria and supporting guidelines for the assessment of petroleum hydrocarbon contaminants in soil and groundwater. Criteria have been derived for protection of human health for different land uses, for a combination of source depths and soil types, and are presented in a series of tables. Chronic health risk is the most stringent endpoint for deriving criteria. The development of the criteria has not considered basements, or aesthetic issues such as odour. Discussion on protection of ecological receptors is provided but this has not been incorporated into the criteria (which are primarily human health-based). For groundwater, additional criteria are derived for irrigation use and stock water use.
- The US EPA has a number of different protocols for soil and groundwater criteria, although these have been developed separately. Separate guidance documents are presented for conducting health risk assessments and ecological assessments. Region 9 Preliminary Remediation Goals (PRGs) are human health-based, and do not consider aesthetic effects, such as odour. Total petroleum hydrocarbons (TPH) are also not considered.
- The UK Environment Agency together with the UK Department for Environment, Food and Rural Affairs (DEFRA), have developed a software package called 'The Contaminated Land Exposure Assessment Model' (CLEA). This software is similar to the United States RBCA model, except it is designed for developing Tier 1 criteria. The model contains a database with default exposure parameters, soil types, chemical toxicity and physical properties, and modelling parameters. The model is designed to derive site-specific soil criteria, while keeping the default exposure pathways and parameters. The model allows site-specific items such as depth to contamination source and soil type to be included into the development of criteria, instead of presenting multiple levels of tables to account for these variables. The model has yet to include petroleum hydrocarbons, and it is understood that this is currently being implemented. The CLEA model is a work in progress, and is likely to have amendments.
- The Canadian Council of Ministers for the Environment (CCME) has developed a guidance document for addressing petroleum hydrocarbons. The guidance provides soil criteria for a number of land use types, but assumes a single depth and soil type. Detailed risk-based criteria are derived also for ecological receptors, including terrestrial animals.

- In Germany, contaminated land assessments and remediation are governed by the Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV) dated 12 July 1999. The document outlines the triggers and requirements for investigation and remediation. Some criteria are provided for different land uses, but do not extend to petroleum hydrocarbons. The document primarily addresses protection of human health, but also considers protection of plants, particularly in parks and recreational areas. The document also provides leachate criteria for protection of groundwater.
- In the Netherlands, under the framework of the Dutch Soil Protection Act (1987), the Dutch Target and Intervention Values for Soil and Groundwater were developed with the latest revision in 2000. The target value is based on potential risks to ecosystems, while the intervention value is based on potential risks to humans and ecosystems. These risk-based guidelines present soil and groundwater intervention values for mineral oil, which are considered to represent the TPH C<sub>10</sub>-C<sub>40</sub> threshold concentration. The Dutch Intervention Values (DIVs) have been reviewed by RIVM (2001) and Serious Risk Concentrations have been calculated for soil, sediment and groundwater (SRC<sub>human</sub>) using the human exposure model CSOIL, that may at some point replace the DIVs.

It can be seen that other countries have not taken a uniform approach on the development of criteria, although most provide criteria for the protection of human health, and criteria for protecting other environmental values are considered separately.

In the PAG workshop it was noted that the NEPM structure recognises the usefulness of HSLs in determining acceptable levels of contamination, but it is important to keep in mind how they have been derived and how they are intended to be used. In many cases HSLs will be a limiting factor in determining the acceptability of contamination and an important consideration in setting clean-up criteria.

The identification of particular land uses and groundwater uses that need to be considered is discussed in Sections 5.1 and 5.2 of this document.

### **Suggestion**

The scope of the guidelines be restricted to the development of criteria for the protection of human health in the first instance.

The development of criteria for the protection of other beneficial uses such as aesthetics and terrestrial ecology take place as a separate project at a later time. Until such criteria have been developed, such considerations would need to be assessed on a site-specific basis.

Note: other options are possible. For example, it would be possible to include a commentary (rather than criteria) on the requirements for ecological protection; a literature search on effects on plants could be included to provide information on phytotoxicity; and information on odour thresholds and the calculation of criteria for protection against odours.

The PAG agrees that there is a need for the development of both HSLs and EILs. However, the PAG supports limiting the scope of this project to HSLs, as this will increase the likelihood of a concrete outcome. Supporting documentation should include reference to the context of the HSLs and other potential drivers for remediation.

## 2.3 What type of sites will this document address?

Typically, petroleum industry sites can include:

- small sites such as service stations
- medium-size sites such as storage depots
- large sites such as refineries
- crude oil pipeline spill sites.

The selection of the range of sites and situations that the guidelines are to apply to is an important consideration because it can affect the range and composition of chemicals that are to be assessed.

This is particularly important for total petroleum hydrocarbons (TPH) fractions, as different types of fuel vary in the proportion of TPH in different carbon ranges, and in the proportion of aliphatic and aromatic components in the fuel.

The occurrence of non-hydrocarbon contaminants such as lead, tetraethyl lead, or vanadium (present in some crude oils) will also vary depending on the type of site.

Information from supporting documentation is as follows:

- The AOIEGWG document was targeted to fuels associated with service stations, depot and refuelling facilities, and oil and bulk storage terminals.
- The UK EA document *The UK Approach for Evaluating Human Health Risks from Petroleum Hydrocarbon in Soils* indicates that applicable sites will include small sites handling petrol and diesel, and sites that involve storage and transport of heavy crude oil. Consideration of TPH fractions up to C70 has been recommended in their methodology.
- The CCME document *Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil* states that 'the CWS will also find application in the cleanup and restoration phases of responses to pollution emergencies involving petroleum products and crude oils'. This suggests that the guidelines include sites that handle crude oils.

Some other considerations are as follows:

- Often the subject site is not the source site. If the subject site happens to be next to a site such as a refinery or pipeline, then similar issues on source properties apply.
- Similar to above, often a site is a redeveloped site, and therefore the site history is important. Consideration must be given to the former site use and the type of fuel located on the site.
- There may be issues associated with large facilities such as depots and refineries, where the business of the site is the processing and storage of petroleum hydrocarbons. There has been debate as to whether these sites should be assessed and regulated under the NEPM and enHealth guidelines, or whether these sites should be assessed and regulated under Worksafe regulations. Note that in the latter instance Worksafe regulations would only apply on-site, and NEPM and enHealth requirements would apply off-site.

### **Suggestion**

The guidelines should be applicable to the assessment of contaminants that are found on a range of petroleum industry sites, including sites such as service stations, storage depots, refineries, and pipelines, and can be limiting.

The guidelines will not extend to contaminants that are not normally found to be limiting on petroleum sites, at least in the first instance.

This is further considered in Section 3.

## **2.4 Risk assessment methodology**

In general, the methodology used in Australia for deriving HSLs follows a risk-based approach. Methodologies for conducting human health-risk assessment in Australia are published in two primary documents, which are endorsed by the regulatory organisations in Australia, and in some states are ratified by law. These are:

- NEPC (1999) *National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council, December 1999
- enHealth (2004) *Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards*, Department of Health and Aging and enHealth Council, June 2004.

These two documents outline a similar overall approach to carrying out risk assessment, although there are some differences in particular components. The general methodology is derived from the process used in the USA and originally presented in the Risk Assessment Guidelines for Superfund sites (RAGS). In summary, the process involves the following steps:

- Hazard identification/issue identification – identification of issues to be addressed, including source characterisation, identification of chemicals, receptors and pathways. Usually, this section requires the development of a conceptual site model.
- Toxicity assessment/hazard assessment – review of health effects and toxic endpoints of assessed chemicals, and determination of dose-response.
- Exposure assessment – identification of receptors and complete exposure pathways, quantification of dose. May involve fate and transport of contaminant.
- Risk characterisation – based on results of toxicity assessment and exposure assessment, health risk may be quantified for each receptor and scenario for a given endpoint.

Health risk assessment may be carried out as a forward process, whereby for a given source, the risk may be estimated for a receptor through a given exposure pathway. Alternatively, the risk assessment process may be reversed by starting with an acceptable risk and deriving soil or groundwater criteria for a given receptor and exposure pathway. This is the process that is adopted for deriving HSLs.

The primary difference between the NEPM and enHealth documents with respect to the assessment of risks to human health is that the NEPM is restricted to the issues and requirements for assessment of contamination, whereas the enHealth document expands the methodology to include risk management.

For those involved in the assessment and management of contamination on petroleum industry sites, it is important to understand how criteria should be applied, when further, more detailed site-specific risk assessment is required, and the requirements for managing the risk.

Further discussion on risk management is presented in Section 9.

### **Suggestion**

The guidelines should be based on NEPM and enHealth guidance, and should include guidance on how the criteria should be applied for the assessment of contamination and reaching conclusions as to whether contamination might pose a risk to human health, and therefore management control becomes necessary. The guidelines will include a set of look-up tables with clear guidance on their use and limitations.

The guidelines should not extend to providing information on methods of managing risks, the management controls that could be applied, or remediation methods, at least in the first instance.



### **3. Characteristics of hydrocarbon contamination**

#### **3.1 What range of hydrocarbon contamination should be considered?**

The range of hydrocarbon contamination to be assessed is dependent on what types of petroleum sites are to be included. For service stations consideration should be given to leaded and unleaded fuel as well as diesel. Jet fuel could be considered for airport storage facilities. Depots and refineries need to also consider heavier oils including crude.

The selection of the types of hydrocarbon contamination to be considered will influence other decisions such as the selection of carbon fractions in TPH, and the primary chemicals of concern.

Consideration of what range of hydrocarbon contamination is to be considered is linked to the question of what type of sites the guidelines will address (refer to Section 2.3).

#### **3.2 Carbon ranges and aliphatic/aromatic speciation**

*What are the carbon ranges for the different fuels? What is the composition of aliphatic and aromatic components of the different carbon ranges?*

There are two main considerations:

- What are the historical and current procedures for analytical sampling and reporting for total petroleum hydrocarbon (TPH)?
- What are the recommended fractions to assess for fate and transport properties and toxicological properties of chemicals?

Historically, TPH has been measured and reported in Australia with carbon fractions C<sub>6</sub>-C<sub>9</sub>, C<sub>10</sub>-C<sub>14</sub>, C<sub>15</sub>-C<sub>28</sub> and C<sub>29</sub>-C<sub>36</sub>. The NSW EPA guidelines for assessment of service station sites recommended these fractions for assessment in 1994, and this has been the primary driver for the selection of these ranges. Historically, aliphatic and aromatic hydrocarbons have not been speciated and assessed. As many hydrocarbon-impacted sites will have historical data in this form, consideration should be given to retaining these carbon fractions for assessment.

The AOIEGWG petroleum guideline document considers the hydrocarbon fractions C<sub>6</sub>-C<sub>9</sub>, C<sub>10</sub>-C<sub>14</sub>, C<sub>15</sub>-C<sub>28</sub> and C<sub>29</sub>-C<sub>36</sub>, and were based only on aliphatic components. Aromatic components were addressed by surrogate chemicals, naphthalene, pyrene and benzo(a)pyrene.

The NZ MfE petroleum guideline document similarly considers the hydrocarbon fractions C<sub>7</sub>-C<sub>9</sub>, C<sub>10</sub>-C<sub>14</sub> and C<sub>15</sub>-C<sub>36</sub>, and are based only on aliphatic components. Aromatic components were addressed by surrogate chemicals, naphthalene, pyrene and benzo(a)pyrene.

The TPH Criteria Working Group (TPHCWG) in the USA is considered to be one of the better sources of toxicological and physical property studies for TPH. The UK Environment Agency is also in the process of establishing risk-based concentrations for hydrocarbons. In 2004 a workshop was held in consultation with UK EA. The recommended approach is as follows (UK EA Science Report P5-080/TR3 2005):

- *For the more common problem of weathered hydrocarbon products, a hybrid method was developed that uses fractions and carcinogenic (non-threshold) indicator compounds. TPHCWG supports the use of appropriate indicator compounds, based on the type of petroleum identified at the site (e.g. benzene for gasoline sites, PAHs for heavy oil sites).*
- *TPHCWG established its petroleum hydrocarbon fractions on the basis of the fate and transport properties of the compounds (TPHCWG, 1997a). The fractions selected are based on equivalent carbon (EC) numbers and are considered to be closely related to compound mobility in the environment (TPHCWG 1999).*
- *In considering the properties of petroleum constituents, the aromatic compounds tend to be more soluble in water and slightly less volatile than aliphatic compounds with similar EC numbers. On this basis, TPHCWG divided petroleum constituents into aromatic and aliphatic hydrocarbon fractions.*
- *In the TPHCWG approach, the aromatic and aliphatic fractions are further divided into 13 transport fractions, with leaching and volatilisation factors that differ by approximately one order of magnitude (TPHCWG 1999).*
- *The threshold toxicity of each of the 13 fractions is represented by reference doses (RfDs) and reference concentrations (RfCs) for 'surrogate' compounds or mixtures. A surrogate is an individual compound or mixture within each fraction deemed to represent the toxicity of the fraction. TPHCWG preferred the use of mixtures as surrogates, as they allow for the interactions between compounds within the fraction. For fractions exhibiting similar toxicity, the same toxicity criterion is applied to each fraction. In this way, the toxicity of petroleum hydrocarbon in soil can be estimated by quantifying seven broader fractions. However, TPHCWG recommended (TPHCWG 1999) quantification of all 13 fractions, thus enabling the detailed modelling of the potential for human exposure owing to different transport properties.*
- *Aliphatic fractions EC >5-6, >6-8, >8-10, >10-12, >12-16, >16-35, >35-44*
- *Aromatic fraction EC >5-7, >7-8, >8-10, >10-12, >12-16, >16-21, >21-35, >35-44*
- *Unspeciated EC >44-70*

The UK EA also has involved analytical laboratories in the working group and is proposing to specify changed analytical methods to meet its requirements.

If heavier crude oil is to be assessed then heavier fractions also need to be considered. Following the publication of the TPHCWG methodology, the API reviewed the suitability of their methodology for evaluating human health risks from petroleum contamination at oil exploration and production (E&P) facilities. The API found that the TPHCWG approach was suitable for refined products, such as petrol and diesel, but was not suitable for the heavier petroleum fractions associated with mineral oils, petroleum jelly and crude oil. The API resolved this by modifying the TPHCWG fractions on the following basis:

- The >EC21 to EC35 aromatic carbon number fraction was replaced by a >EC21 to EC44 carbon number fraction.
- The >EC16 to EC35 aliphatic carbon number fraction was replaced by a >EC16 to EC44 carbon number fraction.

The CCME (2000) has derived soil criteria for 4 TPH fractions:

1. Fraction 1 encompasses the range of ECN from C6 to C10
  - a) This fraction is composed of the following TPHCWG sub-fractions:
    - i. aromatics C>7-C8, C>8-C10
    - ii. aliphatics C6-C8, C>8-C10
  - b) Physical-chemical properties are well defined for TPHCWG subfractions within this range.
  - c) Unique RfDs and RfCs are defined for each aromatic or aliphatic subfraction in the range.
  - d) BTEX should be analysed separately and their concentrations subtracted from aromatics in this fraction.
  - e) Aliphatics in this range are represented by two RfD and RfCs; for C6-C8, and for C>8-C10.
  - f) Non-BTEX aromatics are represented by two RfD and RfCs; for C>7-C8 and C>8-C10.
2. Fraction 2 encompasses C>10 to C16
  - a). This fraction is composed of the following TPHCWG sub-fractions:
    - i. aromatics C>10-C12, C>12-C16
    - ii. aliphatics C>10-C12, C>12-C16
  - b) Physical-chemical properties are well defined for TPHCWG sub fractions within this range.
  - c) Aliphatics in this range are represented by a single RfD and RfC.
  - d) Aromatics are represented by a single RfD and RfC.

3. Fraction 3 encompasses the range of ECN from C>16 to C34

- a) This fraction is composed of the following TPHCWG sub-fractions:
  - i. aromatics C>16-C21, C>21-C34
  - ii. aliphatics C>16-C21, C>21-C34
- b) Physical-chemical properties are well defined for TPHCWG subfractions within this range.
- c) Aliphatics in this range are represented by a single RfD.
- d) Aromatics are represented by a single RfD.

4. Fraction 4 encompasses the range of ECN from C>34 to C50

- a) This fraction is composed of the following TPHCWG sub-fractions:
  - i. aromatics C>34
  - ii. aliphatics C>34
- b) This fraction can represent a substantial and significant proportion of environmental PHC contamination, and of petroleum products and crude oils.
- c) Although the physical-chemical properties are less well defined in this fraction, the material is not volatile and is expected to have minimal environmental migration.
- d) A study of mixtures provides the basis for an RfD for aliphatics in this range.
- e) There is no data available to derive an RfD for aromatic PHCs in this range, specifically. However, the toxicity of aromatics can be conservatively assumed to be equivalent to that of pyrene, as is currently done for all aromatics with an ECN C>16 under the TPHCWG scheme.

The CCME present recommended portions of each fraction based on typical fuel composition.

The PAG workshop discussed the benefits of analysing TPH using the TPH Working Group methodology versus the conventional band splits. There was no clear resolution of this: there was some concern with using the TPHWG methodology because of unreliable laboratory performance with aliphatic/aromatic splits, and some benefit in the use of the TPHWG method because of the availability of mobility data. A compromise position of shifting the chain length splits from the traditional C6-C9, C10-C14, C15-C28 and C29-C36 was suggested, but this would require involving the laboratories in further discussion of this topic.

**Suggestion**

Further discussion is required on this topic. This should include involvement of analytical laboratories for input on testing methods.

### 3.3 What chemicals should be considered?

Historically, hydrocarbon-impacted land assessments in Australia focused on BTEX, lead (inorganic), TPH fractions C6-C9, C10-C14, C15-C28, C29-C36, benzo(a)pyrene toxic equivalence (TEQ), naphthalene and pyrene.

International literature tends to agree with this list, with slight variations with TPH fractions. The relevant international documents are summarised as follows:

- The AOIEGWG document includes the following chemicals: BTEX, lead (inorganic), TPH fractions C<sub>6</sub>-C<sub>9</sub>, C<sub>10</sub>-C<sub>14</sub>, C<sub>15</sub>-C<sub>28</sub>, C<sub>29</sub>-C<sub>36</sub> (note TPH based only on aliphatics), benzo(a)pyrene TEQ, naphthalene and pyrene.
- The NZ MfE document includes the following chemicals: BTEX, TPH fractions C<sub>7</sub>-C<sub>9</sub>, C<sub>10</sub>-C<sub>14</sub>, C<sub>15</sub>-C<sub>36</sub> (note TPH based only on aliphatics), benzo(a)pyrene eq., naphthalene and pyrene.
- The US EPA has not published a document that relates specifically to the assessment of petroleum hydrocarbons, although there are a number of related documents pertaining to the assessment and modelling transport of petroleum chemicals, and carrying out health risk assessments.
- The UK propose to include TPH as described above. The actual list of indicator compounds has yet to be confirmed, but is likely to include BTEX and PAHs (including benzo(a)pyrene and naphthalene).
- The CCME assess the aliphatic and aromatic TPH fractions in their document *Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale*. Indicator compounds are not considered in this document, but a wider range of chemicals is addressed in their other technical documents.

There is a question as to whether some other chemicals should be included such as trimethylbenzenes, MTBE, and other additives, which currently are not routinely assessed in Australia. Whether these other chemicals should be included depends on their historical and current existence in Australian petroleum products, and whether their concentrations are such that they can become limiting considerations.

The PAG workshop discussed this issue, and there was general consensus that the HSLs should focus on hydrocarbons. It was noted that toxicity information on the other chemicals (trimethylbenzenes, MTBE, and other additives) was variable and uncertain, and it was agreed that they should not be included in this study. One of the PAG participants noted that MTBE was primarily an aesthetic issue. It was also agreed that lead should be excluded.

#### **Suggestion**

The guidelines should focus on petroleum hydrocarbons, in particular TPH, BTEX, and PAHs (particularly naphthalene, pyrene and the carcinogenic PAHs).

## 4. Hazard/toxicity assessment

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### 4.1 Introduction

There are two elements to the toxicological assessment (from enHealth 2004):

- **Hazard identification:** Examines the capacity of a chemical to cause adverse health effects in humans and animals. It is a qualitative description based on the type and quality of the data, complementary information and the weight of evidence from these sources. Key issues include nature, reliability and consistency of human and animal studies; availability of information about the mechanistic basis for activity; and the relevance of animal studies to humans.
- **Dose-response assessment:** Examines the quantitative relationships between exposure and the effects of concern. Important issues include relationship between extrapolation models and biological mechanisms; appropriateness of data sets; basis of selecting interspecies scaling factors, relevance of exposure routes, environmental conditions (e.g. pH); and the different susceptibilities in population subgroups.

Australia currently does not have a list of government-recommended toxicity criteria for chemicals such as that published in the USA or UK. The risk assessment methodologies published in Australia recommend using sources from numerous organisations, and as a result there is a lack of consistency between risk assessments conducted in Australia.

The following sections discuss issues associated with selection of appropriate toxicity criteria for petroleum hydrocarbons.

### 4.2 What are the preferred sources of toxicity criteria to be used in Australia?

The basis for the selection of sources of toxicity information for human health is outlined in the two primary documents, NEPM and enHealth. In the case of the enHealth document, the hierarchy of preferred sources is listed as:

- NHMRC (including Australian Drinking Water Guidelines)
- Therapeutic Goods Administration
- World Health Organisation and related documents, include drinking water guidelines, air quality guidelines, and IPCS documents
- enHealth Council documents
- National Environmental Health Forum (NEHF) documents
- International Agency for Research on Cancer (IARC)
- NICNAS Priority Existing Chemicals
- US Agency for Toxic Substances and Disease Registry (ATSDR)
- OECD Standard Information Data Sets (SIDS)
- US EPA Integrated Risk Information System (IRIS).

In the case of the NEPM, the hierarchy of sources is similar, although whereas enHealth considers the US EPA to be a level 1 source, the NEPM considers US EPA as a level 3 source for cancer slope factors, even though US EPA's database on toxicity criteria is considered to be one of the most comprehensive databases available, and the US EPA has a rigorous basis for review of toxicity information.

With respect to the toxicity of TPH carbon fractions, the work conducted by TPHCWG is generally considered to be the most relevant information available and has been used by UK EA and CCME in the development of their equivalent Petroleum Sites Screening criteria documents.

#### **Suggestion**

The enHealth hierarchy for selection of sources of toxicity information should be adopted. This should include reference to US EPA information as may be relevant (e.g. if it includes reference to studies that are more recent than the studies cited by WHO, NHMRC or IARC).

### **4.3 How do we address carcinogenic chemicals?**

Carcinogenic chemicals are assessed differently by various international organisations:

- The US EPA has recently published *Guidelines for Carcinogen Risk Assessment* (US EPA 2005a) and *Supplementary Guideline for Assessing Susceptibility from Early-Life to Carcinogens* (US EPA 2005b). These documents outline the methodology for assessing carcinogenic chemicals and deriving dose-responses (which are presented on the Information Risk Information System (IRIS) online database). The documents focus on weight of evidence, mode of effect, and extrapolation models to lower doses. New to the previous methodology is assessment of susceptibility and dose-response to children. Some chemicals (e.g. vinyl chloride) are found to affect the developmental growth of children and therefore separate toxicity criteria are presented for continuous exposure as an adult, and continuous exposure from birth to adult.
- Dose-responses for cancer-causing chemicals are presented as slope factors (SF) for linear dose-response and reference doses (RfD) for threshold dose-response. The mode of effect is dependent on the type of cancer. Non-linear methods may also be used if determined to be appropriate, including the benchmark dose. US EPA also presents SFs in terms of Unit Risks for both inhalation (air concentration) and oral (drinking water concentration). These criteria are normally presented for a range of lifetime cancer risks from  $1 \times 10^{-6}$  to  $1 \times 10^{-4}$ .
- The Canadian Council of Ministers of the Environment (CCME) follows the same approach as the United States for addressing non-threshold carcinogens.
- The enHealth (2004) and NEPM (1999) documents indicate that the preferred approach for assessing carcinogenic chemicals is to use the benchmark dose (BMD) approach, in which the BMD corresponds to a predetermined increase (usually 5%) of a defined effect in test population. The advantages of the BMD approach are that it takes into account information from the entire dose response curve rather than focusing on a single test dose (e.g. NOAEL), and the use of responses within the experimental range versus relying on extrapolations to doses

considerably below the experimental range. Note that the use of BMD eliminates the issue of defining an acceptable incremental cancer risk level. Jack Dempsey (2003) presented an estimate of BMD<sub>0.05</sub> for benzene in the proceedings of the Fifth National Workshop on the Assessment of Site Contamination, although this has not yet been endorsed by the NHMRC or the Contaminated Sites workshop.

- There are not many chemicals with BMD criteria developed that are endorsed by environmental authorities in Australia, and it is probably not practical to adopt BMD criteria at this time. The enHealth and NEPM documents support the use of other sources of toxicity criteria as outlined in Section 4.2. This includes WHO which nominate unit risks/slope factors for genotoxic carcinogens such as benzene and benzo(a)pyrene.
- The EA UK define a term 'index dose' (ID) which applies to non-threshold cancer chemicals, and is similar to tolerable daily intake (TDI). The ID is the level at which risk is considered minimal. The ID represents an exposure from a single source (e.g. soil), and background exposure is not incorporated into the assessment of dose.

#### **Suggestion**

Criteria should be prepared using BMD toxicity criteria endorsed by Australian regulatory agencies where these are available. Where these are not available, enHealth (rather than NEPM) guidelines should be used to select and apply toxicity information from other sources. This may include the use of slope factors and unit risks for carcinogenic chemicals. Commentary should be provided on recent work by US EPA, such as impacts on developmental growth to young children.

#### **4.4 What toxicity criteria are recommended for indicator chemicals?**

In the case of indicator chemicals, toxicity criteria for oral and inhalation exposure are required to assess risks from different exposure pathways. A primary issue in this is what sources should be used for the toxicity criteria, and the comments in the preceding section are relevant.

Toxicity criteria can also be expressed as inhalation unit risks (UR), reference concentrations, or guideline values. Where used, these should be expressed in terms of cancer slope factors, or inhalation acceptable daily intakes (ADI), for comparison with estimated chronic daily intake (CDI).

In the case of indicator chemicals, the selection of toxicity criteria should follow the more general approach outlined for other chemicals. In particular, consideration should be given to WHO Air Quality Guidelines for air toxicity, and the NHMRC Australian Drinking Water Guidelines and WHO Drinking Water Guidelines for oral toxicity. In the absence of relevant current information, US EPA toxicity information (particularly for cancer slope factors) should be used. These are listed in Table 1.

#### **Suggestion**

In the case of indicator chemicals, the selection of toxicity criteria should follow the more general approach outlined for other chemicals.



**Table 1. Toxicity criteria**

Chemicals	Carcinogens		Non-carcinogens	
	Inhalation SF (mg/kg/d) <sup>-1</sup>	Oral SF (mg/kg/d) <sup>-1</sup>	Inhalation ADI (mg/kg/d)	Oral ADI (mg/kg/d)
Benzene	0.021 <sup>(1)</sup>	0.03 <sup>(2)</sup>	-	-
Toluene	-	-	0.074 <sup>(1)</sup>	0.22 <sup>(2)</sup>
Ethylbenzene	-	-	6.29 <sup>(1)</sup>	0.097 <sup>(2)</sup>
Xylenes	-	-	0.25 <sup>(1)</sup>	0.179 <sup>(2)</sup>
Naphthalene	-	-	8.57 x 10 <sup>-4</sup> <sup>(4)</sup>	0.02 <sup>(4)</sup>
Pyrene	-	-	0.03 <sup>(4)</sup>	0.03 <sup>(4)</sup>
Benzo(a)pyrene-TEQ	304 <sup>(1)</sup>	0.5 <sup>(3)</sup>	-	-

**Notes:**

1. WHO (2000) Air Quality – UR converted to SF, Guideline value converted to ADI based on an adult 70 kg inhaling 20 m<sup>3</sup>/d
2. ADWG (NHMRC 2004)
3. WHO (2005) Drinking Water Guidelines
4. US EPA IRIS

**4.5 What toxicity criteria are recommended for TPH fractions?**

The selection of toxicity criteria for TPH fractions will depend on:

- What type of sites or contamination sources the document is going to address (e.g. as discussed in Section 2.3). If sites with heavy crude are to be included then consideration of heavy TPH is required.
- What types of fuel and what carbon range should be considered (e.g. as discussed in Sections 3.1 and 3.2).

International organisations such as UK EA, CCME and NZ MfE refer to the work carried out by the TPH Criteria Working Group in Massachusetts, USA:

- The UK EA (2005) recommend using criteria for TPH for each individual carbon fraction listed in the TPHCWG documents.
- CCME (2000) models each individual TPH fraction and then weights the fractions into four larger fractions based on composition. This is similar to the method used to derive the TPH toxicity values used in the AOIEGWG (1999) and NZ MfE (1999) documents.

**Suggestion**

TPHCWG should be used as the source of toxicity criteria for carbon range TPH fractions. A process for deriving toxicity criteria for the fractions using a weighting approach similar to that used by CCME should be applied, as outlined in Table 2.

Note that this suggestion is dependent on the selection of TPH fractions as discussed in Section 3.2.

**Table 2. Toxicity criteria for TPH**

Fraction	Inhalation RfC (mg/m <sup>3</sup> )	Inhalation ADI (mg/kg/d) <sup>(1)</sup>	Oral ADI (mg/kg/d)	Comments
C6-C9 aliphatic	14	4.0	3.5	Weighted 75% C <sub>5</sub> -C <sub>8</sub> range and 25% C <sub>9</sub> -C <sub>16</sub> range
C6-C9 aromatic	0.35	0.16	0.10	Weighted 75% C <sub>5</sub> -C <sub>8</sub> range and 25% C <sub>9</sub> -C <sub>16</sub> range
C10-C14 aliphatic	1.0	0.29	0.10	C <sub>&gt;8</sub> – C <sub>16</sub> range
C10-C14 aromatic	0.2	0.057	0.04	C <sub>&gt;8</sub> – C <sub>16</sub> range
C15+ aliphatic	1.0	0.29	0.10	C <sub>&gt;8</sub> – C <sub>16</sub> range
C15+ aromatic	0.2	0.057	0.04	C <sub>&gt;8</sub> – C <sub>16</sub> range

**Notes:**

1. Inhalation RfC is converted to ADI using US EPA convention based on an adult 70 kg inhaling 20 m<sup>3</sup>/d.  $RfD = RfC \times IR / BW$ .

## 4.6 For threshold chemicals, how do we account for background exposure?

Threshold chemicals, by definition, require that all sources of exposure be considered to determine the total intake level. This includes exposure from background.

Key guideline documents use the following approach to address background exposure:

- The AOIEGWG document does not account for background in non-carcinogenic calculations.
- The NZ MfE document does not account for background in non-carcinogenic calculations.
- The Dutch IVs and SRC<sub>human</sub> do not take into account background exposure (e.g. via food or air) by other routes than (indirectly) via the contaminated soil.
- The US EPA Region 9 does not account for background in non-carcinogenic calculations. However, guidance is provided in the *User's Guide* on addressing background issues. Generally US EPA does not require clean-up to below natural background levels. For anthropogenic chemicals, the *User's Guide* refers to US EPA's guidance document on background exposure.
- US EPA *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (2002) quotes the following policy with regard to background exposure in health risk assessments:

'A baseline risk assessment generally is conducted to characterize the current and potential threats to human health and the environment that may be posed by hazardous substances, pollutants, and contaminants at a site. EPA's 1989 Risk Assessment Guidance for Superfund (RAGS) provides general guidance for selecting COPCs, and considering background concentrations. In RAGS, EPA cautioned that eliminating COPCs based on

background (either because concentrations are below background levels or attributable to background sources) could result in the loss of important risk information for those potentially exposed, even though cleanup may or may not eliminate a source of risks caused by background levels. In light of more recent guidance for risk-based screening and risk characterization, this policy recommends a baseline risk assessment approach that retains constituents that exceed risk-based screening concentrations. This approach involves addressing site-specific background issues at the end of the risk assessment, in the risk characterization. Specifically, the COPCs with high background concentrations should be discussed in the risk characterization, and if data are available, the contribution of background to site concentrations should be distinguished. COPCs that have both release-related and background-related sources should be included in the risk assessment. When concentrations of naturally occurring elements at a site exceed risk-based screening levels, that information should be discussed qualitatively in the risk characterization.'

- The CCME (2000) indicates that (apart from PAHs) there is little evidence of the presence of mid to heavy TPH (i.e. C10+) in background water, air and diet. Therefore background levels for these TPH fractions can be considered to be negligible. For lighter fractions, air is likely to provide the only significant contribution to background exposure. Based on data taken from the TPHCWG, CCME calculated background air concentrations for the lighter fraction and this dose is subtracted from the TDI when deriving Tier 1 criteria. Note that in the CCME (1996) the target HI was set to 0.2. Because people are exposed to five primary media (i.e. air, water, soil, food, and consumer products), 20% of the residual TDI is apportioned to each of these five media. Therefore, 20% of the RTDI accounts for soils when deriving soil remediation guidelines, allowing for 80% of the remaining tolerable incremental exposure to be reserved for other media.
- The UK Environment Agency calculates background mean daily intake (MDI) from the diet and air. The MDI is subtracted from the tolerable daily intake (TDI) to calculate a tolerable daily soil intake (TDSI). The exception is that if the TDSI is greater than 80% of the TDI, the TDSI is set at 20% of the TDI.

Other documents to consider are:

- The WHO Air Quality Guidelines (2000) includes background exposure in the derivation of guideline values.
- The NHMRC Australian Drinking Water Guidelines (2004) includes a background factor of 80-90% to account for exposure from other sources.

There have been some studies conducted in Australia for background exposure:

- For TPH and BTEX, a study of air concentrations in a Brisbane industrial area may be used: reference Hawker, D, Hawas, O, Chan, A, Cohen, D, Christensen, E, Golding, G & Vowles, P 2002, *Characterisation and Identification of Sources of Volatile Organic Compounds in an Industrial Area in Brisbane*, 16th International Clean Air Conference, Christchurch, New Zealand, 18-22 August 2002.

- Limited information is available on the background levels of exposure for naphthalene. Naphthalene has generally not been identified in foods (two of 13,980 food samples showed positive detection), and exposure from food and water has been determined to be negligible with a daily intake of approximately  $5 \times 10^{-5}$  mg/kg body weight (ATSDR 1995). A review of PAH ambient air sampling data in Australia (Berko 1999) determined that ambient air concentrations of naphthalene (vapour and particulate) in Brisbane range from 40 ng/m<sup>3</sup> to 150 ng/m<sup>3</sup>, with an average of 75 ng/m<sup>3</sup>, and that the major source of naphthalene is due to diesel fuel exhaust. The latter value could be referenced and used in the derivation of criteria for naphthalene.

In summary, there are two ways of using background data for threshold chemicals when assessing risk or deriving criteria:

- Add the background dose to the chronic daily intake (CDI). This value is then compared to the acceptable daily intake (ADI) to estimate a hazard index (HI). The inverse is used to derive criteria.
- Subtract the background dose from the ADI to derive a residual acceptable daily intake (RADI) – UK approach. This value is then compared to the CDI from site contamination to estimate a HI. The inverse is used to derive criteria.

Both methods will result in the same criteria for each chemical. However, it can be seen that the two methods will have different impacts when it comes to assessing cumulative effects. The first method may give rise to difficulty if the background levels are significant, as combining the risks of background exposure may inadvertently result in unacceptable risks without any contamination contribution, when conservatively assuming additive effects of all chemicals. The second method effectively estimates HI based on site contamination only, after subtracting background effects. In this way, additive effects are considered only for site contribution and not additive effects of background. While the first method is strictly speaking more correct, the second method may be more appropriate if it is assumed that the effects of all chemicals are additive.

The PAG workshop discussed the issue of how best to consider background exposure. It was noted that there is little data on background levels and this makes it difficult to take background exposure in account when developing the HSLs. It is not clear as to whether the NEPM review process will deal with this issue. There was not a clear resolution on how to address background exposure and it was agreed that this was an issue that required further consideration.

### **Suggestion**

Further consideration is required to determine how best to take background exposure into account in the development of the HSLs.

## 4.7 How do we address bioavailability and absorption ratio?

Bioavailability is a measure of the fraction of chemical intake that is absorbed by the human body (or any other receptor). There are generally three types:

- oral bioavailability
- inhalation (known as lung retention factor), and
- dermal (known as absorption ratio).

Typically the approach adopted by enHealth, NHMRC, WHO, US EPA and most organisations is to assume an oral bioavailability of 1, unless there is strong evidence to use an alternative value. It should be noted that for many chemicals, oral toxicity criteria are based on administered dose and not absorbed dose. Therefore, the bioavailability factor is usually incorporated into the toxicity criteria. Additional information is provided in the US EPA IEUBK model for lead exposure.

The bioavailability factor may also differ due to the form of the chemical in the environment. For example, mineralised forms of metals may not be bioavailable because they are precipitated or can be bound within aquifer sediments or rock materials.

The recommended value for lung retention factor for dust and particles is 75% (enHealth 2004 Section 8.16.5). This is consistent with US Superfund Methodology (US EPA 1989). For volatiles, lung retention is assumed to be 100%.

The absorption ratio for skin is usually less than 100%. In 2003 US EPA updated its Dermal Exposure Assessment Guidance originally released in 1992. This states that absorption factors for volatiles should default to 3%, and semi-volatile to 10%. Assessment of dermal absorption for PAHs is considered a special case and guidance is provided separately for this chemical group.

### **Suggestion**

Bioavailability for oral exposure should default to 100%, unless there is strong evidence to use an alternative factor.

Dermal absorption ratio should follow the recent guidance provided by US EPA.

## 4.8 How do we address carcinogenic PAHs?

Carcinogenic PAHs are usually assessed using a toxic equivalence (TEQ) method. Each carcinogenic PAH is assigned a toxic equivalent factor (TEF) which is its relative toxicity compared to benzo(a)pyrene. To calculate a toxic equivalent PAH concentration, each individual PAH concentration is multiplied by its TEF, and summed to result in a single value for PAH TEQ. This concentration may then be compared to the criteria derived for benzo(a)pyrene.

A number of regulatory organisations use this approach, including US EPA. The recommended set for use in Australia is that presented by Fitzgerald (1998) in the Contaminated Sites Monograph Series, No.7.

Note that benzo(a)pyrene is, by convention, the base chemical on which the TEFs are compared to, and the criteria derived for benzo(a)pyrene should not depend on the set of TEFs selected.

The only limitation to the application of PAH TEQ is that all chemicals are assumed to inherit the same physical properties of benzo(a)pyrene. This is not the case for naphthalene as it is considered to be semi-volatile. For this reason naphthalene is assessed independently of PAH TEQ, and it is also assumed to have a threshold toxic effect.

A discussion of the application of TEQ is presented in the Risk Management section of the document under 'Application of Criteria'.

#### **Suggestion**

Carcinogenic PAHs should be assessed using the toxic equivalent approach based on benzo(a)pyrene, with criteria being derived based on B(a)P.

Naphthalene should be assessed independently due to its different physical properties.

### **4.9 Do we consider other toxicity effects (acute)?**

Under the majority of circumstances, criteria derived for protection of long-term chronic exposure to chemicals will be protective of short-term acute exposure. However, consideration of acute exposure may be required for shorter-term exposure. Such scenarios may include:

- exposure to intrusive maintenance workers entering trenches, and
- short-term exposure in cellars/basements. Note that in this situation, the occurrence of odour may be the limiting criteria.

The US EPA, CCME and UK documents are based on long-term human health effects and do not specifically address acute issues.

The AOIEGWG (1999) document and NZ MfE (1999) documents do not consider short-term acute effects.

One way to address acute issues to intrusive maintenance workers is to derive criteria based on Worksafe air standards, irrespective of the short duration. Further discussion on this is provided in Section 4.10.

It should be noted that for petroleum hydrocarbon chemicals, criteria derived to protect human health based on long-term exposure considerations are generally more stringent than criteria derived on the basis of avoiding odour.

#### **Suggestion**

Consideration should be given to deriving criteria that will provide safe working conditions for workers, such as may occur in trenches. Consideration should be given to both Worksafe criteria and environmental assessment criteria (refer to Section 4.10).

## 4.10 Under what situations can Worksafe criteria apply?

There is considerable debate as to whether Worksafe criteria apply in the context of commercial/industrial sites, and in a number of cases there are discontinuities between legislation and uncertainty whether the methods of assessment that should be adopted should be those of the EPAs or Worksafe Australia (now governed by the Australian Safety and Compensation Council).

Generally, the NEPM and enHealth do not discuss the relevance and application of using Worksafe criteria in risk assessments for commercial and industrial workers for contamination assessment. However, enHealth (2004) Section 7.2.2 states the following on occupational health and safety sources:

‘These may be a useful source for toxicological data and reviews but occupational exposure criteria must not be used in a general public health context without appropriate adjustment for the different durations of exposure, the inclusion of susceptible sub-population in the general community (e.g. children) and the methodological difference in the setting of criteria.’

This is an important issue, as Worksafe Standards are generally higher than air concentrations that would be derived using the approach outlined in enHealth or NEPM, sometimes by two or three orders of magnitude.

Special consideration for sites with an ongoing use for petroleum industry purposes may be required if this land use is to be included in the guidelines. For example, at a service station, workers can be exposed to fugitive emissions resulting from car refuelling activities, and this can be important when assessing chemicals exhibiting threshold toxic effects. This consideration would lead to lower criteria under the enHealth and NEPM methodologies, and may not be practical for such sites.

A factor in determining the relevance of Worksafe standards is whether workers are appraised of the potential for exposure, and therefore can take appropriate action to minimise exposure (e.g. through the use of personal protection equipment). While petroleum industry workers might expect to be exposed to petroleum chemicals on petroleum industry sites, it is not clear that this would be the case for workers in an unrelated industry (such as office workers).

The US EPA, CCME and UK guidance documents do not include ongoing petroleum handling facilities as a land use, and neither does the NZ MfE document *Guidelines for assessing and managing petroleum hydrocarbon contaminated sites in New Zealand* (1999).

In the AOIEGWG document, ongoing petroleum use has been assessed based on Worksafe criteria rather than on the basis of toxicity criteria. While the Worksafe standard may be considered to be applicable to these sites, the standard applies to exposure from all sources and it is likely that the greatest contribution of exposure to service station workers is fumes from cars and vapour from the petrol bowsers. A method for addressing this might be to determine the average working day (eight hour) exposure concentration from the site contamination for a service station worker, and to subtract this concentration from the Worksafe Time Weighted Average (TWA) standard assuming it forms a background exposure.

As noted in the previous section, Worksafe Standards may also be used for intrusive maintenance workers digging trenches to ensure that the air concentrations do not exceed the allowable level for a workplace environment, irrespective of the short duration of excavation works.

The PAG workshop discussed this issue. There were differing opinions on the use of occupational standards in deriving HSLs. It was noted that the difference between occupational and environmental approaches may be more than two orders of magnitude, and the exposure of workers involved in the excavation of trenches could be a limiting risk scenario and drive remediation. There was also discussion on whether consideration should be given to construction workers who might move from site to site and thereby incur increased exposure. There was no clear resolution of these issues, although there was reservation on using only Worksafe criteria for assessing exposure of trench and construction workers, and there was general agreement that both environmental and occupational methods should be considered and compared.

### **Suggestion**

If the guidelines are to extend to sites used for ongoing petroleum use (e.g. service stations) where workers can expect to be exposed to petroleum hydrocarbons during the course of their work, then the criteria should be based on Worksafe Standards, with a check to confirm that the criteria will also be protective of other exposures (such as may occur to the public that visit such a site) assessed using enHealth methods. The daily contribution of exposure to workers at these facilities from the site activities (such as refuelling) should be considered when determining the allowable exposure.

For trench and construction workers, both occupational and environmental methods should be considered and compared.



## 5. Exposure assessment

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### 5.1 Which land uses/settings should be considered?

There are a number of potential land use settings that may be assessed, some more common than others. There are also some land use types that have specific issues associated with them, some that require specific information to address environmental risks. The inclusion of particular land uses may also include subsets with different assumptions (e.g. low and high density residential land).

A review of Australian and international literature indicates:

- The AOIEGWG document considers four land use settings for the derivation of soil criteria. These are residential (low density), commercial/industrial, recreational/parklands, and ongoing petroleum facilities. This document does not consider buildings with basements, or high density residential premises, or agricultural settings.
- The NZ MfE document considers three land uses. These are residential (low density), agricultural and commercial/industrial land use. Residential land use assumes slab construction on ground.
- The US EPA Region 9 considers residential land (low density), and commercial/industrial land. This document does not consider vapour intruding into buildings.
- The CCME has developed *Canada-Wide Standards for Petroleum Hydrocarbons in Soil* (2001). The land uses included in the document are agricultural, residential, commercial and industrial. Agricultural land is protective of growing crops and livestock. Residential land also includes parklands. Commercial land is also protective of children in day care. The standards do not consider basements.
- The UK CLEA model considers residential use (with varying building configurations including basements) and with/without produce, allotments (which is non-commercial farmland dedicated to production of fruit and vegetables for the family), and commercial/industrial land use.
- The German Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV) (1999) requires that investigations categorise land use as playgrounds, residential, parks and recreational areas, and industrial/commercial land.

It is desirable that the selection of land uses should represent a large proportion of sites that require to be addressed in Australia. Typically, these are residential, open space, commercial and industrial, and these land uses should be considered in the guidelines. It is also common in Australia to distinguish residential land on the basis of low, medium and high density use.

With the exception of the UK CLEA model, all guideline documents do not consider the issue of cellars and basements. This poses a considerable limitation for sites in Australia where basements are becoming more common, and in general basements need to be considered where a site is to be assessed for unrestricted use. The inclusion of cellars not only requires consideration of inputs with regard to intrusion of vapours into a confined space, but also potential migration into the living areas of the

house. Therefore risks to residents will increase as a result of exposure, and the potential for odour may also become a limiting issue.

With respect to vapour intrusion into residential buildings, there is not likely to be significant differences in criteria as a function of dwelling density (i.e. low, medium and high density land use) for dwellings with a slab on ground construction, although there can be major differences between dwellings with or without a basement carpark.

Ongoing petroleum use has been assessed as well in the AOIEGWG document, although criteria were based on Worksafe criteria rather than on the basis of toxicity assessment. For further discussion on the application of Worksafe criteria, refer to Section 4.10.

Agricultural land may be considered significant for rural areas. However, with the exception of PAHs, petroleum hydrocarbons typically do not tend to accumulate in plants and therefore are unlikely to contribute significantly to health risk. It would therefore be possible to consider rural/agricultural land as standard residential land. Issues associated with produce could be considered independently through beneficial use of water (refer to Section 5.3).

The PAG workshop discussed the difference between ongoing petroleum use sites and standard commercial/industrial sites. Industry members of the PAG noted their preference for distinguishing a distinct petroleum land use site on which assessment could be based on occupational Worksafe Standards. There was no final agreement on this.

The PAG workshop also discussed the definitions of low, medium and high density residential, commercial and industrial land use, and noted that there is a need for formal definitions. It was also noted that in some states child care facilities may be located within commercial/industrial premises (e.g. this can be the case in New South Wales).

#### **Suggestion**

- Criteria should be developed for the following land uses: residential (with varying density of development), open space, commercial/industrial, and ongoing petroleum use (e.g. service stations). Clear definitions of each land use should be presented.
- Criteria should be provided for assessing the intrusion of volatile contaminants through floor slabs into buildings, and into cellars and basements.
- Commentary should be provided regarding the application of the criteria to agricultural land.
- The assessment of ongoing petroleum use sites (e.g. service stations) should consider Worksafe Standards and enHealth exposure assessment as noted in Section 4.10.

## 5.2 Which beneficial uses of groundwater should be included?

Apart from the issue of volatile chemicals emitting from groundwater, beneficial uses of groundwater that are required to be considered can involve any extraction use of groundwater, and protection of ecosystems. The beneficial uses to be protected in Australia are usually determined based on legislative requirements for each state and territory, as well as where the point of compliance is required. The beneficial uses may include:

- potable use
- irrigation use
- stock watering
- industrial water use
- primary contact recreation
- buildings and structures, and
- protection of ecosystems.

In the case of the guideline document, a decision needs to be made as to whether criteria need to be presented to protect all of these uses, or for only uses and exposure pathways relevant to assessing human health. Restricting the derivation of criteria to human health effects is consistent with this, although it is not necessarily helpful to assessors who will usually have to consider the requirements for protection of all of these beneficial uses. In order to be helpful, it is suggested that criteria be included in the guidelines where relevant criteria have been published, but to not develop non-health-based criteria for uses where such criteria are not readily available (such as criteria for certain hydrocarbons in irrigation water that will not adversely affect plant growth).

Criteria for some chemicals are present in literature for a number of the beneficial uses listed above. Where no criteria are available, fate and transport modelling and risk calculation modelling may be required. For example, if irrigation is likely to give rise to exposure of persons to water spray, then modelling of the exposure may be necessary (e.g. using model for a shower spray involving dermal and inhalation exposure). Similarly, if irrigation water is likely to give rise to exposure through uptake by plants and consumption of the plants, then this exposure may need to be considered.

### **Suggestion**

The beneficial uses of groundwater that are to be protected should be determined by the relevant regulatory requirements.

Criteria should be provided for the protection of human health where relevant for each of the beneficial uses.

Criteria should be listed for the protection of each of the beneficial uses where the relevant criteria have been published.

### 5.3 Do we consider the risks to human health associated with consuming home-grown produce?

The consumption of home-grown produce such as fruit, vegetables, poultry meat and eggs is usually associated with rural residential and agricultural land where large gardens are possible. Consumption of home-grown produce may also potentially occur in urban low density residential settings, but residents in urban settings usually purchase most of their food with home-grown produce making up a small percentage of their diet, although a small percentage of population do grow and consume a significant amount of their own fruit and vegetables.

As discussed in Section 5.1, petroleum hydrocarbons are unlikely to accumulate in produce, with the exception of PAHs.

Key guideline documents use the following approach to address home-grown produce:

- The AOIEGWG document does not include the consumption of home-grown produce in the development of soil criteria. Where produce is considered to be of major concern, it is recommended that a site-specific assessment be conducted. For groundwater, criteria were developed based on irrigation spraying and consumption of produce. Poultry have not been considered.
- The NZ MfE document considers plant uptake and home-grown produce. For agricultural land use it is assumed that 100% of fruit and vegetables are home-grown. For residential land 10% of home-grown produce is assumed.
- The US EPA Region 9 PRGs do not consider home-grown produce.
- The CCME considers home-grown produce under the scenario of agricultural land use. Protection of plant toxicity is considered for both agricultural and residential land uses, but protection of human consumption of produce has not been considered.
- The UK CLEA model includes a detailed calculation for produce uptake and consumption.
- The German Ordinance document considers protection of plants in vegetable gardens, grasslands and agricultural land, with regard to growth impairment of cultivated plants.

#### **Suggested approach**

Commentary should be provided on the risk associated with uptake of chemicals in home-grown produce, with inclusion of plant uptake from soil in the derivation of criteria only where this is likely to be significant (expected to be only for PAHs).

In the case of setting groundwater use criteria, the potential for uptake should be considered when setting irrigation beneficial use criteria.

## 5.4 How do we address the issue of source depth? How do we address different soil types?

There are a number of ways to address these issues. Potentially, the easiest and most conservative way is to choose a conservative soil type from a vapour perspective (e.g. sand) and assume that contaminated soil is located within the top metre where direct contact may occur. This is the basis of a number of guideline documents (NEPM, US EPA Region 9 PRG) and is generally the approach taken for non-volatile chemicals where soil ingestion and dermal contact is likely to constitute the majority of the health risk. In particular:

- The NEPM does not distinguish between depths. For example, a residential lead soil criterion of 300 mg/kg applies equally in surface soils as it does at 5 m below ground surface.
- The US EPA Region 9 PRGs do not distinguish between depths or soil types. For soils one set of PRGs is presented for residential land use for all assessed chemicals. For volatile chemicals, such as benzene, the inhalation pathway is assessed based on outdoor air exposure resulting from volatilisation in surface soils. The soil properties are conservatively based on porous soil such as sand or fill. Exposure to indoor air is not assessed in the derivation of soil PRGs. However, an air PRG is also presented. This can be used to derive an equivalent soil PRG, but an attenuation factor is required to be calculated through vapour emission modelling (i.e. site-specific modelling) – see Section 6.
- The CCME derives soil criteria for two different soil types, fine and coarse grained soil. The definition of fine grain soil is defined as having greater than 50% by mass particles less than 75 µm mean diameter. The CCME does not make any distinction between depths of contamination and conservatively assumes that direct contact occurs in each scenario, irrespective of source depth.
- The Dutch Target and Intervention Values do not distinguish between different soil depths. The values for soil and sediment were expressed as the concentration in a standard soil with 10% organic matter, 25% clay and a pH 6.
- The UK CLEA model derives criteria for a number of soil types, but the contamination is assumed to be directly beneath the building foundation or in surface soil for outdoor exposure. There are no allowances for soils at depth. For groundwater, the depth to the water table may be input into the model.

The difficulty with setting and using Tier 1 criteria for volatile chemicals is that there are many variables which determine the rate of volatilisation from a subsurface source, and the range of emission rates can vary by four orders of magnitude, or more, as a result of soil lithology, depth to source, moisture content and organic carbon content. Because of this, it is difficult to set a single Tier 1 criterion for a volatile chemical, as this criterion would have to be very conservative to be protective of most scenarios.

A 'single depth' approach could be favoured because of the uncertainty associated with uncontrolled sites. For sites where there are no controls over the redevelopment of the site, subsurface contaminated soil at depth may be excavated and placed at or near the surface during the construction. In addition, consideration of basements significantly impacts the rate of vapour intrusion into the building due the foundations being closer (if not within) the contaminated soil.

However, while the potential for subsurface contaminated soils to be brought to surface or basements constructed on uncontrolled sites needs to be considered, it is common practice in Australia to assume that soils can safely remain *in situ* on controlled sites. In general, whether to use *in situ* subsurface source scenarios or surface soil scenarios where there are no controls on a site development would need to be determined and justified on a site-specific basis.

An alternative approach for deriving Tier 1 values for volatile chemicals has been used by the New Zealand Ministry for the Environment (MfE 1999) and the Australian Petroleum Institute (AOIEGWG 1999). This has involved estimating criteria corresponding to vapour emission modelling for a variety of land uses, soil depths and soil types. These have been listed in look-up tables and provide a set of values that can be referred to when assessing the significance of contamination on a particular site.

- The AOIEGWG document presents Tier 1 criteria for soil and groundwater for seven different soil classifications (non-porous fractured rock, porous fractured rock, sand, silt, silty clay, clay and gravel) based on typical soil properties reported for Australian soils. For soils, criteria have been presented for surface soils, soils 1 m+, and soils 4 m+. For groundwater, the depths to the water table that were modelled were 2 m, 4 m and 8 m. Scenarios where the water table was shallower than 2 m were not represented by these derived criteria. The various depths specifically impact the vapour modelling calculations (the deeper the source, the more resistance to vapour transport). In addition, consideration of exposure pathways related to depth are incorporated into the criteria. For example, oral ingestion and dermal contact will occur in surface soils by residents as well as inhalation of volatiles, but for soils 1 m+ direct contact by residents is unlikely but inhalation of volatiles occurs. Also, maintenance workers involved in trenching will be exposed by direct contact even in deeper soils.
- The NZ MfE document presents a similar process to the AOIEGWG document. Six different soil types had been used representative of typical soils in NZ (sand, sandy silt, silty clay, clay, pumice and peats). The modelling depths are the same as those in the AOIEGWG document.
- The UK CLEA model has three default soil types, but has the provision for adding to the database.

While these methods assess subsurface contamination, assessment is limited to *in situ* soil with homogeneous soil profile. Therefore, these methods cannot be used for assessing encapsulation methods such as clay capping.

### **Suggestion**

Criteria should be developed for a range of soil types and depths similarly to the approach used in the AOIEGWG and NZ MfE documents. The selection of soil types and depths should be reviewed.

Commentary should be provided regarding the application of the criteria and the factors that should be considered regarding the potential for soil at depth to be brought to the surface.

## 5.5 Which exposure pathways are considered relevant?

With respect to soil contamination, the primary exposure pathways are soil, ingestion, dermal contact, and inhalation (particulate and volatile). Less typical exposure pathways such as home-grown produce may also be of concern in particular land use situations.

The approach taken in the various key documents with regard to considering particular exposure pathways is as follows:

- The NEPM considers only the primary exposure pathways, and these are applied for all receptors without distinguishing between depth of contamination. Home-grown produce is listed under Health Investigation Levels (HSLs) B and C, but no values are presented.
- The AOIEGWG document considers inhalation of volatiles, oral ingestion and dermal contact for soils. Inhalation of dusts has not been included as risks from dust inhalation are considered small compared to oral and dermal exposure. Note that dust inhalation will only occur for surface soils for primary receptors. For groundwater, the exposure pathways are specific for the beneficial use. Protection of land considers only inhalation of volatiles (note that only primary receptors are considered, not trench workers, and therefore direct contact has not been considered).
- For groundwater, exposure associated with irrigation was estimated for dermal and oral exposure to children playing under sprinklers, and inhalation of aerosols and consumption of produce by adults and children. For stock water, calculation of uptake by stock and consumption of animal products (meat and milk) were estimated.
- The NZ MfE document follows a similar process to the AOIEGWG document. Consideration is given to inhalation of volatiles, oral ingestion and dermal contact for soils. Inhalation of dusts has not been included as risks from dust inhalation are considered small compared to oral and dermal exposure. For agricultural and residential land, ingestion of produce is also considered.

For groundwater, the exposure pathways are specific for the beneficial use. Protection of land use considers inhalation of volatiles from groundwater (note that only primary receptors are considered, not trench workers, and therefore direct contact has not been considered). For irrigation use exposure is estimated for dermal and oral exposure to children playing under sprinklers, inhalation of aerosols and produce consumption for adults and children. For stock water, uptake by stock and consumption has been included in the estimates.

- The US EPA Region 9 PRGs consider inhalation, dermal and oral exposure for the soil PRGs. Inhalation is based on volatiles if Henry's Law constant is greater than  $10^{-5}$  atm.m<sup>3</sup>/mol and the molecular weight less than 200 g/mole, and otherwise on particulate emissions based on fugitive dust.

For groundwater, PRGs for potable use are based on ingestion and inhalation. The inhalation component is based on assumptions of water use (showering, laundering and dishwashing).

- The CCME considers incidental ingestion, dermal, inhalation of vapours and ingestion of drinking water. Exposure to ecological receptors are based on direct contact and food-chain analysis.
- The UK CLEA model allows complex exposure calculations. These include oral ingestion, dermal exposure, inhalation of dust, inhalation of volatiles, home-grown produce uptake and consumption. It should be noted that indoor inhalation of volatiles is not included in the default model, but can be included if deemed a relevant exposure pathway.
- The German Ordinance document primarily considers direct contact issues for human health. Site-specific investigations are required if vapour intrusion into buildings is identified.
- The Dutch Intervention Value is calculated in the human exposure model CSOIL which includes several exposure routes. These include ingestion and dermal uptake of soil, inhalation via air, intake of drinking water, dermal contact and inhalation during showering and consumption of home-grown crops (comprising 10% of the total consumed vegetables) (RIVM 2001).

#### **Suggestion**

The exposure pathways used in the AOIEGWG guidelines should be adopted.

## **5.6 How are different age groups addressed?**

The selection of age groups is an issue for residential land use and public open space. Key factors to be considered include:

- differences in parameters as a result of growth (e.g. body weight, inhalation rate, skin surface area), and
- differences in behaviour (e.g. soil ingestion rate).

The enHeath and NEPM guidance documents do not specifically provide guidance on the selection of age groups for assessing risks. However, some of the data presented are subdivided into three groups:

- young children (up to age of 5)
- children (between 6 and 15), and
- adults (16+).

For threshold chemicals, daily intake is generally higher for young children and can be expected to be limiting. This is due to the higher soil ingestion rate for this age group. In addition, the inhalation to body weight ratio is greater than the other two age groups.

Other risk-based guidance documents use the following approaches:

- US EPA RAGS use two age groups, children aged 1–6, and adults (7+). It is accepted that young children are usually the most exposed receptor (i.e. the highest daily dose per body weight). This is because the inhalation rate per body weight ratio of young children is approximately three times that of adults. Also, young



children have a higher soil ingestion rate than adults as a result of crawling around on hands and knees and increased hand-to-mouth activity. Young children are usually the receptor for which threshold chemical risks are assessed.

- The Australian and New Zealand Oil industry guidelines are based on the same approach as the US EPA RAGS.
- The UK CLEA model contains statistics on exposure parameters for each year of age from 1 to 16, and adults. The model estimates risk for each year of exposure. For lifetime risks, the doses are averaged across all age groups.
- The CCME takes a similar approach to the US EPA RAGS in developing soil quality guidelines; however, child exposure is based on toddlers aged between 6 months and 4 years.

### **Suggestion**

The three age groups recommended by enHealth should be used for the derivation of criteria.

## **5.7 What are recommended exposure parameters for exposure settings?**

The primary exposure factors used are body weight, inhalation rate, soil ingestion rate, skin surface area, exposure time indoor/outdoor, exposure frequency (days per year), and exposure duration (number of years). The selection of exposure parameters can depend on the age groups that are to be considered, as discussed in the preceding section.

Exposure parameters are usually selected to represent a 'reasonable worst case' exposure. This does not mean that the most conservative value for each parameter is selected, because to do this would result in an exposure that is considered to be too conservative and unlikely. Instead the parameters are selected on the basis that when combined, an upper level of exposure is estimated that would represent the upperbound of the general population. Most of these parameters are based on survey and statistical distributions of the general population.

Exposure duration, however, is one parameter for which there is considerable debate to whether it is acceptable to use a statistical approach to assess risks. The US EPA RAGS and PRGs use an exposure duration of 30 years for residential land, being the 90th percentile for a person to live in the same place of residence in the US. This is different to the guidance in the NEPM and enHealth, which indicate that a person has 'the right' to live their entire life in one place without being exposed to an unacceptable level of risk. By convention this exposure duration is 70 years. Note this parameter only affects carcinogenic chemicals that are assessed over a lifetime.

Other risk-based guidance documents use the following approach:

- The UK CLEA model is based only on threshold approach and therefore does not consider incremental risks from child to adulthood. The exposure duration assessed for young children is 6 years, and the average daily dose is based on this age group.

Deriving criteria for carcinogenic chemicals in this way would result in highly conservative criteria, as the daily dose for adults is generally lower than children.

- The Australian and New Zealand Oil Industry Guidelines preceded the publication of the NEPM and enHealth documents, and are based on the approach presented in the US EPA RAGS.
- The CCME soil quality guidelines assess non-threshold chemicals on adult exposure over a 70-year period.

In Australia, recommended exposure parameters from the NEPM are defined in the *Proceedings of the National Workshops in the Health Risk Assessment and Management of Contaminated Sites* Monograph Series. A number of these are referred to in enHealth (2004). There are some slight differences between the NEPM and enHealth documents. For example, NEPM recommends an adult body weight of 70 kg, while enHealth recommends 64 kg. NEPM recommends 24 hours per day exposure time indoors for residents, while enHealth recommends 20 hours per day indoors and four hours per day outdoors. In general, Australian practice to date has been to use the values recommended in the NEPM.

International agencies use their own data. The US EPA has an *Exposure Assessment Handbook* which lists statistical-based exposure parameters. The UK makes use of its own statistics in the CLEA model. The data are comprehensive and include data for every age from 1 to 16, and adults. The Canadian guidelines use their own data, and some data from the USA.

Inhalation rate is another key exposure parameter where there are significant differences in literature values. With petroleum hydrocarbons, inhalation of vapours intruding into buildings is one of the most significant exposure pathways for receptors. Inhalation rates used will have a significant impact on the resulting criteria. For example, for residential exposure it can be assumed that there will be some active periods and some non-active periods (i.e. sleep). The US EPA RAGS recommends a daily average inhalation rate of 20 m<sup>3</sup>/day (or 0.833 m<sup>3</sup>/hr). However, Langley (1993) indicates the mean inhalation rate for adults (men and women) is 22 m<sup>3</sup>/d or 0.92 m<sup>3</sup>/h, which is 10% higher than the US value. Differences for children are greater. The US EPA RAGS use a value of 0.21 m<sup>3</sup>/hr for young children. Langley (1993) presents daily average inhalation rates for a one year old and 10-year-old as 0.15 m<sup>3</sup>/hr and 0.625 m<sup>3</sup>/hr, respectively. Use of the one-year-old inhalation rate would only be meaningful if the body weight corresponded to a one-year-old. Typically a two- to three-year-old can be considered to be more representative of the young child age group. Langley et al. (1996) published inhalation rates for different age groups and different activities. The mean inhalation rate of young children for lying, sitting and standing is 0.39 m<sup>3</sup>/hr, which is significantly higher than for a one-year-old and higher than the US EPA RAGS value of 0.21 m<sup>3</sup>/hr, by almost two-fold. Separate consideration would also need to be given to inhalation during outdoor activities.

### **Suggestion**

Assumptions regarding exposure parameters should follow enHealth or NEPM recommendations, and guidance as to which of these should be adopted should be sought from the relevant Australian regulatory agencies.

## 5.8 Should secondary receptors be considered?

'Secondary receptors' refers to receptors that are expected to be present at a site for only a short period. These include for example:

- intrusive maintenance workers (utility maintenance involving trenching), and
- construction workers.

Concern over protection of these receptors is a recent issue and has not been discussed in the NEPM and enHealth documents. The concern has arisen as a result of the large amount of site redevelopment that has occurred over the past five years or so, and information regarding the requirements for protection of these receptors is limited.

There are a number of questions associated with these receptors:

- What settings are used to model exposure, e.g. trench dimensions and air exchange rate?
- What exposure parameters should be used, primarily how many days and how many years? Is it acceptable to consider health risk to the worker working at the site for the duration of their works, or do we have to consider a maintenance/construction worker that may move from one contaminated site to another contaminated site?

The key documents reviewed take the following approaches:

- The AOIEGWG document considers excavation and construction workers. Vapour modelling has been conducted incorporating a typical scenario. Exposure for construction workers was based on a typical building scenario with a duration of one year and frequency of 50 days (i.e. a single exposure event). Maintenance workers have been assumed to work for 50 days per year for 20 years (repetitive exposure).
- The NZ MfE document considers excavation workers. Vapour modelling has been carried out based on a typical scenario. Maintenance workers have been assumed to work for 50 days per year for 20 years (repetitive exposure).
- The US EPA Region 9 PRGs, CCME and UK CLEA consider only the primary receptors and do not consider construction or intrusive maintenance workers.

Review of potential exposure scenarios indicates that the potential for exposure during subsurface maintenance works may be considered in terms of the following subcategories:

- Surface intrusion – telephone, electricity, local gas, water and sewer. The majority of these utilities are located within the top 1 m of soil. Incidents will require quick repair/replacement (say a maximum of 10 days duration), but may occur frequently, say once a year. Accumulation of gases in trenches is minimal due to the nature of shallow excavations, and may be modelled using an outdoor air vapour model.
- Deep intrusion – deep sewer, water or gas mains. These utilities require deep excavation (down to 2 m), but are not often located on individual sites, as they are usually found along roads or within their own easement corridor. Incidents for these repairs/replacements are infrequent (say once every 10 years) but require more time

for repairs (say a maximum of four weeks duration). Note that some deep sewers may extend greater than 5 m depths (for these circumstances a site-specific assessment may be more appropriate). Vapour modelling may be similar to that conducted for the AOIEGWG and NZ MfE documents.

Criteria could be derived for both of these sub-receptor groups. For surface intrusion, an outdoor air volatilisation model could be used with the wind speed set to say 10% of the average (an average will be based on Bureau of Meteorology data for the major city centres). For deep intrusion, estimation of the vapour exposure that occurs during subsurface works could use the parameters listed in Table 3. A typical trench could be 2 m deep x 1 m wide, and it could be assumed that contamination in the surface to 2 m depth will apply throughout the trench.

**Table 3. Exposure parameters – intrusive maintenance workers**

Parameter	Symbol	Units	Surface intrusion maintenance worker	Deep intrusive maintenance worker
Exposure frequency	EF	D/yr	10 <sup>9</sup>	20 <sup>9</sup>
Exposure duration	ED	Yrs	30 <sup>2, 10</sup>	3 <sup>2, 10</sup>
Exposure time	ET	Hrs/d	8 <sup>2, 3</sup>	6 <sup>4</sup>
Body weight	BW	Kg	70 <sup>2</sup>	70 <sup>2</sup>
Inhalation rate	IR	M <sup>3</sup> /hr	2.1 <sup>5</sup>	2.1 <sup>5</sup>
Soil ingestion rate	IGRs	Mg/d	330 <sup>8</sup>	330 <sup>8</sup>
Soil adherence	AH	mg/cm <sup>2</sup> /d	1.5 <sup>7</sup>	1.5 <sup>7</sup>
Skin area	SA	Cm <sup>2</sup>	4700 <sup>6</sup>	4700 <sup>6</sup>
Lung retention factor (dust)	LR	-	0.75 <sup>3</sup>	0.75 <sup>3</sup>
Averaging time	AT	Yrs	70 for carcinogenic, ED for non-carcinogenic <sup>1</sup>	

**Notes:**

1. US EPA (1991)
2. NEPC (1999)
3. enHealth (2004)
4. Deep trench worker not expected to continuously work the entire working day in trench vicinity results in a total inhalation rate of 10,666 litres per eight hour working day or 1.33 m<sup>3</sup>/hr.
5. Langley (1996) – Inhalation rate of 35 L/min for moderate level of work (digging with spade) such as in excavation work.
6. Langley (1996). Skin area is based on the total body surface area and the percentage of the surface area that is exposed. An adult has an average total surface area of 19,400 cm<sup>2</sup> with 24% of this area exposed.
7. US EPA (1989)
8. US EPA (1991) – Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual Supplemental Guidance Standard Default Exposure Factors.
9. Single event, two working weeks for shallow utility maintenance, four working weeks for deep utility maintenance.
10. Repair once a year for shallow utility, once every 10 years for deep utility.

If a trench should intersect the water table then a site-specific assessment would need to be conducted, as there can be significant issues with regard to contaminated water seeping into the trench (including the accumulation of gases in confined space and disposal of contaminated water). The scenarios to be considered and the exposure parameters to be assumed need to be agreed if such scenarios are to be assessed.

**Suggestion**

Criteria should be derived for both shallow and deep receptor subgroups. The basis for setting exposure parameters for each sub-group should be reviewed and may follow those listed in Table 3.

## 5.9 Soil protective of groundwater

In general, groundwater quality should be protected, and it should be confirmed that residual soil contamination will not adversely affect groundwater quality.

Issues associated with ensuring contamination levels in soil are protective of groundwater quality include:

- Predicting the leaching of soil contamination and the subsequent mixing and dispersion in groundwater and effect on groundwater quality is difficult, and dependent on factors such as infiltration rate and groundwater flow rate, and the organic content and pH of the soil. This has a high level of uncertainty.
- Setting target endpoints for groundwater quality is a complex matter. As there can be a range of beneficial uses of groundwater that can require protection, this could result in the need for multiple sets of soil criteria for protection of groundwater.

Review of the key documents indicates the following:

- The AOIEGWG document does not consider soil protective of groundwater.
- The NZ MfE document calculates soil criteria protective of groundwater for potable use. The calculation uses a complex model by Genuchten and Alves, which is used in the BP RISC software. Assumptions are made on water infiltration rates and hydraulic conductivity for different soil types, and chemical degradation half-life. A hydraulic gradient of 0.01 m/m was assumed.
- The US EPA Region 9 PRGs present a soil screening level (SSL) for the protection of groundwater. SSLs are back-calculated from acceptable groundwater concentrations (usually drinking water criteria). First the acceptable groundwater concentration is multiplied by a dilution factor to obtain a target leachate concentration. Then a partition equation is used to calculate the total soil concentrations (i.e. SSL) corresponding to this soil leachate concentration. The SSL methodology was designed for use during the early stages of a site evaluation when information about subsurface conditions may be limited, but is not proposed as a substitution for groundwater investigation. Because of this constraint, the methodology is based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface. The PRG tables present SSLs using a dilution attenuation factor (DAF) of both 1 and 20. In addition, if a soil criterion exceeds a level at which the water phase exceeds its solubility limit, then the soil criterion is set at its saturation concentration (i.e. the bulk soil concentration which has a corresponding water concentration equal to the saturation limit). In this way leaching PSH is avoided.
- The CCME calculates a soil criteria protective of drinking water quality. The method of determining the leaching potential is similar to that used by US EPA Region 9 PRGs. The dilution attenuation factor representing groundwater recharge and lateral flow to estimate the soil pore water concentration at the soil source.
- The UK CLEA model does not consider soil protective of groundwater. However, soil leachability tests are carried out to provide information on this issue.
- The German Ordinance document presents criteria for leachate concentrations protective of groundwater.

The setting of soil criteria protective of groundwater and modelling options is further discussed in Section 7.2.

**Suggestion**

It is not clear as to whether soil criteria should be developed for protection of groundwater quality, because of the complexity and uncertainty involved. It is suggested that in the first instance only commentary should be provided on how such criteria setting might be undertaken, and the uncertainties inherent in this, and that where possible primary reliance should be placed on direct measurement of groundwater contamination.

## **6. Vapour emission issues and modelling**

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### **6.1 Background**

The potential for vapour emissions from impacted soil and groundwater to the interior of buildings is an uncertain exposure pathway, and is often included as part of an assessment of risk associated with hydrocarbon contamination. However, prediction of vapour intrusion into buildings by modelling is a complex matter and can have a high level of uncertainty, and there is considerable international and national debate as to the most appropriate approach for such an assessment.

Assessment of the significance of vapour emissions may be carried out via direct measurements of vapours below and in buildings. However, this is also a complex and uncertain matter. Transients and background concentrations can sometimes confound direct measurements of vapours in houses, and spatial variability, transients and biodegradation processes can complicate measurements beneath buildings. A systematic description of the typical behaviour of volatile petroleum hydrocarbons was given by Davis et al. (2006), and investigation strategies and a review are given in Davis et al. (2004).

In the following sections the issues involved in setting criteria based on protection of human health from adverse effects of volatile emissions from hydrocarbons in soils and groundwater are discussed.

### **6.2 Selection of vapour model**

#### **6.2.1 Introduction**

There are numerous models being used in Australia and internationally to model hydrocarbon vapours, each with their advantages and disadvantages. Selection of an appropriate model should consider the following aspects:

- acceptance of model by industry and regulators
- history of validation of model through field trials
- representativeness of theory versus observation
- accessibility and availability of model for this project and site-specific risk assessments (i.e. publicly available models versus proprietary models)
- appropriateness of model for specific scenario (e.g. slab on ground construction versus crawl spaces).

NICOLE (2004) summarised outputs from several available models – and for some models found large discrepancies. CSIRO Land and Water (Davis et al. 2004) presented a report to the Western Australian Department of Environment, which includes a review of some of the available vapour models. The more commonly used models are discussed in the following sections.



### **6.2.2 Johnson and Ettinger**

The following information has been drawn from Davis et al. (2004). The Johnson and Ettinger model, first published in 1991, has undergone a number of updates since that time. The US EPA supplies spreadsheet versions of the model for free. It comprises eight excel spreadsheets, with separate models for soil contamination, groundwater contamination, soil vapour and NAPL contamination. The model supports both finite and infinite sources, as well as direct input of observed concentrations and soil properties. The explicit effects of temperature on chemical properties are included, and a van Genuchten formulation is used to model capillary effects near the water table. The aim of the model is to establish typical values or ranges of attenuation rates  $\alpha$  – this being the ratio of the concentration of the vapour in indoor air in a building to the concentration found at some distance beneath the building.

The unsaturated zone is idealised as a set of homogeneous horizontal layers over which the vertical net effective diffusion coefficient is calculated by a harmonic layer average. The building inner space is assumed to be perfectly mixed. The model uses a single crack model at the join of the building walls and floor, through which soil vapour may advect into the building space at a rate determined by the specific soil-building pressure gradient. The system is assumed to be in steady-state.

Two of the primary assumptions in the US EPA model release pack are:

- no allowance is made for biodegradation processes, and
- pressure gradients (i.e. from ventilation) are steady.

### **6.2.3 RISC WorkBench Version 4**

RISC WorkBench (RISC 2004) is a stand-alone software package based on the BP RISC implementation of the 1D Johnson and Ettinger vapour model, with additions in compliance with US EPA's *Risk Assessment Guidance for Superfund*.

While the vapour model is effectively the same as the US EPA package, the user interface is clean and easy to use. The model does have an advantage over the US EPA version, in that it supports biodegradation and has limited capacity to deal with transient issues such as seasonal water tables.

The RISC model is based on slab on ground construction, and also has an option for considering basements.

### **6.2.4 Turczynowicz and Robinson**

Turczynowicz and Robinson (2001) have developed a proprietary vapour model from soil to indoor air environments. It is limited to the case of dwellings with crawl spaces. The model builds on the Jury (1983) Behaviour Assessment Model (BAM) and work conducted by Anderssen and Markey (1998). Robinson (2003) describes some additional cases.

The model incorporates first order degradation in the vapour phase and assumes that fate and transport in the soil column occurs via liquid advection and molecular diffusion, vapour molecular diffusion, adsorption of the liquid phase to the soil solids, and

first-order degradation associated with total concentration. Initial soil and vapour concentrations are incorporated into the boundary conditions, in the solutions of the partial differential equations, which describe fluxes of different phases. The solution represents a transient state (i.e. a function of time), which may be integrated over a specified time period to derive an integrated average.

For specific boundary conditions, analytical solutions may be found in papers by Jury, Anderssen and others. These analytical solutions are quite complex, solved using Laplace transforms, and often incorporate terms such as Error Function. More complex boundary conditions require numerical solutions.

#### **6.2.5 CLEA model – Ferguson-Krylov-McGrath**

For volatilisation into indoor air the UK CLEA model uses two vapour models; the Ferguson-Krylov-McGrath (FKM) (1995) for slab on ground construction, and the Krylov-Ferguson (KF) (1998) model for suspended floor construction. Vapour emissions are confined to directly beneath the building and don't model diffusion through the soil column. The model incorporates diffusion and advective flow based on pressure differential. The model incorporates parameters for typical construction of buildings in the UK, and also includes floor coverings.

It is understood that recently the UK EA decided to abandon this model due to its inaccuracy (Clay, personal communication).

Emission to outdoor air is based on Johnson and Ettinger infinite source model.

#### **6.2.6 Canada-Wide Standards for PHC in Soil**

The PHC CWS excel spreadsheet (2003) is a Tier 1 and Tier 2 system for the assessment of sites contaminated with petroleum hydrocarbon. The process explicitly follows the CCME *Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines*. The vapour model incorporated into the model is the Johnson and Ettinger methodology. The PHC CWS does not account for intrinsic degradation of vapour within the soil, nor transient effects to do with seasonal variations or climatic influences.

#### **6.2.7 Other key information**

Davis (2004) concluded that there are no models that are fully representative of the observations of vapour emissions – especially related to biodegradation processes, multi-species transport and pressure driven flows. Davis et al. (2005) and Franzmann et al. (1999) found that wherever oxygen was present, hydrocarbon vapours were absent, indicating that aerobic biodegradation was occurring. They found that primary mass loss due to aerobic biodegradation was occurring over a thin zone where oxygen and hydrocarbon vapours 'met' within the subsurface soil profile. This suggests that using a simplified zero- or first-order degradation rate throughout the soil profile during modelling could lead to misleading outcomes.

More complex codes have been developed by Öhman (1999) and Abreu and Johnson (2005). The former linked vapour and oxygen transport and hence biodegradation

processes, to model fully transient and biodegradation processes. Abreu and Johnson (2005) coupled oxygen and vapour transport and incorporated pressure differentials (indoor to outdoor) to determine potential ingress of vapours to basement and slab on ground dwellings.

Paul Johnson has been developing a Johnson 3D model; this includes modelling the influence of oxygen ingress on degradation rates<sup>1</sup>.

Of the simpler models, there are some key considerations to note:

- The Johnson and Ettinger model is currently the most widely used vapour emission model by environmental practitioners in Australia. This is an important consideration in the selection of a model for use in deriving soil criteria, as the method used for development of soil criteria should be able to be applied and extended by environmental practitioners to other soil contamination situations.
- The Johnson and Ettinger model has been demonstrated to be conservative.
- Turczynowicz and Robinson (2001) have developed a model that shows some reasonably good correlations between field work and theory, for houses with crawl spaces where degradation has a significant impact on the rate of intrusion into buildings. However, while many older houses are buildings with crawl spaces, a large portion of site remediation works in Australia are driven by site redevelopment into residential or commercial buildings, with most new buildings involving slab on ground construction.
- With respect to concrete slab on ground construction, a key issue is whether the slab will affect the supply of oxygen to the subsurface. Recent studies by Davis et al. (2006) indicate that a building with concrete slab on ground can prevent oxygen supply to the soil vapours, creating an anaerobic environment and therefore preventing aerobic biodegradation of hydrocarbon vapours under a slab. There is currently further work being undertaken to confirm these findings.

In summary, the following issues need to be considered when developing HSLs for volatile hydrocarbon constituents and selecting a vapour model for this purpose:

- Whether it is desired to develop a simple set of HSL look-up tables considering only a range of soil types and depths of general applicability to Australia (perhaps with commentary on the limitations of these HSLs), or whether a greater range of situations are to be considered and a more complex set of HSL look-up tables are to be developed, such as different floor construction situations, different levels of oxygen ingress, and different soil conditions (moisture and permeability).

If a simple set of HSLs are to be developed, then presumably these should be conservative and applicable for a range of soil types and depths, and could assume for example that there is no oxygen ingress. In this situation, it might be that a simple model can suffice, with the recommendation that if other situations are involved, then this should be considered through more detailed risk assessment.

- Whether an advanced (and perhaps proprietary) model should be used that will provide for the most detailed assessment of the range of situations that might be encountered, or whether a relatively simple model and a limited range of situations

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<sup>1</sup> Information on this was provided in a presentation by CSIRO at the PAG workshop.

should be considered. For example, in the latter situation the Johnson and Ettinger model might be appropriate as it is in wide use in the industry. Use of such a model would have the advantage of allowing consultants to consider the effect of other situations (such as changed soil moisture or depth) on the HSLs, and for any such estimates to be readily checked (e.g. by auditors and regulators).

The selection of a soil vapour model was discussed at the PAG workshop. While consensus was not achieved on what model should be used and the range of situations that should be the focus of the HSLs, it was noted:

- any model proposed for use should be validated to avoid excessive conservatism in the development of the HSLs
- the model and its parameters should be relevant to Australian situations
- a critical issue is whether it can be assumed that oxygen ingress into ground will occur; this might not be the case under a concrete slab on ground. Real-world data should be gathered to confirm this process.

#### **Suggestion**

Criteria for contamination in soils should be developed using modelling to predict the exposure that will occur as a result of vapour emission through soils and into buildings.

Further discussion is required to determine the process that will lead to the selection of an appropriate model and to define the range of situations that HSLs are to be developed for.

### **6.3 Do we consider modelling of PSH or NAPL?**

Phase separated hydrocarbons (PSH) (also referred to as non-aqueous phase liquids (NAPL)) are an important issue to be addressed on contaminated sites, and it is a common objective that all such material should be removed unless it can be shown that the residual does not pose a risk.

There are a number of issues associated with modelling the vapours that arise from PSH and NAPL. The first is that the theory is not well understood. The Johnson and Ettinger model uses a simplified method by which the vapour phase concentration is estimated using Raoult's Law, which incorporates molar composition of the liquid and relative vapour pressures of each component. While applicable, it is generally uncertain as it is dependent on knowing the composition of the mixture, and their physical properties, such as vapour pressure, molecular weight and solubility in water. In addition there is uncertainty with respect to interactions between chemicals, for example some chemicals will dissolve more readily in a solvent such as toluene rather than water.

There are a number of policy issues associated with PSH:

- Theoretically, the vapour phase concentration is independent of the mass of NAPL in the subsurface – rather it is directly related to its relative contribution (molar mass). Therefore, the predicted indoor air concentration will also be capped at a maximum level. If this air concentration was below the level determined to be a risk

to human health, then the soil concentration would never result in an unacceptable risk through inhalation (provided that direct contact is eliminated).

- Holistic assessment of the vapour and groundwater releases from PSH/NAPL and its potential cumulative impact on human health would need to be developed in order to generate health-based soil acceptance criteria.
- What composition of PSH is to be assumed.

Review of relevant documents indicates the following:

- The AOIEGWG and NZ MfE documents have modelled vapour emissions from PSH using Raoult's Law to predict the maximum air possible indoor and outdoor air concentration. Composition for BTEX was set for typical motor fuel. Composition of TPH and PAHs were conservatively set with a mole fraction of 1 for each component. It should also be noted that for vapour emission from soil and groundwater, where groundwater or pore water in soil exceeds solubility limits for a typical petroleum mixture, no criteria have been presented, rather it is indicated that unacceptable health risks from the chemical will not occur.
- The US EPA Region 9 calculate a 'soil saturation limit'. This limit corresponds to the contaminant concentration in soil at which the adsorptive limits of the soil particles, the solubility limits of the soil pore water, and saturation of soil pore air have been reached. Where PRGs from vapour emissions are higher than the Csat value, Csat is set as the remediation goal (i.e. the goal is to achieve soil that is not saturated with NAPL). Note that these calculations are based only on pure compound solubility and do not take into account the effects of mixtures.

The PAG workshop discussed the issue of assessing PSH. The suggestion that the presence of PSH should trigger a Tier 2 risk assessment met with divided responses. It was noted that there is the question as to whether the presence of PSH is a health issue or not, and if it is, it should be dealt with in the guideline. It was agreed that this is an area where further discussion is required.

### **Suggestion**

Further discussion is required on the issue of how best to include consideration of PSH in the guidelines.

## **6.4 Vapour intrusion into trenches**

The potential for vapour intrusion into a trench and pose a risk to workers involved in subsurface works is an important aspect of the assessment of risk of soil contamination, and is now being commonly included in risk assessments in Australia.

Predicting the extent to which vapour emissions will enter and build up in a trench is a complex undertaking, as the air concentration within the trench is dynamic, and is influenced by pit dimensions (width, length, depth), wind speed, stability and orientation to the trench. Air movement inside a trench may only be properly assessed using complex modelling, which is costly and time-intensive. However, due to the large uncertainties associated with exposure (such as the question of whether an intrusive

maintenance worker would actually work within the confines of a deep trench for an extended period of time – Worksafe regulations prevent this on safety grounds), trench models have generally been assessed with simplified assumptions, such as using an indoor vapour model with an assumed air exchange rate.

As indicated in Section 5.8, during a review of potential exposure scenarios it was noted that the potential for exposure during subsurface maintenance works might be considered in terms of the following subcategories:

- Surface intrusion – telephone, electricity, local gas, water and sewer. The majority of these utilities are located within the top 1m of soil. Incidents will require quick repair/replacement (say 10 days), but may occur frequently, say once a year. Accumulation of gases in trenches is minimal due to shallow excavation.
- Deep intrusion – deep sewer, water or gas mains. These utilities require deep excavation (down to 2 m), but are not often located on individual sites, as they are usually found along roads or within their own easement corridor. Incidents for these repairs/replacements are infrequent (say once every 10 years) but require more time for repairs, say four weeks.

A possible way to model vapour emissions in trenches is as follows:

- For surface intrusion, an outdoor air volatilisation model could be used with the wind speed set to 10% of the average.
- For deep intrusion, estimation of the vapour exposure that occurs during subsurface works could model a deep trench (2 m deep x 1 m wide) and be based on a simple box model dilution rate with an air exchange rate of  $6\text{h}^{-1}$ . This air exchange rate would represent partial exposure within and outside the trench vicinity.

### **Suggestion**

The approach to modelling exposure to volatile contamination entering a trench and giving rise to exposure of workers working in the trench should be reviewed, and agreement sought for any proposed method.

Commentary should be provided indicating that if a trench intersects the water table, then a site-specific assessment should be conducted.

## 7. Other fate and transport models

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### 7.1 Introduction

Apart from volatilisation, other chemical fate and transport models may need to be used to derive soil and groundwater criteria. These models may or may not need to be utilised depending on which scenarios are decided to be included in the document.

Note that the majority of fate and transport models relate to predicting groundwater migration. These will not be discussed here, as assessment of groundwater migration is an issue that should be assessed on a site-specific basis; although some standardised ways of assessing and modelling hydrocarbon behaviour in groundwater was described by Prommer et al. (2003) in the *Proceedings of the Fifth National NEPC Workshop on the Assessment of Site Contamination*.

The models that may be required in the development of criteria include:

- soil leaching to groundwater (soil criteria protective of groundwater)
- primary contact recreation (swimming pool makeup water)
- irrigation water.

### 7.2 Leaching models

A discussion of assessing leaching of contamination from soil and predicting the impact on groundwater quality was discussed in Section 5.9. While it is generally preferred to measure the impact of soil contamination on groundwater quality directly, if it is decided that soil criteria for protection of groundwater quality is required then there are a number of options available. Some of these are discussed below (in increasing order of complexity).

#### **7.2.1 Dilution attenuation factor (DAF)**

The simplest approach is to predict the concentration of contaminants that will be in water that is in contact with the contaminated soil, and to apply a dilution attenuation factor (DAF) to this concentration.

The pore water concentration can be estimated based on the three-phase partitioning equations used in the vapour models.

The source pore water concentration is multiplied by a DAF to estimate a groundwater concentration, which may be compared to a groundwater quality objective (e.g. ecological criteria, drinking water criteria). The DAF represents the attenuation of pore water leaching into the groundwater table (at which it will dilute with the clean groundwater), and then migrate with the groundwater. The DAF is derived based on groundwater flow rate and the depth of mixing assumed between infiltrating leachate water and groundwater. Instantaneous mixing over a prescribed depth interval is assumed.

The US EPA Region 9 PRGs use a default DAF of 20. This is generally conservative for a variety of chemicals and scenarios. However, as an alternative, a chemical-specific and soil type specific value may be calculated by using Darcy's Law, given some reasonable hydrogeological parameters such as hydraulic gradient and permeability. This approach is less often used, probably because most practitioners will use the other approaches noted in the following sections if such modelling is necessary. It also does not consider recent advances in understanding the way that infiltrating contaminants enter and move in groundwater – no instantaneous mixing is apparent, separate from dispersion and advection.

### **7.2.2 Van Genuchten and Alves**

Van Genuchten and Alves (1982) present a model of the leaching process, 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. The model considers net infiltration rate for different soil types, pore water vertical velocity, horizontal groundwater movement (Darcy's Law), and source depletion (from volatilisation, leaching rate and first-order degradation).

The model, while complex, is incorporated into the RISC software. It has also been used in the NZ MfE Guideline document.

### **7.2.3 Hydrologic evaluation of landfill performance (HELP) model**

HELP is a rigorous model designed to compute estimates of water balances for municipal landfills, and other land disposal systems. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, frozen soil, run-off, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners.

The HELP model was developed at the U.S. Army Engineer Waterways Experiment Station under a cooperative agreement with the U.S. Environmental Protection Agency, to support RCRA and Superfund programs.

While the HELP model was not designed for assessing leaching at contaminated sites, it can be adapted for this purpose.

### **7.2.4 Conclusions**

In Section 5.9 it was suggested that it was not clear as to whether soil criteria should be developed for protection of groundwater quality, because of the complexity and uncertainty involved. It was suggested that in the first instance only commentary should be provided on how such criteria setting might be undertaken, and the uncertainties inherent in this, and that where possible primary reliance should be placed on direct measurement of groundwater contamination.

If criteria are to be developed for soil protective of groundwater, then a reasonable approach might be to not derive a soil criteria per se, but to derive a soil attenuation



factor (SAF) similar to the DAF. The SAF could be estimated for each chemical and soil type (assuming reasonable hydrogeological parameters). In doing so an assessor may derive their own soil criteria by multiplying the SAF by the appropriate groundwater quality objective for the site (rather than defaulting to, say, a drinking water guideline level). The selection of the water quality objective is dependent on the individual site, jurisdiction obligations and legislation requirements.

#### **Suggestion**

The need to develop soil criteria protective of groundwater quality requires further consideration, and the suggestion in Section 5.9 is relevant. Consideration could be given to deriving a Soil Attenuation Factor for various contaminants and soil types.

### **7.3 Primary contact recreation**

Primary contact recreation refers to swimming and recreational activities in water where total body submersion is likely. This is a common scenario and is often a limiting consideration when assessing groundwater contamination.

There are two potential scenarios:

- The water quality goal applies directly to the concentration of water in which swimming occurs. This may be applicable to, say, a creek where direct measurement of the water can be compared to criteria. Criteria may be simply calculated by estimating exposure for dermal contact and incidental oral ingestion. Equations are available for also determining the rate of volatilisation and hence including inhalation of vapours above the water surface.
- The water quality goal applies to the groundwater for a scenario where groundwater is used for make-up water in swimming pools. This is usually the case that is of greater concern with regards to groundwater pollution, and is more relevant to managing hydrocarbon-impacted sites. The calculations for exposure are the same as that for the simple approach. However, the water (and air) concentration will change as a result of topping up with groundwater and loss due to volatilisation (note that it is unlikely that an entire swimming pool will be filled using groundwater). As a result, the concentrations of hydrocarbons in the swimming pool would be much less than the groundwater concentration itself. For volatile chemicals, this difference may be an order of magnitude or more.

#### **Suggestion**

Criteria for the protection of groundwater quality for swimming pool make-up should be developed. In addition to considering exposure resulting from dermal absorption and ingestion, consideration should be given to the steady-state concentration that is likely to result in a swimming pool.

## 7.4 Irrigation

The use of groundwater for garden watering and irrigation is a common scenario, and often requires consideration. In general, guidelines for irrigation listed in the ANZECC *Australian Water Quality Guidelines for Fresh and Marine Waters* should be referred to, however criteria for petroleum hydrocarbons are not presented in the current edition.

Groundwater quality for irrigation can be divided into two groups:

- irrigation of crops associated with agricultural estates and farms for the production of food, and
- irrigation of home-grown produce by residents, followed by consumption of food.

While there are specific requirements and standards to be met with respect to food production, the higher risk scenario is the home-grown produce scenario. This scenario is also likely to be representative of the majority of cases, particularly in urban areas.

Walden and Spence (1997) developed a protocol for the development of groundwater acceptance criteria for irrigation use, which has subsequently been incorporated into the BP RISC model, and was also used in the AOIEGWG and MfE Guideline documents. The scenario assumes that a sprinkler will be used during growing seasons to water gardens. Adults will be exposed through inhalation of aerosols. Children will be exposed to inhalation, as well as dermal exposure from playing under sprinklers. The model estimates the rate of uptake in the crops and hence the intake from consumption of home-grown produce.

### **Suggestion**

Criteria should be developed for protection of groundwater for irrigation and garden watering. Consideration should be given to using the Walden and Spence model for the development of criteria, with reference to available Australian data on production and consumption of home-grown produce.

## 8. Risk characterisation

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### 8.1 What is an acceptable cancer risk?

Most Australian state and territory environmental authorities have not developed policies on this matter. There is still considerable debate on whether an acceptable incremental lifetime cancer risk of  $1 \times 10^{-6}$  or  $1 \times 10^{-5}$  be adopted for contaminated land. Relevant considerations include:

- The Victorian *State Environment Protection Policy (Air Quality Management)* (EPAV 2001) adopts an incremental lifetime risk of cancer of 1 in 100,000 ( $1 \times 10^{-5}$ ) for screening individual chemicals in air.
- Victorian and New South Wales Environmental Auditors and Queensland Third-Party-Reviewers generally consider incremental lifetime risks of cancer of less than 1 in 100,000 ( $1 \times 10^{-5}$ ) to be acceptable.
- No policy on this matter has been decided yet in Western Australia.
- NSW Department of Environment and Conservation in the document *Approved methods for the modelling and assessment of air pollutants in New South Wales* (2005) indicates that:
  - a cancer risk less than  $1 \times 10^{-6}$  is acceptable
  - a cancer risk greater than  $1 \times 10^{-4}$  is unacceptable, and
  - a cancer risk between  $1 \times 10^{-6}$  and  $1 \times 10^{-4}$  requires best practice in air emission management.
- The AOIEGWG document does not provide guidance on this particular issue. Instead, for each criterion a range of values corresponding to acceptable risks of  $1 \times 10^{-6}$  to  $1 \times 10^{-4}$  is presented for cancer risk.
- The NZ MfE document uses a default acceptable cancer risk level of  $1 \times 10^{-5}$  lifetime cancer risk.
- The US EPA accepts different levels of acceptable risk on a case-by-case basis. Acceptable cancer risks may be up to  $1 \times 10^{-4}$  given particular circumstance. The US EPA Region 9 uses a default acceptable cancer risk level of  $1 \times 10^{-6}$  lifetime cancer risk, and it is common for practitioners to adjust the criteria so that the risk is less than  $1 \times 10^{-4}$ .
- The UK Environment Agency presents index doses (ID) for non-threshold chemicals, which represent a dose that poses a minimal risk level from cancer-causing substances (similar to non-cancer hazard index). The IDs are based more on observed effects (e.g. LOAELs and NOAELs) or measurement feasibility (e.g. groundwater detection limits) rather than mathematical models and acceptable cancer risk levels as presented by US EPA. It is understood that currently the development of IDs has stalled in the UK, and so assessors are reverting to slope factors, and using maximum acceptable risk levels of  $10^{-4}$ .
- The Dutch RIVM uses a cancer risk level of  $1 \times 10^{-4}$  in deriving the health protection element of the Dutch Intervention Values.

- The CCME document *A protocol for the derivation of environmental and human health soil quality guidelines* (1996) indicates that soil guidelines for non-threshold chemicals should be based on a cancer risk of  $1 \times 10^{-6}$ .

From other sources of information:

- WHO (2005) *Guidelines for Drinking Water Quality* are based on a risk of 1 in 100,000 ( $1 \times 10^{-5}$ ).
- NHMRC (2004) *Australian Drinking Water Guidelines* nominate a negligible level of risk of 1 in 1,000,000 ( $1 \times 10^{-6}$ ) for developing guideline values for individual chemicals in drinking water.

There has been advice from one of the regulatory authorities suggesting that an additional order of magnitude of safety should apply for uncertainty with respect to synergistic effects of multiple cancer-causing chemicals. In petroleum fuels, benzene is usually the only carcinogenic chemical present in significant concentrations. Benzo(a)pyrene may also be present in diesel fuels, however the concentrations of benzo(a)pyrene and benzene are low in such fuels and significant exposure to both benzo(a)pyrene and benzene is unlikely. Further, exposure to benzo(a)pyrene is only likely to occur through ingestion, whereas exposure to benzene is more likely to occur through the inhalation route.

The issue of acceptable risk level was discussed at the PAG workshop, and there was general agreement that the incremental lifetime risk of cancer from all chemicals present should not exceed  $1 \times 10^{-5}$ . It was noted that there are various ways of assessing cancer risk, and an approach that is being used in assessing the risk in water supplies where pathogens are of concern is to use the concept of micro-DALY (disability adjusted life years), although the NEPM and enHealth do not endorse this method. It was agreed that further consideration is required as to the risk levels that are to be used for the derivation of criteria, and that health regulation bodies will need to be involved in this decision.

### **Suggestion**

Further consideration is required as to the risk levels to be used for the derivation of criteria, and health regulation bodies should be involved in this process. For initial purposes, it should be required that the incremental lifetime risk of cancer from all chemicals present should not exceed  $1 \times 10^{-5}$ .

## **8.2 What is an acceptable threshold HI?**

It is generally accepted that the hazard index (HI) (i.e. the summation of hazard quotients for the chemicals present) should not exceed 1.

Note that this relates to protection of human health, and factors other than protection of human health may need to be considered (refer to Section 2.2.1).

In terms of setting criteria, a HI of 1 corresponds to the situation in which the estimated dose is equivalent to the maximum allowable dose. In general, it can be expected that a HI of 1 will correspond to a safe condition, as the toxicological assessments that underlie the estimate include safety factors.

The maximum allowable dose will generally consider background exposure.

Key guideline documents use the following approach:

- The AOIEGWG document is based on individual chemicals with a HI of 1. Note that the criteria do not take into consideration cumulative effects of multiple chemicals.
- The NZ MfE document is based on individual chemicals with a HI of 1. Note that the criteria do not take into consideration cumulative effects of multiple chemicals.
- The US EPA Region 9 is based on individual chemicals with a HI of 1.
- The CCME (2000) develops soil criteria for individual carbon fractions based on a HI of 1. However, guidance is provided that states an overall criteria for all TPH should be calculated based on the criteria of individual fractions of TPH and their mass fraction proportions. It should be noted that this is different to their more general guideline for deriving soil quality guidelines (1996) in which they set the target HI to 0.2. Because people are exposed to five primary media (i.e. air, water, soil, food, and consumer products), 20% of the residual TDI is apportioned to each of these five media. Therefore, 20% of the RTDI accounts for soils when deriving soil remediation guidelines, allowing for 80% of the remaining tolerable incremental exposure to be reserved for other media.
- The UK Environment Agency CLEA model is based on individual chemicals with a HI of 1.

#### **Suggestion**

Criteria for threshold chemicals should be based on a HI of 1, with consideration given to the contribution from background exposure to the acceptable daily intake (refer to Section 4.6), and multiple chemical exposure (refer to Section 8.3). Note that this will depend on the approach taken to include background exposure.

### **8.3 How do we deal with cumulative effects of multiple chemicals?**

When evaluating health risk, it is usual to consider the potential for cumulative effects of multiple chemical exposures. Usually non-threshold carcinogens are assessed to determine an overall incremental lifetime cancer risk. Likewise, threshold chemicals are assessed to determine a total hazard index resulting from exposure to all of the chemicals present.

There are options for dealing with cumulative effects of multiple chemical exposure.

- One option is to weight each chemical criterion assuming a fuel mixture composition, such that if each individual chemical was equal to the derived criteria, then the total hazard index would be below 1. An assumed composition of non-degraded petrol would result in a conservative approach as it contains the highest proportion of volatile aromatics, which tend to result in the greatest risks to site users. This process should be conservative because criteria would be derived assuming all petrol fuel components are present. However, if this changes as a result of weathering, degradation or different rates of natural attenuation, then the chemicals are likely to be present in different proportions. There can also be

difficulty deriving criteria for naphthalene and carcinogenic PAHs, which are more likely to be in diesel fuel, rather than petrol.

- An alternative option is to follow the US EPA Region 9 PRGs which do not account for cumulative effects of multiple chemicals in the development of the criteria. However, instructions are given in the *User's Guide* on how to address multiple chemicals. Firstly, chemicals are grouped as cancer or non-cancer. For the cancer chemicals, each chemical reported concentration is divided by its criterion. These are then summed to give a score. If the score exceeds 1 then the cumulative cancer risk exceeds the allowable risk. The same process is used for the non-cancer chemicals. This approach allows flexibility in the application of the derived criteria with site contamination. If one chemical is dominant then more weight is given to this particular chemical, allowing appropriate management, rather than applying stringent criteria for chemicals that may not be present.

Key guideline documents take the following approaches to this issue:

- The AOIEGWG and NZ MfE document do not account for cumulative effects of chemicals.
- The US EPA Region 9 PRGs do not account for cumulative effects of multiple chemicals in the development of the criteria. However, instructions are given in the *User's Guide* on how to address multiple chemicals. Firstly, chemicals are grouped as cancer or non-cancer. For the cancer chemicals, each chemical's reported concentration (maximum of 95% UCL) is divided by its PRG. These are then summed to give a score. If the score exceeds 1 then the cumulative cancer risk exceeds the allowable risk. The same process is done for the non-cancer chemicals. This is a conservative process in that no distinction is made on target organs.
- The CCME does not account for cumulative effects of chemicals. However, the target acceptable risk by CCME is selected to be conservative with a cancer risk of  $1 \times 10^{-6}$  or a HI of 0.2.
- The UK Environment Agency indicates that multiple chemicals should be handled in the same manner as US EPA, where measured concentrations are divided by the soil guideline value to derive a fraction. The sum of the fractions should be less than 1. There may be allowance for carbon fractions exhibiting different toxicological properties to be excluded from the addition of fractions.

It can be seen that the approach that is generally taken is to not assume a particular composition and account for cumulative effects in this way, but to provide criteria for individual chemicals. This allows flexibility in the application of the derived criteria to the contamination present. If one chemical is dominant then the fraction approach allows appropriate weight to be given to this chemical when determining the level of risk and the requirements for clean-up. However, this does require an additional level of complexity to interpretation by assessors, potentially leading to misinterpretation. It is not uncommon for assessors to simply use the criteria for individual chemicals without consideration of cumulative effects, and this can significantly underestimate the risk and may not lead to a site that meets the requirements.

The alternative approach of weighting by an assumed composition is simple, but its rigor depends on the assumed composition and variations in this composition. As such, it may or may not be conservative.

Another approach, relevant to petroleum hydrocarbon mixtures, is to provide both criteria for individual chemical constituents, together with criteria for a defined mixture (such as petrol or diesel).

#### **Suggestion**

Criteria should be developed for individual chemicals, together with criteria for a defined mixture such as petrol or diesel.

Advice should be provided on how the criteria should be applied to take into account cumulative effects.

### **8.4. When is soil ecological protection required?**

Separate to HSLs, the application of soil ecological protection is defined by the beneficial uses that are to be protected for any site. Note that there may be specific requirements in each state's legislation on where ecological protection is required. The application of soil ecological protection can be broken up into two separate categories:

- Phytotoxicity for the protection of plants. Generally, this issue is considered for sensitive land use (i.e. residential, agricultural, parkland) and where plant health is important for aesthetics (e.g. on commercial property).
- Terrestrial animals. These typically apply to natural conservation areas, and are usually not considered for residential, open space, commercial and industrial sites. This consideration may also be required for farm land.

Consideration also needs to be given to applicable depths. For example, ecological protection of plants may not be necessary for contamination located 5 m below ground surface.

Key guideline documents address this issue as follows:

- the AOIEGWG document discusses the aspect of ecological assessment, but the derived soil criteria are based on human health only
- the NZ MfE document discusses the aspect of ecological assessment, but the derived soil criteria are based on human health only
- the US EPA Region 9 PRGs do not consider ecological protection in the derivation of the PRGs. However, the US EPA does have numerous guideline documents for separately addressing ecological issues. A lot of data is sourced from the Texas Natural Resource Conservation Commission and the Oak Ridge National Laboratory
- The CCME derives soil criteria for ecological receptors. The approach adopted for the derivation of Tier 1 levels of PHCs in soils for the protection of ecological receptors is based on a 'weight of evidence' method as outlined in the CCME 1996 Protocol with some modifications. This approach facilitates the incorporation of disparate types of high quality information on the risks of PHCs to ecological receptors by calculating a percentile of the effects data set to estimate a concentration in soil expected to cause no adverse biological effects. Tier 1 levels are derived to protect key ecological receptors that sustain normal activities on the four previously defined land use categories: agricultural, residential/parkland,

commercial and industrial. The derivation of Tier I levels for ecological receptors focuses on the effects of PHCs on the biotic component of a terrestrial ecosystem. Specifically, it evaluates the potential for adverse effects to occur from exposures to soil-based PHCs at point-of-contact or by indirect means (e.g. soil to groundwater pathways, food chain transfer).

- The UK EA indicates that their scope to develop soil criteria for petroleum hydrocarbons is limited only to human health aspects and not ecological receptors.
- The German Ordinance document considers different criteria for grasslands, vegetable gardens and agricultural land.
- The Dutch Target Value is based on potential risks to ecosystems, while the Intervention Value is based on potential risks to humans and ecosystems. However, the ecotoxicological risks of TPH (i.e. mineral oil) were not taken into account due to limited literature information.

It should be noted that due to the project budget and time constraints it has not been envisaged that the scope of the guidelines would extend to include ecological assessment.

#### **Suggested approach**

In the first instance, criteria should be developed only for protection of human health. Commentary should be provided regarding whether ecological effects are likely, and where information relevant to the assessment of these effects may be found.

As a later stage, criteria for protection of ecological values can be developed.

## **8.5 Where is amenity protection required?**

Like ecological protection, amenity protection is defined by the beneficial uses that are to be protected for any site, and there may be specific requirements in each state's legislation on where amenity protection is required.

Surface staining should be addressed based on visual observation during site investigations. Criteria for volatile chemicals could be derived based on odour detection, although in cases other than confined space scenarios, such as basements/cellars, chronic exposure is more likely to be the limiting endpoint.

Key guideline documents address this issue as follows:

- The AOIEGWG document discusses the aspect of aesthetic issues, but the derived soil criteria are based on human health only.
- The NZ MfE document discusses the aspect of aesthetic issues, but the derived soil criteria are based on human health only. Odour issues have been considered for the development of irrigation spraying criteria.
- The US EPA Region 9 PRGs do not consider amenity issues.
- The CCME currently doesn't consider amenity issues, but indicates that this may be reviewed in the future.



- The UK EA, in its recent consultation workshop, has decided that while assessment of odour should be considered in environmental assessment, derivation of soil criteria based on odour will not form part of their current scope of works.

Generally, for petroleum hydrocarbons, criteria for health issues will usually be more stringent than for avoiding problems associated with odour, particularly in the situation where long-term exposure is involved (such as in residential dwellings). In such situations criteria protective of human health are likely to be protective of amenity.

If, however, the assessment of basements and cellars are considered, then odour could be a limiting consideration as exposure time in cellars would be short and higher concentrations of contaminant could be tolerated from a health perspective.

### **Suggestion**

Because of the complexity of developing soil criteria protective of amenity, criteria should be developed only for protection of human health. Commentary should be provided regarding whether odour may be a limiting consideration, and how field observations can be used to assess such effects.

At a later stage, consideration can be given to the development of criteria for protection of odour.

## **9. Risk management/application of criteria**

Risk management involves the application of the guideline document and Tier 1 criteria to the investigation site, and how it can be used to make risk management decisions. It is usually not as simple as comparing soil results to the criteria. There are many issues to consider. The following sections look at the level of information required to guide an assessor through the decision making process.

### **9.1 Investigation and clean-up targets**

Investigation and clean-up targets are often considered to be the same when it comes to a risk-based approach – although the NEPM emphasises that HSL/EILs are investigation levels only and not clean-up levels.

If only one criterion is to be presented per land use, such as that in the US EPA Region 9 PRGs, investigation targets should be conservative to account for the majority of soil types, depths and receptors. Developing criteria for multiple depths and soil types, such as in the AOIEGWG document, provides a better definition of the requirements for protection of human health for specific contamination situations. As such, they can provide a better indication of clean-up targets for protection of human health.

If these criteria are to be used as clean-up targets, then the question arises as to whether there should be an additional level of safety added so that after remediation the residual risk will be well below the maximum acceptable risk, and not just marginally below. However, since several levels of conservative assumptions underlie these criteria it seems unlikely that additional safety factors need be applied.

Key guideline documents use the following approach:

- The AOIEGWG document provides clean-up targets protective of human health.
- The NZ MfE document provides clean-up targets protective of human health.
- The US EPA Region 9 PRGs indicate that the PRGs are designed as investigation criteria. These should not be considered as clean-up levels without the nine-criteria analysis specified in the National Contingency Plan (or comparable analysis for programs outside of Superfund), or without verifying numbers with a toxicologists/regional risk assessor.
- NEPM considers investigation levels (HSLs, GILs and EILs) to be a trigger for further investigation if exceeded, and are not clean-up targets.
- While the CCME does not distinguish between investigation and clean-up criteria, it is stated in the CCME guidance that the Canada-wide standards for petroleum hydrocarbons in soil (PHC CWS) is a remedial standard, and is part of a tiered approach to assessment and management of contaminated sites.
- The UK EA does not make any distinction between investigation and clean-up criteria in the CLEA model. However, if the guideline values are exceeded, then a site-specific assessment is required.

- The Dutch Intervention Values are used to classify historically contaminated (i.e. before 1987) soil as seriously contaminated. In the case of serious soil contamination the volume of soil contamination has to be assessed. Risk assessment is required where soil contamination greater than 25 m<sup>3</sup> and groundwater greater than 100 m<sup>3</sup> is present. The risk assessment will determine whether remediation is required urgently.

The PAG discussed the issue of whether HSLs can be used as clean-up criteria. There were differing opinions on this matter, and further clarification by the PAG on the scope of the project in this respect is required.

### **Suggestion**

Further clarification by the PAG on the scope of the project with respect to deriving and advising on clean-up levels is required. It appears that commentary should be provided in the guidelines regarding the use of the criteria in the derivation of clean-up criteria. This should refer to the fact that the criteria are protective of human health, and consideration of other factors such as the potential for odour and ecological effects, and particularly jurisdictional requirements such as the need to clean up PSH, may need to be considered.

## **9.2 How should the soil criteria be interpreted and applied?**

There are a number of issues associated with interpretation of acceptability of soil. Statistical analysis and issues pertaining to hotspots are two issues of concern, in which results may be subjective and interpreted differently by assessors. The goal is to produce a unified approach to applying the criteria.

In Australia, there are two primary documents that have been endorsed by regulators for applying statistics to soil analytical results:

- *NSW EPA Sampling Design Guidelines* (1995). Section 1.2 states:  
 ‘The sampling results should be interpreted statistically. In general, if the results indicate a lack of hot spots and the 95% upper confidence limit (UCL) of the arithmetic average contaminant concentration of the site is below a threshold limit, the site can be considered uncontaminated or successfully remediated for a specific end-use.’  
 The document also presents the method for calculating the 95% UCL for normal and lognormal distributions. Note this approach is similar to that used by the US EPA.
- *NEPM (Assessment of Site Contamination)* (1999). Schedule B (7A), Table 11-A Note 5, states:  
 ‘The arithmetic mean must be compared to the values given in Table 11-A. The relevance of localised elevated values must be considered and should not be obscured by consideration only of the arithmetic mean of the results. The results must also meet the following criteria:
  - The standard deviation of the results must be less than 50% of the values given in Table 11-A.
  - No single value exceeds 250% of the relevant value given in Table 11-A.’

Consideration of statistical approach and hotspot management is unlikely to influence the development of the criteria, but will determine how it is applied to site investigations.

With respect to hotspots, the NSW EPA document indicates that the statistics should not apply if hotspots have been identified. The NEPM accounts for hotspots by applying an upper limit for hotspots. NEPM is limited by normal distribution profile, based on the standard deviation, but this is accounted for by NSW EPA in applying the 95% UCL, which includes a test for normal and lognormal distribution. Therefore, an acceptable approach could be a mixture of the two guidelines:

- no single value exceeds 250% of the relevant criteria, and
- the 95% UCL of the arithmetic mean soil concentration should be below the relevant criteria. The test as outlined in the NSW EPA document that determines if the results fit a normal or lognormal distribution should be performed.

Other issues relevant to this section have been discussed in other sections of this paper:

- the application of ecological criteria has been discussed in Section 0
- the application of amenity criteria has been discussed in Section 8.5
- the application of multiple chemical exposures has been discussed in Section 8.3.

#### **Suggestion**

The guidelines should include commentary on the application of the criteria.

### **9.3 What beneficial uses of groundwater need to be protected?**

While criteria may be developed for protection of human health for certain groundwater beneficial uses, not all will be relevant for every site. The beneficial uses to be protected are governed by state and territory legislation, and require consultation with the appropriate authorities.

While protection of site users' health is necessary for vapours from groundwater, the approach to extraction and use of groundwater is not as well defined. Groundwater should be protective of aquatic ecosystems if there are any surface water bodies in the vicinity. Other beneficial uses such as potable use, stock water, irrigation and swimming pool make-up, may or may not be required to be protected. Generally, these uses will depend on existing uses in the vicinity, surrounding land use, groundwater quality (e.g. salinity) and yield.

#### **Suggestion**

A brief outline of each state and territory's approach and legislation pertaining to selection of beneficial use of groundwater should be included.

## 10. Concluding remarks

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There are a number of issues with respect to deriving health-based criteria for petroleum hydrocarbons in soil and groundwater. Some of the key issues are discussed in this paper.

A workshop was held in December 2006 with the PAG to address some of the key issues, which are summarised in this paper. Detailed minutes of the workshop are presented in Appendix A.

There are a number of outstanding key issues, which were identified to need further discussion prior to the development of HSLs. These are:

- selection of appropriate TPH carbon fraction ranges
- how to incorporate background exposure into HSLs for threshold chemical exposure
- how to address non-aqueous phase liquids (NAPL) or phase separated hydrocarbons (PSH), and
- selection or development of an appropriate vapour model.

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## **APPENDIX A.**

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### **Notes from the PAG workshop 12 December 2006**

**Meeting commenced 9:30 am, GHD Offices, Melbourne**

**Present:**

Dennis Monahan	Chairman – Petroleum Project Advisory Group
Ravi Naidu	CRC CARE
David Steele	CRC CARE
Jack Ng	National Research Centre for Environmental Toxicology
Brian Priestly	Australian Centre for Human Health Risk Assessment
Nathalie Allaz-Barnett	Department of Human Services, Victoria
Andrew Mitchell	Department of Environment and Conservation (NSW)
Andrew Pruszinski	Environment Protection Authority (SA)
Greg O'Brien	Queensland Environment Protection Agency
Jean Meaklim	Environment Protection Authority Victoria
Chris McAuley	Environment Protection Authority Victoria
Andrew King	BP Australia
Geoff Borg	Shell Company of Australia
Perry Buckland	Mobil Oil Australia
Stuart Rhodes	Rio Tinto
Rob McLaughlan	University of Technology Sydney
Greg Davis	CSIRO Land and Water
Len Turczynowicz	Coffey Environments
Neville Robinson	Coffey Environments
Eric Friebe	GHD
Peter Nadebaum	GHD
Jason Clay	ERM Australia
Anthony Lane	Lane Piper
Raghava Dasika	URS Australia
Jackie Wright	URS Australia

**Opening Sessions**

1. Welcoming comments were provided by Dennis Monahan, chairman of the Petroleum Project Advisory Group on behalf of CRC CARE. Following brief introductions of those present, Dennis advised that the aims of the workshop were to provide a broad introduction to risk assessment and subsequently to run through the issues raised in the GHD background paper.
2. Ravi Naidu provided an introductory presentation which noted an international shift to bioavailability based legislation and adoption of a risk-based approach to management of site contamination. He also discussed the outcomes of a meeting with Jack Dempsey of the Commonwealth Department for Health and Ageing, at which it was agreed that development of petroleum HILs was critical,

\* CRC CARE Technical Report no. 4 uses the terminology 'HSLs' throughout the document. However, 'HILs' is maintained as part of Appendix A: Notes from the PAG workshop 12 December 2006, as this was the name of the workshop held on this date and used in the notes that arose from it.

it was noted that there was a need for Health representatives to be involved in the HIL development process, and potential mechanisms for the uptake of the HILs, including through the NHMRC, were discussed. It was noted that a meeting of the scoping group for the NEPM Review was to be held on 15 December, and CRC CARE's involvement in this process would be raised at that meeting.

3. Perry Buckland of Mobil Oil Australia provided an outline of the work that Mobil undertakes in relation to environmental/site contamination issues throughout Australia, New Zealand and the Pacific Islands, and noting that the workshop outcomes are critical to the AIP member companies, described their expectations from the HILs development process.

In summary:

- The outcome sought is a set of guidelines based on best science and best practice which are acceptable to regulatory bodies, industry and practitioners
- The output is envisaged to be in the form of lookup tables for values for hydrocarbon impacted soil and groundwater, below which remediation would not be required
- The tables would cater for multiple land uses and different soil types, etc

Perry clarified that what the project is seeking to achieve could be looked at as replacing the work currently being done on countless sites in the form of individual risk assessments with a series of risk assessments for groupings of typical site and contaminant attributes, such that in future the risk assessment can be performed as a Tier 1 assessment using lookup tables; however, the science is the same.

Perry noted that rising landfill charges are increasing the need for an appropriate set of guidelines which should assist in reducing unwarranted offsite soil disposal. He commented that international experience has shown that success in developing accepted guidelines is predicated on government leadership, and commented that the make-up of CRC CARE including industry, researchers and regulators is critical.

The path to adoption was briefly discussed, and Perry noted that it will be important that users (and reviewers of use of) the criteria will need to have a high level of understanding of the correct application of the criteria; the challenge to the developers is educating practitioners to use the guidelines safely.

4. Andrew Pruszinski of the SA Environment Protection Authority was invited to make comment from a regulatory perspective; he noted that his comments arose from discussions with some but not all other regulatory agencies, and this did not necessarily represent their views.

With respect to the GHD paper, Andrew commented that the paper represents an excellent literature review and as such forms a valuable starting point; a focussed and deliberate approach to the next stages is required given the number of issues identified for resolution.

Andrew commented that the SA EPA is in agreement with the need for a better set of HILs that currently available for hydrocarbons; but added a cautionary word that other drivers than just health may need to be considered in site assessment; that is, the HIL may not always be the driving factor in decision-making.

He suggested that the key product for progress on hydrocarbon HILs is a validated vapour model for Australian conditions that is accepted by regulatory authorities (EPA and Health). He also noted that having the work agreed to and adopted by NEPC and NHMRC is essential.

Andrew asked whether there would be consultation with commercial analytical laboratories, noting that the cost to analyse for the selected HIL parameters is an important factor.

5. General discussion about the project and its scope followed:

The issue of whether the project addressed HILs only or would include EILs was raised, especially in light of the reference to cleanup levels in the project title. It was agreed to revisit this matter later in the workshop.

Clarification was provided that the project will be seeking EPA endorsement of the guideline values developed; their development will not occur in isolation from the EPAs.

It was also noted for the information of the broader workshop group that the role of the PAG is to ensure the project does not move ahead without an appropriate level of consensus.

### **Risk Assessment Presentation (Jason Clay, ERM Australia Pty Ltd)**

Jason provided a 20 minute presentation (slides attached) outlining the process of human health risk assessment and the application of a tiered approach, including examples of how differing soil types may affect derived investigation levels for different hydrocarbon groups to differing extents. The presentation concluded that the tiered risk based approach is enshrined in Australian guidance and in some legislation and is likely to be further endorsed following the NEPM review. Internationally, many countries have their own Tier 1 values, each with their own idiosyncrasies. While there is no perfect solution, it is possible to generate robust and defensible Tier 1 numbers.

Discussion followed:

- A hazard quotient > 1 does not necessarily imply that risk is unacceptable, given uncertainty and in-built conservatism
- The process of developing benchmark dose guideline values (referred to in Jason's presentation) encountered difficulties using human data. Although slow to date, more effort is being put into it, and ongoing success is expected. Benzene did not model well in earlier work.
- Risk models do not seem to take into account natural degradation of benzene in the environment.

- Risk assessment tends to be overly conservative: consultants are risk-averse, regulators lose experienced staff and loss of experienced staff introduces conservatism.

### **Issues Paper Discussion (Peter Nadebaum, GHD Pty Ltd)**

Peter led a discussion using the Literature Review/Issues Paper as a guide. Peter explained that while the ultimate aim of Industry was development of HILs and EILs for petroleum hydrocarbons, the work undertaken by GHD to date was a literature review as the first step in the process. Peter also acknowledged the working group/technical review team involved in the work to date.

Issues were discussed as they appear in the draft Issues Paper; discussions are summarised below with reference to the Issues Paper section.

#### **11.1.1 Section 2.2 – Scope**

- It was suggested that the HIL document developed give investigation levels for soils, and provide guidance as to how ecological issues and groundwater beneficial use should be dealt with; as such, the current project can focus on HILs and leave EILs/GILs for later work.
- It was mentioned that the NEPM review is looking to come up with 'screening levels' which reportedly won't differentiate between EIL/HIL, etc but will take both health and ecological risks into account
- Support was expressed for development of HILs as there was a recognised need, just as there is also a need for EILs. However, limiting the project to HILs was seen as increasing the likelihood of a concrete outcome to this stage of the works. This approach was noted to have support from Health regulators.
- While CRC CARE sees both EILs and HILs as important, the current project is focused on HILs.
- It was noted that the NEPM structure recognises the usefulness of HILs; comment was made that it is important to keep in mind what the HILs are and how they are intended to be used. HILs may be the driving factor in a large number of site cleanups; in any case, HILs will be used to inform what the cleanup criteria will be.
- It was noted that the process should virtually reflect current practice; just replacing individual risk assessments with a look-up table (unless policy change is reflected); HILs should not effectively be any more conservative than current practice.

In summary, there seemed to be consensus that there was benefit in progressing with development of HILs, provided the outputs of the project included a context, possibly with reference to other potential remedial drivers.

#### 11.1.2 Section 2.3 – Chemicals

Brief discussion of what chemicals would be included in the study led to consensus that lead would be excluded on the basis that there was already a HIL for lead as part of the NEPM.

#### 11.1.3 Section 2.4 – Policy

There was consensus that development of HILs should use current policy and guidelines; it was suggested that recommendations from this project could be forwarded to the NEPM review committee.

Peter suggested a vision for the output of the project to be a set of lookup tables with accompanying application guidance, and a supplementary report to provide a commentary, which could include recommendations for policy changes. A suggestion from the floor was that the guideline document should make the application of the guidelines clear rather than rely on any supplementary report being read in detail. It was further suggested, and generally agreed, that documentation should generally take the form of guidance rather than commentary.

There was discussion on the issue of presenting the study outcomes as a set of HILs with accompanying notes on their use and/or exclusions. This was supported, on the understanding that the methodology to derive the HILs would be transparent to allow derivation of site specific values to take into account specific situations, and provided there is clear definition in the final document of the application of HILs and cleanup criteria.

#### 11.1.4 Section 3.2/3.3 – Range of Contaminants

For reasons including MtBE concerns being associated more with an aesthetic issue than known toxicity, and limitations on available toxicity data for other additives, it was agreed that the study would not include additives.

There was some discussion on the benefits of analysing TPH using the TPH Working Group methodology vs. the conventional band splits. Some opposition to using the TPHWG methodology was expressed on the basis of unreliable laboratory performance with aliphatic/aromatic splits; use of the TPHWG method was favoured to benefit from the mobility data available. A compromise position of shifting the chain length splits from the traditional C6-C9, C10-C14, C15-C28 and C29-C36 was suggested, as was involving the laboratories in further discussion of this topic.

*This issue was flagged as a significant technical process issue for future further discussion.*

#### 11.1.5 Section 4.6 – Background Concentrations

It was noted that there is very little data on background levels, which makes incorporation into a set of HILs difficult; the background issue has been raised in the CLEA review in the UK.

It was queried whether this issue would be dealt with in the NEPM review process; an opposing view was that this project's outcomes should feed into the NEPM review. It was suggested that we should know how we propose to deal

with background concentrations before proceeding with derivation of HILs, although it was argued that should the method of dealing with background concentrations change, this would require an adjustment to the HIL values only.

In conclusion, there was not a firm resolution of this issue; further consideration is required.

#### 11.1.6 Section 4.10/4.11 – Worksafe Values

A lengthy discussion followed Peter's introduction which explored if and why construction works, etc, on a site warranted consideration in a HILs project, and explored the implications of using Worksafe rather than environmental approaches, noting a typical difference in resultant guideline values of around 2 orders of magnitude.

Comments included frustration with a current lack of guidance for such scenarios, and note from industry that excavation workers are often the limiting pathway, and industry is very keen for the HILs to cover this issue; the aim is a set of lookup tables to facilitate protection of future site users.

An opposing view was that site management plans may be effectively used to cover such issue, although it was suggested that this is contrary to a regulatory push to avoid reliance on management plans.

Differentiation between voluntary risk and involuntary risk was raised as a means of determining when Worksafe guidelines should be applied.

The issue was summarised by Peter as (1) do the developed HILs need to consider protection of construction (excavation) workers, and then (2) if so, in developing HILs for their protection, should reference be made to environmental risk methods or Worksafe (occupational) guidelines?

Another issue raised was that some jurisdictions require the assumption that although construction exposure is typically short term, the worker might be exposed to such contaminant concentrations on various sites. This was apparently not an agreed position, and further discussion indicated that risk assessment for maintenance workers is difficult, and it is hard to reach realistic outcomes.

While a further suggestion to use Worksafe guidelines and put the derived guideline value in context was made, a subsequent suggestion to develop HILs using several scenarios to allow comparison and further discussion met with generally favourable response.

#### 11.1.7 Section 5.1 – Land Use Selection

In response to the suggestions in the Issues Paper, there was one comment querying the grouping of commercial and industrial land in view of the Victorian legislative approach; however, most of the ensuing discussion revolved around the issue of Continued Petroleum Use (CPU). Industry explained their preference for its inclusion given the significant number of assessments associated with property transactions; there was an opposing view that such a classification was not a necessary element of a set of health screening levels. Reference was made to the previous discussion of Occupational vs. Environmental guidelines, which is key to the difference between CPU and



general Industrial land use. In response to some additional expressions of support for inclusion of CPU from the floor, the PAG Chair noted that the PAG should be mindful that it will need to be comfortable to sign off on the guidelines.

#### 11.1.8 Section 5.2 – Groundwater

Peter outlined the suggestion from the GHD paper in detail; namely:

- Develop criteria for human health protection only
- Define beneficial uses by reference to regulations
- List criteria for the protection of each beneficial use
- Develop criteria to protect human health when not already published, but not for other beneficial uses.

Following discussion, there was general agreement with the suggestion.

#### 11.1.9 Section 5.3 – Garden Produce

Comments on the issue of garden produce included that there was little data and this would make HIL development difficult, but that if available, such guidelines would be useful for risk communication. It was noted that NEPM HILs took consumption of garden produce into account. However, it was suggested that the benefit of exploring this issue needs to be weighed up against the allocation of resources to other key issues.

#### 11.1.10 Section 5.4 – Soil Type and Depth

There was general support for the GHD suggestion; comment was made that input from soil scientists would be appropriate.

#### 11.1.11 Section 5.5/5.7 – Exposure Assessment - Soils

Discussion followed in regard to issues such as groundwater entry into basements, etc; the discussion resulted in agreement that there was a need to clearly define what scenarios the Tier 1 includes, and anything outside this requires a Tier 2 assessment. Allowance for basements should be included.

#### 11.1.12 Section 5.5 – Land Uses

The issue of child care was raised; it was noted that in NSW, Industrial Zoning includes childcare centres. There was also discussion of definitions of low, medium and high density residential development. In general, the approach suggested was agreed, although the detail remains to be finalised.

#### 11.1.13 Section 5.8 – Subsurface Works

Given the previous discussions, there was no further discussion at this point. It was noted that there was in-principle agreement that the guideline development needs to take subsurface works into account.

#### 11.1.14 Section 5.9 – Soil Concentrations protective of Groundwater

The suggestion that this is excluded, along with a recommendation for direct measurement, appeared to be accepted and did not attract comment.

#### 11.1.15 Section 6.2 – Vapour Modelling

Peter qualified the suggestion made in the issues paper; the J&E model was suggested as it was a widely accepted model, but discussion of this issue was deferred until the later Vapour Modelling presentation by Greg Davis.

#### 11.1.16 Section 6.3 – PSH / NAPL

The suggestion that the presence of PSH trigger a Tier 2 risk assessment met with a divided response. There was some industry acceptance, but views expressed also that PSH itself is not a health issue and should be able to be dealt with using the HILs. It was noted that regulators typically react unfavourably to the presence of PSH.

Following a brief discussion, it was suggested that PSH may have to be considered as a topic to explore further at another time, but should not delay progress with the HILs development.

#### 11.1.17 Section 8.1/8.2 – Risk Characterisation

The Issues Paper suggestion for Threshold Chemicals was to accept a Hazard Index (HI) of 1, and to include consideration of background intake. It was noted that the background intake issue had earlier been referred for future discussion; otherwise there was agreement in this regard.

For Cancer (Non-Threshold) Chemicals, it was noted that acceptable risk values are typically in the  $1 \times 10^{-4}$  to  $1 \times 10^{-6}$  range, and that this method of setting acceptable risk is used in the absence of benchmark data. The variable application of such risk values (yearly risk vs. lifetime risk increase) was discussed, with a suggestion that we should perhaps be considering use of  $1 \times 10^{-4}$ . Comment was made from the floor that carcinogens need not be considered differently, as there is always a threshold in reality.

Discussion followed about the alternative use of micro-DALYs (Disability-Adjusted Life Years), a concept originating from epidemiology studies; however, it was noted that neither the NEPM nor enHealth structure support the DALYs concept.

Peter Nadebaum made the comment that selection of a risk value may be modified late in the project, and that there have been mixed messages from regulators about what is acceptable.

*It was suggested that at this stage, it is proposed to move forward on the basis of an acceptable increased lifetime cancer risk of  $1 \times 10^{-5}$ . Comment was made that this has not been endorsed; Health regulatory bodies will need to be involved in this decision.*

#### 11.1.18 Section 8.5 – Odour

Discussion following Peter's outline of GHD's suggestion suggested that at the very least, there should be commentary on the topic of odour in the guidelines (possibly as footnotes to the tables); it was recognised that there is concern about the odour/health risk relationship; however, the difficulty in quantitatively relating odour to health risk is recognised. The NEPM review will apparently be considering odour.

#### 11.1.19 Section 9.1/9.2 – Investigation and Cleanup Targets / Application of Criteria

GHD's Paper suggests providing guidance on the application of criteria in derivation of cleanup criteria. The resulting discussion indicated varying opinions; there was comment that development of cleanup criteria was presumed to be outside the scope, and that perhaps the project title should be changed; comment from elsewhere indicated that in a number of situations, such as UST pull scenarios, HILs will in fact often be used as cleanup criteria, as time precludes Tier 2 assessment and HILs are the driver. In the absence of agreement, clarification of the scope was referred to the PAG.

### **Volatile Modelling Discussion (Greg Davis, CSIRO Land and Water)**

Greg presented briefly on observations of vapour migration from a subsurface source and degradation with the ingress of oxygen, and how the presence of surface structures may affect oxygen ingress and this affect degradation and promote vertical migration. He then discussed various models and their advantages and limitations, including Johnson and Ettinger (no biodegradation), Abreu and Johnson (2006), the RISC model (includes 4 variants of J&E, 2 of which include biodegradation).

In conclusion, Greg suggested that a model used to derive HILs should include biodegradation, intelligent selection and use of the model is required, and noted that although data to validate models is sparse, it is improving (refer Greg's slide presentation).

Greg suggested the project should:

- Review the status of models and capabilities
- Establish a scenario set relevant to Australia
- Review a parameter set to run the models; and
- Hold a national workshop on vapour behaviour and modelling to progress this work

Greg also commented that while the Johnson 3D model might not be suitable for general use, but would be suitable for use in developing HILs of as high a calibre as possible.

Comments following from Greg's presentation included:

- In response to a query on the issue of validation, Greg noted that CSIRO are currently instrumenting a site, intending to have it modelled by Johnson.

- Neville Robinson noted that he and Len Turczynowicz have a 2005 3D model that includes crawlspaces.
- There was a request that any model proposed for use be validated to avoid excessive conservatism in development of the HILs.
- The issue of temporal change in concentrations was raised. In response, however, it was noted that the HILs are intended to reasonably protect against human health risk without excessive conservatism, but are not to be considered precise.
- Peter Nadebaum concurred with Greg's suggested approach, indicating that building an Australian scenario set is a key element.
- It was queried how much difference use of the Johnson 3D model might change the HILs where vapour estimates from the J&E model were found to be the limiting case in a risk assessment; it was responded that a significant effect would likely be apparent, to the extent that vapour issues might become non-limiting.
- It was indicated that the recent models can include differing degradation rates for different contaminant components.
- Concern was raised about using a 3D model including biodegradation, and then finding the solution was overly optimistic should oxygen not permeate into the soil and promote degradation. This point was used to promote a National Review to gather real-world data.

The discussion concluded with a note that the aim is to identify or develop a robust and useable model, and that validation of the model selected is a key aspect to a number of those present at the Workshop. Greg Davis suggested that CRC CARE might wish to consider whether funding can extend to such a project.

## **Workshop Conclusion**

Dennis Monahan thanked all participants, and advised that further comments or submissions could be provided in writing to CRC CARE for distribution to the Project Advisory Group. The PAG would consider the outcomes of this workshop and any subsequent comments when advising CRC on the future of this project.

