Ministry for the Environment
Manatū Mō Te Taiao

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

MODULE 6
Development of site-specific acceptance criteria

August 1999

Contents

6 Development of site-specific acceptance criteria

Module 6 provides general guidance for the development of risk-based site-specific soil and groundwater acceptance criteria as part of Tier 2 and Tier 3 site assessments.

6.1 Introduction

This module is designed to provide additional guidance for the development of site-specific soil and groundwater acceptance criteria in the context of Tier 2 and Tier 3 assessments. In particular, the following items are addressed:

- the development of Tier 2 site-specific acceptance criteria, based on the risk assessment methodology used for the development of Tier 1 acceptance criteria (outlined in Module 4) and a range of other risk assessment models;
- key requirements for the development of Tier 3 site-specific acceptance criteria. Given the highly site-specific nature of detailed risk assessment, it is not possible to fully define procedures for the development of Tier 3 criteria. Rather, the general requirements for such detailed site-specific risk assessment are outlined, together with an indication of the level of detail and site-specific input required as part of a Tier 3 assessment.

The objective of this module is not to provide detailed or definitive guidance regarding the conduct of Tier 2 and 3 assessments, but rather to provide a general indication of the issues that may require consideration and the level of detail required as part of Tier 2 and 3 assessments. The complexity of the Tier 2 and 3 assessments mean that the scope of work should be determined by appropriately qualified and experienced hydrogeologists, environmental engineers and risk assessment professionals on a site by site basis.

6.2 Developing Tier 2 acceptance criteria

The philosophy and general approach for deriving Tier 2 soil and groundwater acceptance criteria are discussed. Consideration is given to site-specific information requirements and options for more detailed fate and transport modelling.

6.2.1 Overview

A Tier 2 assessment is initiated where:

- the measured contaminant concentrations exceed the Tier 1 acceptance criteria (or the Tier 1 acceptance criteria are regarded as inappropriate)
- the likely savings in remediation costs resulting from this less conservative acceptance criteria compensates for the additional cost associated with a Tier 2 assessment.

The development of Tier 2 acceptance criteria is based on:

- the procedures outlined in Module 4 for the development of Tier 1 generic acceptance criteria or alternative risk assessment models, as outlined in Section 6.2.3

- replacement of generic data used in developing Tier 1 criteria with site-specific data.

Based on the results of the Tier 1 assessment, site conditions and receptor locations, a critical review of the completeness and relevance of exposure pathways should be conducted. The identification of relevant and complete exposure pathways is a critical element of any Tier 2 assessment.

The development of Tier 2 acceptance criteria can be based largely on screening level fate and transport models with incorporation of site-specific data to reduce the level of conservatism inherent in the criteria development. Alternatively, simple two-dimensional fate and transport modules may be used to refine risk estimates and site-specific acceptance criteria[1].

6.2.2 Information requirements

Examples of site-specific information that can be included in the derivation of Tier 2 criteria include:

- the depth to contamination
- soil type and properties (e.g. moisture content, porosity, density, organic carbon content), including variability in soil properties through the soil profile
- local climatic conditions (e.g. temperature and wind speed)
- building construction details and ventilation rates
- quantity of home-grown fruit and vegetables likely to be consumed (based on site use and physical constraints
- current and potential site use and activity patterns (e.g. duration of indoor and outdoor exposure, distance from the contamination to the receptor)
- nature and diversity of ecosystems, including the occurrence of specific species which have been identified as sensitive and likely to control the derivation of ecologically-based acceptance criteria
- physical setting of the site and the relevance of beneficial uses considered in the derivation of the Tier 1 acceptance criteria.

In some cases direct measurement of parameters noted above is not possible, however, improved estimates may be made based on the available site information.

Prior to collecting additional information, the review of exposure pathways should be completed such that the information gathering can be focussed toward addressing the exposure pathways identified as relevant and complete.

As part of a Tier 2 assessment, it is generally inappropriate to vary parameters used in the development of acceptance criteria that do not vary on a site-specific basis, e.g. toxicity and physical/chemical properties of the chemicals, unless specific new information becomes available. If parameters that are not site-specific are to be varied, detailed justification should be provided.

It is anticipated that the documentation associated with a Tier 2 assessment may include:

[1] The scope of a Tier 2 assessment undertaken in the context of these guidelines is more detailed and complex than that undertaken in accordance with the ASTM RBCA standard, reflecting the greater level of flexibility and detail inherent in the Tier 1 assessment as presented in these guidelines. The use of simple two-dimensional models as part of the Tier 2 assessment differs from the ASTM RBCA standard which has been configured to use simple analytical models which provide a unique output for a unique input.

- an overview of the setting of the site and the site-specific considerations
- justification for the adoption of site-specific values for parameters of relevance to the derivation of Tier 2 criteria
- details of the calculation of acceptance criteria using the procedures outlined in Module 4
- an assessment of the uncertainty associated with the adopted acceptance criteria and the likely impact of use of default values for some parameters where site-specific data is not available.

The Tier 2 assessment focuses on the refinement and validation of input parameters for the risk assessment (including fate and transport modelling), based on site-specific information. A Tier 2 assessment would normally include limited validation of fate and transport predictions (e.g. based on information gathered as part of the site assessment).

6.2.3 Alternative risk assessment models

A range of computer-based models have been developed for use in risk assessment, some specific to the assessment of petroleum contamination. The development of Tier 2 site-specific acceptance criteria may be streamlined by the use of such models, although the assumptions underlying such models should be carefully reviewed and documented as part of any derivation of Tier 2 acceptance criteria.

Therefore, two options exist for derivation of Tier 2 site-specific acceptance criteria:

- use of the equations set out in Module 4 for derivation of Tier 1 generic acceptance criteria, together with site-specific information
- use of one of a range of alternative, computer-based models together with site-specific information.

The derivation of Tier 2 acceptance criteria based on the equations used for derivation of the Tier 1 criteria has the advantage of streamlining the regulatory acceptance, given that the equations used for the Tier 1 analyses have undergone extensive peer review and that regulators will be familiar with the basis for the derivations. Additional information may be required to support alternative approaches, although these may be equally valid. Some of the alternative risk assessment models that may be considered for use in deriving Tier 2 acceptance criteria include:

- RISC, developed by BP Oil. The RISC model incorporates the VADSAT and Johnson and Ettinger volatilisation sub-models.
- Decision Support System (DSS), developed on behalf of the API
- HESP, developed by Shell (The Netherlands)
- RBCA Implementation Tools, developed by Groundwater Services Inc, incorporating the Johnson and Jury sub-models
- Fate 2, developed by Shell (US).

A range of other risk assessment models are also available, some of which may be useful in the derivation of Tier 2 site-specific acceptance criteria. Some of the models listed above require a considerable amount of site-specific information and effort, and may be more appropriately applied at a Tier 3 level.

Some of the alternative risk assessment models incorporate different assumptions regarding the fate and transport of contamination compared to those used to derive the Tier 1 generic acceptance criteria. Where assumptions regarding fate and transport differ, careful documentation is required. It is important that key assumptions and limitations underlying each model are carefully reviewed in selecting a model for use in the Tier 2 assessment.

In some cases, research is continuing with the aim of refining the risk assessment models. When such information becomes available, it may be incorporated in the derivation of Tier 2 acceptance criteria, and used to refine the existing risk assessment models. For example, opportunity exists for further refinement and validation of approaches to account for biodegradation in volatilisation.

If groundwater contamination is of particular concern, modelling of groundwater fate and transport using dedicated groundwater fate and transport models may be warranted. Some of the groundwater flow and fate and transport models that may be used in Tier 2 assessment are listed in Section 6.4.3.

Many of the same models may be used in Tier 2 and Tier 3 assessments, the difference being in the level of detail incorporated in setting up the models and the amount of effort spent on calibration and verification of the models (refer Section 6.4.3).

In addition, the RISC and DSS models incorporate groundwater fate and transport modelling capabilities, based on the VADSAT and AT123D sub-models respectively. BP Oil is upgrading RISC to include a surface water mixing model and a sediment partitioning model for use in situations where a groundwater plume intercepts a surface water body. The updated model will also include food chain pathways for ecological receptors RISC v4.0 will also include a modified Johnson model which incorporates vapour degradation and models to account for exposure via ingestion of vegetables and by use of contaminated water for irrigation .

Each of the risk assessment models listed above incorporates some consideration of leaching of contaminants from the unsaturated zone, thus predicting the impact of soil contamination on groundwater quality. Other stand-alone one-dimensional leaching models for use in Tier 2 assessments include VLEACH and CHEMFLOW, both developed by and available from the USEPA.

6.3 Developing Tier 3 acceptance criteria

A Tier 3 assessment is designed to reflect site-specific conditions and incorporate state-of-the-art risk assessment. Therefore, only the general requirements and level of detail necessary as part of a Tier 3 assessment and the derivation of Tier 3 site-specific acceptance criteria, are discussed.

Site-specific acceptance criteria developed in the context of a Tier 3 investigation incorporate a high degree of site-specific information, and state-of-the-art-risk assessment. The development of Tier 3 acceptance criteria may involve considerable expenditure and therefore the benefit gained from reduced conservatism is only able to be realised on a relatively small number of complex sites. The decision to proceed with Tier 3 assessment requires judging whether the remediation savings likely to result from less conservative criteria outweigh the cost associated with the Tier 3 assessment.

The Tier 3 assessment and the development of Tier 3 site-specific acceptance criteria may involve:

- detailed consideration of the distribution and spatial variability of the contamination
- incorporation of site-specific exposure assumptions, as per the Tier 2 investigations

- detailed site measurements and investigations to refine exposure parameters (e.g. activity patterns for site users), parameters of importance in fate and transport modelling or calibrated/validated fate and transport predictions
- a detailed review of the toxicology of each chemical of concern in order to confirm or refine the dose response factors, including consideration of site-specific factors that may influence the absorption and distribution of contaminants within the body (e.g. form of contaminant)
- detailed fate and transport modelling, particularly in relation to groundwater contamination, in order to improve predictions of contaminant concentrations at the point of exposure
- quantitative uncertainty and sensitivity analysis, incorporating techniques such as probabilistic risk assessment (Monte Carlo).

6.4 Refining site-specific acceptance criteria

Key issues in refining site-specific acceptance criteria relevant to the derivation of both Tier 2 and Tier 3 site-specific acceptance criteria, are discussed. Consideration is given to site-specific measurements, probabilistic risk assessment and detailed fate and transport modelling.

6.4.1 Site-specific measurements

Predicting contaminant concentrations at the point of exposure is an important element of risk assessment. Where the primary exposure route involves direct contact with contaminated soil (e.g. ingestion of contaminated soil) the exposure concentration may be taken directly from the measured soil concentrations. However, where exposure involves cross-media transfer or where the point of exposure is remote from the point of measurement of contaminant concentrations, it is often necessary to predict contaminant concentrations at the point of exposure, based on measurements at other locations. This is a particularly important issue when considering exposure to volatile chemicals, such as those present in gasoline and other hydrocarbon fuels, for which inhalation is the primary exposure route.

The development of Tier 1 and Tier 2 acceptance criteria is largely based on screening level fate and transport models. Such models incorporate a significant degree of uncertainty and conservatism, reflecting the simplifications inherent in the models. Refining fate and transport modelling used in the risk assessment, can have a major impact on the acceptance criteria. Fate and transport modelling incorporated in the development of the Tier 1 acceptance criteria includes:

- emissions from contaminated soil and groundwater to outdoor air
- emissions from contaminated soil and groundwater to indoor air
- uptake of contaminants by plants.

While it is possible to refine fate and transport modelling, the ideal data on which to base risk estimates are measured contaminant concentrations at the point of exposure (e.g. in indoor air). Unfortunately, direct measurement of contaminant concentrations at the point of exposure is often either not possible or not reliable (e.g. measurement of indoor air concentrations may be confounded by other sources). Alternatively, measurement of contaminant concentrations or fluxes at other points along the exposure pathway, may reduce the uncertainty associated with risk estimates.

When the risk assessment is looking forward to possible site redevelopment, it is not always possible to measure contaminant concentrations at the point of exposure. In such circumstances, intermediate measurements and measurement of input parameters may be used to refine or partially validate the fate and transport models. For example if a site is currently used as a service station, it is not possible to measure contaminant concentrations in basements associated with future residential development or in fruit and vegetables grown at the site.

6.4.1.1 Soil properties

Soil and aquifer properties are important input parameters for fate and transport modelling. Fate and transport modelling may be undertaken using default values, as for derivation of Tier 1 criteria, or using typical values for the soil types encountered on site. However, direct measurement of soil and aquifer properties on a site-specific basis provides the most accurate information for use in fate and transport modelling.

Soil and groundwater properties that may be measured on a site-specific basis include:

- bulk density
- particle density
- particle size distribution
- moisture content
- air and water filled porosity
- organic carbon content
- partitioning coefficient chemical specific, (involves trials conducted on a laboratory scale)
- hydraulic conductivity of the aquifer (requires pump tests, slug tests or similar aquifer tests conducted in the field)
- hydraulic gradient
- dissolved oxygen.

In practice, air-filled porosity and organic carbon content are the most important soil parameters relating to volatilisation and dissolved oxygen content; hydraulic conductivity and hydraulic gradient are important in assessing the fate of groundwater contamination. However, the reliable measurement of air filled porosity at a site, in order to obtain a representative value for modelling purposes, is not straightforward.

A level of uncertainty will be associated with each of the above measurements. It is important that a sufficient number of tests be conducted to ensure estimates are representative of the conditions at the site. Further consideration should be given to possible variation in each of the parameters spatially and with depth.

The requirement for site-specific measurement of soil and groundwater properties should be carefully evaluated on a site-specific basis. In some cases prudent use of published information may help, particularly where decision-making is not sensitive to the particular value assumed for a given parameter.

6.4.1.2 Soil gas profiles and emission flux measurements

Inhalation of volatile compounds following diffusion into indoor air is one of the dominant exposure routes for soil contaminated by gasoline and some other petroleum products. Measurements that enable validation of emission modelling are useful in refining risk estimates and reducing the conservatism inherent in the acceptance criteria. Two techniques that could assist in partial validation of the volatilisation models (where direct measurement of, say, indoor air concentrations is not possible) are:

- measurement of emission flux
- measurement of contaminant concentrations in soil gas at a range of depths.

In practice reliable protocols for the measurement of emission flux are yet to be developed and hence such techniques require further development before they can be routinely applied. The measurement of emission flux is most likely to be considered as part of a Tier 3 assessment.

Measurement of soil gas concentrations within the contaminated zone and comparison with the total contaminant concentrations in the soil (as measured by laboratory analysis) can be used to validate the partitioning sub-models used. Further, the profile of soil gas concentrations with depth can be used, in conjunction with detailed lithological data, to examine the extent to which a quasi-steady state has been achieved (assumed in many emission models) and whether loss processes other than volatilisation (e.g. degradation) are likely to be significant. Particular care must be exercised to ensure short-circuiting and infiltration of surface air is minimised when sampling shallow soil gas. Acceptance criteria for use in evaluating soil gas measurements are presented in Appendix 4J.

6.4.1.3 Plant uptake

Where preliminary fate and transport modelling indicates plant uptake and consumption of home-grown fruit and vegetables are potentially significant exposure pathways, consideration may be given to site-specific measurement of contaminant concentrations in plants. The available correlations between soil concentration and contaminant concentrations in edible portions of plants are highly uncertain and may significantly over-predict the uptake of contaminants by plants, particularly in edible portions of the plant.

Where exposure via the consumption of home-grown produce is dominant, then site-specific trials to measure the uptake of contaminants by plants may be considered, depending on the cost of conducting the trials and the likely savings resulting from less conservative acceptance criteria. In practice. specific plant uptake trials are difficult to conduct and there are limitations getting information suitable for use in a quantitative manner.

While plant uptake trials may be considered as part of a Tier 3 assessment, in most cases remediation of surface soils may be more cost-effective (given the cost and uncertainty associated with plant uptake trials).

6.4.2 Probabilistic risk assessment

Probabilistic risk assessment is a tool that can be used to assist in quantifying uncertainty and variability. Historically, risk assessment has been undertaken using conservative point estimates for each of the input parameters, with a single risk estimate resulting. In some cases a range of values may be used for each input parameter, providing a range of risk estimates, reflecting, for example, typical and reasonable maximum exposure. This approach can provide some understanding of the sensitivity of the final risk estimates to various input parameters.

The use of point estimates is a simplification as many of the input parameters used in risk assessment are either:

- uncertain, due to a lack of information

- or variable, that is the parameters vary between each of the individuals that may be exposed, e.g. body weight.

The use of point estimates has an important role in the development of conservative, generic criteria. However, it has been criticised as the combined effect of a series of conservative assumptions can result in an unrealistically conservative final risk estimate. Further, the use of point estimates means that the risk assessor and risk manager may not be able to determine how conservative the final risk estimate is, limiting the consideration of uncertainty in risk management.

Probabilistic risk assessment techniques provide a tool to account for uncertainty and variably in input parameters, allowing understanding of the level of conservatism associated with the final risk estimate.

Probabilistic risk assessment techniques, such as Monte Carlo analysis, involve:

- assigning a probability distribution to each of the input variables (where possible), such as body weight, inhalation rate, soil ingestion rate. The probability distribution may reflect the actual distribution of a parameter, say, through the community (e.g. body weight) or may reflect the range of possible values of a parameter for which there is a lack of reliable information (e.g. adult soil ingestion rate)
- combining each of the input distributions, in accordance with the normal risk assessment equations, by selecting values at random from each of the input distributions, determining the risk estimate for that combination, then repeating the process sufficient times for a reliable output distribution to be established.

The output, or risk estimate distribution, can be used to assist in risk management decisions. The presentation of risk estimates as a probability distribution allows risk managers to consider the proportion of the population that may be exposed to a given level of risk.

6.4.3 Detailed fate and transport modelling

Fate and transport modelling is an essential element of risk assessment, where consideration is given to:

- cross-media transfer of contaminants
- exposure at points remote from the source or point at which measurements have been taken
- future migration of contaminants and exposure of people not currently exposed.

The derivation of the Tier 1 acceptance criteria incorporates screening level fate and transport modelling. More complex, and potentially realistic, modelling can be undertaken in many circumstances, but detailed, site-specific information is required in order to realise the benefits of the additional complexity. In particular, many detailed fate and transport models require careful calibration which can only be undertaken on a site-specific basis.

Fate and transport modelling conducted in support of Tier 2 and Tier 3 assessments should give particular consideration to the presence and impact of preferential pathways for transport of contaminants. Preferential pathways have a major impact on the transport of contaminants, and where significant, must be incorporated in the adopted fate and transport model. The presence of preferential pathways can affect the selection of fate and transport modelling software; more complex models being required to assess the impact of such pathways.

6.4.3.1 Groundwater fate and transport

Groundwater fate and transport modelling can be undertaken on a wide range of levels, from screening level one-dimensional modelling, as used for the derivation of Tier 1 generic acceptance criteria, to simple two-dimensional modelling possibly incorporated as part of a Tier 2 assessment, and complex two- or three-dimensional modelling as part of a Tier 3 assessment.

The level of groundwater fate and transport modelling warranted at a particular site depends heavily on the quality of the data available to describe conditions at the site.

The groundwater fate and transport modelling process may be outlined as follows:

1. Define the objectives of the model.
2. Build a conceptual model of the hydrogeological system at the site.
3. Select an appropriate model type based on the conceptual model, the boundary conditions, soil and groundwater contaminant concentrations, the size of the source and the quality of the data available to support the model.
4. Design the quantitative model.
5. Calibrate the model (required for Tier 2 and 3 assessments).
6. Complete a sensitivity analysis to define the important input parameters and determine the robustness of the model predictions. (Experience indicates biodegradation rates are important and related to DO levels and the hydraulic conductivity, two significant parameters).
7. Use the model to predict the contaminant fate and transport.
8. Verify the model predictions regarding contaminant transport with time by comparison with further monitoring results (likely to be confined to Tier 3 assessments).
9. Report the results.

Most groundwater fate and transport modelling incorporates conventional hydrogeological flow modelling, while modelling of other fate and transport process can be overlain on the basic flow prediction. Justification of the model may range from provision of supporting information for the selection of input parameters, through to calibration and verification of the model against the piezometric surface and measured contaminant concentrations.

Consideration of groundwater contamination as part of the Tier 1 assessment is based on comparison of measured contaminant concentrations with generic criteria developed using screening level, one-dimensional fate and transport modelling.

A Tier 2 assessment may include the assessment of the groundwater impacts using site-specific information to carry out either, one-dimensional analytical evaluations or simple two-dimensional numerical modelling.

One-dimensional analytical evaluations would include consideration of the following dissolved phase, fate and transport processes:

- advection
- dispersion
- adsorption

- diffusion
- biodegradation (if reliable data are available to substantiate its inclusion).

The Air Force Centre for Environmental Excellence, Brooks AFB, Texas, has developed BIOSCREEN, a screening tool for simulating natural attenuation of dissolved hydrocarbons at petroleum sites. The analytical model is based on the Domenico analytical solute transport model which simulates the following processes:

- advection
- dispersion
- adsorption
- aerobic degradation
- anaerobic degradation.

The model will predict the maximum extent of plume migration which can then be compared to the distance to potential points of exposure.

Apart from the use of analytical solutions, numerical two- and three- dimensional models available for use, include:

- **MODFLOW coupled with MT3D**

  MODFLOW is a finite difference, porous media, groundwater flow model that is able to account for flow in two and three dimensions, under both steady state and transient conditions. MODFLOW has been developed by the US Geological Survey. MT3D, developed by S.S. Papadopulos, is used with any block-centred finite difference flow model and is often linked with MODFLOW for the evaluation of the fate and transport of the contaminant of concern. MT3D is a three-dimensional, finite difference model, based on the Eulerian-Lagrangian solution of the advective-dispersive-reactive transport. The model accounts for advection, dispersion and some simple chemical reactions.

- **BIOPLUME (Rice University)**

  BIOPLUME is a two-dimensional, finite difference model for flow and transport of dissolved hydrocarbons. The model considers convection, dispersion, mixing, and oxygen-limited biodegradation.

- **ARMOS (ES&T)**

  ARMOS is a two-dimensional, finite element model for flow and light separate phase hydrocarbons.

- **ASM (University of Kassel)**

  ASM is a two-dimensional, finite difference, flow and transport model. Flow processes considered include, steady state and transient considerations, unconfined, confined and leaky aquifer systems and the inclusion of sources and sinks. The solute is considered on a simplified manner using pathlines.

Each of the models listed above has differing capabilities, particularly with respect to the definition of the physical system (both groundwater and solute). The level of sophistication warranted in modelling is directly proportional to the quality of data available at a particular site, for space and for time.

The groundwater fate and transport models listed above can also incorporate the results of the unsaturated zone models, such as VLEACH (USEPA) and CHEMFLOW (USEPA), which can be used to predict the leaching of contaminants from soil.

In addition, a number of risk assessment software packages, for example the American Petroleum Institute's Decision Support System (DSS, incorporating AT123D) and BP Oil's, RISC model (incorporating VADSAT), include groundwater fate and transport sub-models that may be of use in a Tier 2 assessment.

Whether one-dimensional or two-dimensional modelling is used as the basis for the Tier 2 assessment, some model calibration is required.

A Tier 3 assessment may be based on use of a two-dimensional fate and transport model, such as those listed above, or one of a range of highly complex two- and three-dimensional fate and transport models. The level of modelling undertaken as part of a Tier 3 assessment depends on the complexity of the system to be modelled, the quality of the available data and the objectives of the overall modelling exercise (e.g. the level of accuracy required).

Normally a Tier 3 assessment would involve both calibration and verification of the model.

6.4.3.2 Volatilisation

Relatively few detailed, unsaturated zone, fate and transport models able to predict volatilisation of contaminants under a range of conditions e.g. from groundwater and soil, through various soil types and to outdoor or indoor air, are available.

Some examples are as follows:

- The RISC model developed by BP Oil (US) incorporates some fate and transport modelling, and accounts for some processes not considered in the simplified models used for derivation of the Tier 1 criteria. In particular, RISC incorporates a fully-transient volatilisation model which accounts for the attenuation provided by overlying soil, and the delay between release of the contaminant and establishment of the peak indoor and outdoor air concentrations.
- RBCA implementation tools developed by Groundwater Services International (GSI).
- MEPAS developed by Battelle.
- The Decision Support System (DSS) developed by the American Petroleum Institute.
- VADSAT (also incorporated in RISC), developed by EST Inc.

In addition, a number of models have been published in the scientific literature; some of which are incorporated in the computer-based models listed above. Examples include:

- Jury, Spencer and Farmer 1983,
- Hwang and Falco 1986,
- Johnson and Ettinger 1991.

To date, little work has been completed with the aim of validating the predictions of the volatilisation models. Considerable research aimed at refining the models continues, particularly in relation to methods for considering biological degradation in the unsaturated zone and its impact on emission fluxes. In general, volatilisation models are regarded as conservative, i.e. likely to over-predict emission rates, resulting in relatively low soil acceptance criteria in some circumstances.

6.5 Developing ecologically-based acceptance criteria

The requirements and general approach for the development of ecologically-based acceptance criteria are discussed. The assessment of ecological impact is complex and therefore the methodology to be used should be selected on a site- and project-specific basis.

6.5.1 General

Soil and groundwater contamination may result in adverse health and environmental effects. Where significant contamination occurs, the potential exists for off-site environmental impacts, particularly for large sites or where a site is located within or adjacent to a sensitive ecosystem (e.g. wetlands).

Most petroleum contaminated sites are located within an urban or developed environment, and so the generic Tier 1 soil acceptance criteria include only limited consideration of ecological concerns. This approach is consistent with protection of likely future use of petroleum sites, e.g. the primary ecological concern in a residential context is the support of plant life for domestic gardens.

Due to uncertainty of the impact of petroleum contamination on the terrestrial environment, Tier 1 soil acceptance criteria based on ecological protection have not been nominated. Rather the Tier 1 ecological assessment is based on the identification of:

- sensitive ecological receptors
- complete exposure pathways.

A checklist to assist in this process is presented in Appendix 4I. Tier 1 soil acceptance criteria based on the soil to groundwater pathway and the Tier 1 groundwater acceptance criteria for the protection of aquatic ecosystems may be useful as part of the Tier 1 ecological assessment.

Where off site ecological effects may be significant, more detailed consideration may be warranted.

Agreed approaches for the assessment of ecological risk are yet to be established in New Zealand although information is available from a range of international approaches. As with the health risk assessment of soil contamination, a tiered approach is proposed. No distinction is made between different land uses. Land use may influence the selection of ecological receptors to be protected (e.g. protection of on site terrestrial receptors may not be required in an industrial context), however the approach for assessing impact on the selected receptors is independent of land use.

The proposed approach to ecological risk assessment is outlined as follows:

Tier 1

Identification of possible sensitive ecological receptors and review of exposure pathways to determine relevance and completeness. A checklist has been prepared to assist with this process (refer Appendix 4I). Where sensitive ecological receptors are identified and exposure pathways may be complete, a Tier 2 assessment may be warranted.

Tier 2

A Tier 2 assessment of ecological risk may, in the first instance, involve comparison of contaminant concentrations (estimated or measured) at or near the likely point of impact with soil screening criteria based on a standard methodology and No Observable Adverse Effect Level/Concentration (NOAEL/NOAEC) or similar data. Three approaches for deriving such criteria may be considered; the modified USEPA method, the Canadian approach and the Dutch methodology. These approaches are:

- simplified and based on conservative assumptions
- largely descriptive and qualitative
- based on look-up tables for soil screening criteria
- draw on published information
- assess at a species level.

However, the assessment of ecological risk based on generic screening level criteria has been criticised as being overly conservative.

The development of site-specific ecological soil screening criteria may be considered as an extension of the above approach where the species and media of concern are selected based on site-specific information. This particular approach is:

- semi-quantitative
- uses standard ecological risk assessment methods and models
- has greater emphasis on data collection, focussing on the key issues raised by the Tier 1 assessment
- still assesses largely at a species level.

Tier 3

A Tier 3 assessment involves a fully detailed, site-specific assessment of ecological impact, including:

- considering detailed site-specific data
- predictive fate, transport and exposure modelling
- quantitative information on complex ecosystem responses
- considering complex assessment issues such as chronic effects, interaction between chemicals, interaction between ecosystem levels, and food chain impacts.

An important distinction between the health and ecological risk assessment methodologies is that the health risk assessment focuses on the protection of the individual, whereas the ecological risk assessment focuses on the assessment of impacts in populations.

Further, when assessing possible ecological effects of a given contaminant, consideration must be given to background soil concentrations. It is assumed that the local ecosystem is sustainable at the natural background levels of contaminants in soil and therefore clean-up below background concentrations is not required.

The development of site-specific ecologically based acceptance criteria requires detailed consideration of the affected ecosystem, the value assigned to the ecosystem, and the point at which a given level of protection is to be achieved.

The first step in an ecological risk assessment involves establishment of the project objectives in order that the assessment may be properly focussed. These could be:

- definition of the ecosystem to be considered
- the value and function of the ecosystem (e.g. harbour area allowing passage of fish, or pristine ecosystem preserved as a nation resource)

- the level of protection to be afforded (high level of protection consistent with maintenance of a pristine ecosystem, or minor impacts are tolerable).

The definition of the project objectives allows the direction and level of detail of the ecological risk assessment to be appropriately focussed.

For example, at most sites sufficiently contaminated to warrant a Tier 3 ecological assessment, the on-site ecosystem will be highly modified as a result of general development, rather than simply as a result of the contamination. In such circumstances, it may be appropriate to afford a relatively low level of protection to the on-site ecosystem, consistent with the proposed use (e.g. survival of plants would be required in a residential context), while providing a much higher level of protection to the off-site environment. In particular, specific consideration should be given to possible impacts on nearby surface water bodies.

Deriving Tier 3 ecologically-based criteria must involve:

- detailed site-specific consideration of nature, extent and distribution of contaminants
- detailed predictive fate and transport modelling, to understand possible transport of contaminants, the ecosystems that may be impacted and the likely contaminant concentrations within the impacted ecosystems
- site-specific assessment of the ecosystems impacted, including consideration of the species present and the interaction between various species
- consideration of possible food-chain effects
- detailed consideration of the levels at which onset of chronic effects, particularly sub-lethal effects occur. This may involve some site-specific test work
- assessment of background contaminant concentration and other stresses on the ecosystem.

6.5.2 Fate and transport modelling

As outlined in Section 6.4.3, fate and transport modelling is an essential element of risk assessment, including ecological risk assessment, given that the ecosystem requiring protection is frequently located off-site, remote from the point of contaminant release.

Some important considerations in fate and transport modelling for ecological risk assessment include:

- the nature, extent, level and spatial distribution of contamination
- background contaminant concentrations
- soil type and physicochemical properties that may affect attenuation of contaminants, or other processes such as erosion
- contaminant plume movement (whether the dissolved phase hydrocarbon plume is increasing, decreasing or stable)
- microbiological activity, and likely degradation rates
- aquifer properties and discharge points
- potential for erosion of contaminated soil.

The fate and transport modelling can also be extended (following the assessment of the ecosystem) to account for accumulation and transfer of contaminants through the ecosystem, including consideration of food chain effects.

6.5.3 Assessment of the ecosystem

For each of the ecosystems potentially affected, it is important to develop an understanding of the composition and functioning of the ecosystem on a number of levels. Important considerations include:

- identification of key species for a range of taxonomic groups e.g. earthworms, terrestrial plants, birds
- interaction between the species in the ecosystem, both in terms of food chain and other system functions.

It is important to build a conceptual model of the ecosystem, enabling the impact of stresses on any one part of the ecosystem to be evaluated in terms of its impact on the wider ecosystem. For example, in an aquatic environment a particular species may perform a physical support function, which if compromised could result in an impact on the physical structure of the ecosystem.

6.5.4 Assessment of impact of contaminants

Depending on the species impacted and the cost-benefit relationship, it may be appropriate to undertake controlled sensitivity and uptake trials using key species identified as part of a Tier 3 assessment.

Such information may then be used to undertake predictive modelling of population and community changes at an ecosystem level, with the aim of developing a quantitative understanding of the impact of contaminants on the overall ecosystem.

6.6 References and further reading

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