APPENDIX 15
Complete Concawe report

european oil industry guideline for risk-based assessment of contaminated sites

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ABSTRACT

This report proposes a three-tiered approach to assessing the condition and corrective action requirements for oil industry sites ranging from complex refineries down to retail service stations. The nature and extent of contamination at such sites can range from major to insignificant. The potential for soil and groundwater contamination to expose a neighbour, an on-site worker, or another potential receptor also varies enormously.

This approach uses the principles of risk-based corrective action (RBCA) which follows a flexible approach to decision making whereby corrective action is appropriately tailored to site-specific conditions and hazards. This leads to more cost-effective solutions, and allows the greatest effort to be targeted to where it is most beneficial.

The underlying concepts of Risk-Based Corrective Action are described in this report. Work is still continuing on developing specific guidance on the details of the methods to be used.

KEYWORDS

Clean-up, contaminated sites, contamination, corrective action, oil, oil industry, petroleum, RBCA, refineries, risk, risk based corrective action, screening, terminals, toxicity.

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SUMMARY

Industry, regulatory and public attention to contaminated land in Europe has escalated dramatically over recent years. Faced with a variety of local and national approaches to this problem, a process has been developed to assist the European oil industry in assessing the condition and corrective action requirements for sites ranging from complex refineries down to retail service stations. The nature and extent of contamination at such sites can range from major to insignificant. The potential for soil and groundwater contamination to expose a neighbour, an on-site worker, or another potential receptor also varies enormously.

Some countries have set fixed numerical criteria to decide these issues based on generic assumptions on site conditions such as; soil type, depth to groundwater, geology and hydrogeology, and proximity to potential receptors (e.g. groundwater supply well, basement, surface water body). Such an approach ignores the fact that contaminated sites vary widely in terms of both complexity and the potential risk they may pose to either human health or the environment. As fixed numerical criteria are nearly always set at very low levels, their use leads to the clean-up of more land than may be necessary. The result is wastage of resources (and ultimately added expense to the consumer) with clean-up costs incurred without an incremental reduction in risk to human health and the environment.

In recent years, the principles of risk-based corrective action (RBCA) have been applied. This follows a flexible approach to decision making whereby corrective action is appropriately tailored to site-specific conditions and hazards. This leads to more cost-effective solutions, and allows the greatest effort to be targeted to where it is most beneficial. In its broadest sense, risk assessment in relation to contaminated land can be defined as “an evaluation of whether there is a potential for adverse effects to occur, based on factual knowledge about a site, and scientific evidence concerning the environmental behaviour and toxicity of the chemicals present".

Although this method is applied in the USA (ASTM RBCA)* , there are a number of differences between the USA and Europe. CONCAWE therefore decided to develop similar techniques for Europe and produce a Guideline which sets out an approach which could be adapted to the situations prevailing in the various European countries.

The underlying concepts of Risk-Based Corrective Action are described in this report. Work is still continuing on developing specific guidance on the details of the methods to be used. This will be published at a later date.

The CONCAWE Guideline recommends a three tiered approach to corrective action decision making. It assumes that one starts with relatively little site data, and therefore uses conservative generic assumptions. By conducting additional investigation and analysis, more site-specific knowledge is used in developing subsequent clean-up targets. The result is fully protective of human health and the environment throughout Tiers 1, 2 and 3.

The three tiered approach is based on the principle of source-pathway-target. It starts with an initial assessment of the site which involves gathering general data including potential sources of contaminants, obvious evidence of contamination,

* ASTM (1995) Standard guide for risk-based corrective action applied at petroleum release sites. ASTM E-1739. Philadelphia PA: American Society for Testing and Materials

land-use, presence of potable groundwater, etc. The pathways by which contaminants could reach identified receptors or populations at risk are then identified. This enables a Tier 1 assessment to be performed, in which chemical data on the degree of contamination of the site is collected and compared with Risk Based Screening Levels (RBSL) and other relevant criteria. The RBSLs comprise of a set of trigger concentrations for contaminated soil and groundwater. These figures are not intended to be soil standards or clean-up targets. If exceeded, they are simply an indication that further study is required. RBSLs are derived using conservative assumptions and, as such, are based on a generalised risk assessment. If the observed values are below these levels, then the risk is identified as being insignificant.

If further assessment is required, Tier 2 and 3 studies are performed. These involve refinements to take into account more site-specific considerations, with the possible collection of additional data. The pathways of exposure may be modelled to prepare quantitative risk estimates, and clean-up criteria may be derived by back-calculation from risk acceptability criteria. From this process, Site-Specific Contaminant Target Levels (SSTLs) can be derived. There is an option at the end of each of these Tiers to develop a corrective action programme based on remediation to the SSTLs. Corrective Actions often involve some form of remediation, but could include instituting a monitoring programme as a viable remedy within the risk framework.

Although this procedure may seem complicated, it is expected to provide a consistent framework for decision making. The outcome should be cost-effective in identifying those sites where clean-up is necessary to protect man and the environment.

1. INTRODUCTION

This document presents a Guideline for a uniform approach to corrective action decisions at contaminated European oil industry sites based on risk management. Whilst the focus of the Guideline is sites at which the production, use or storage of petroleum products may have resulted in accidental releases to soil and groundwater, it is expected that the process and its underlying principles can be applied to a broad range of industrial and commercial sites. The Guideline provides details on how to identify whether or not corrective action is required at such sites, and, if so, the form that this should take. The Guideline links the principles of risk assessment with those of site investigation and corrective action decision-making.

The Guideline draws heavily on the principles of Risk-Based Corrective Action (RBCA) as they have been applied in other parts of the world, primarily in North America. It is an attempt to place these principles within a European context, in recognition of the specific circumstances pertaining both to the continent as a whole and to the individual countries within it.

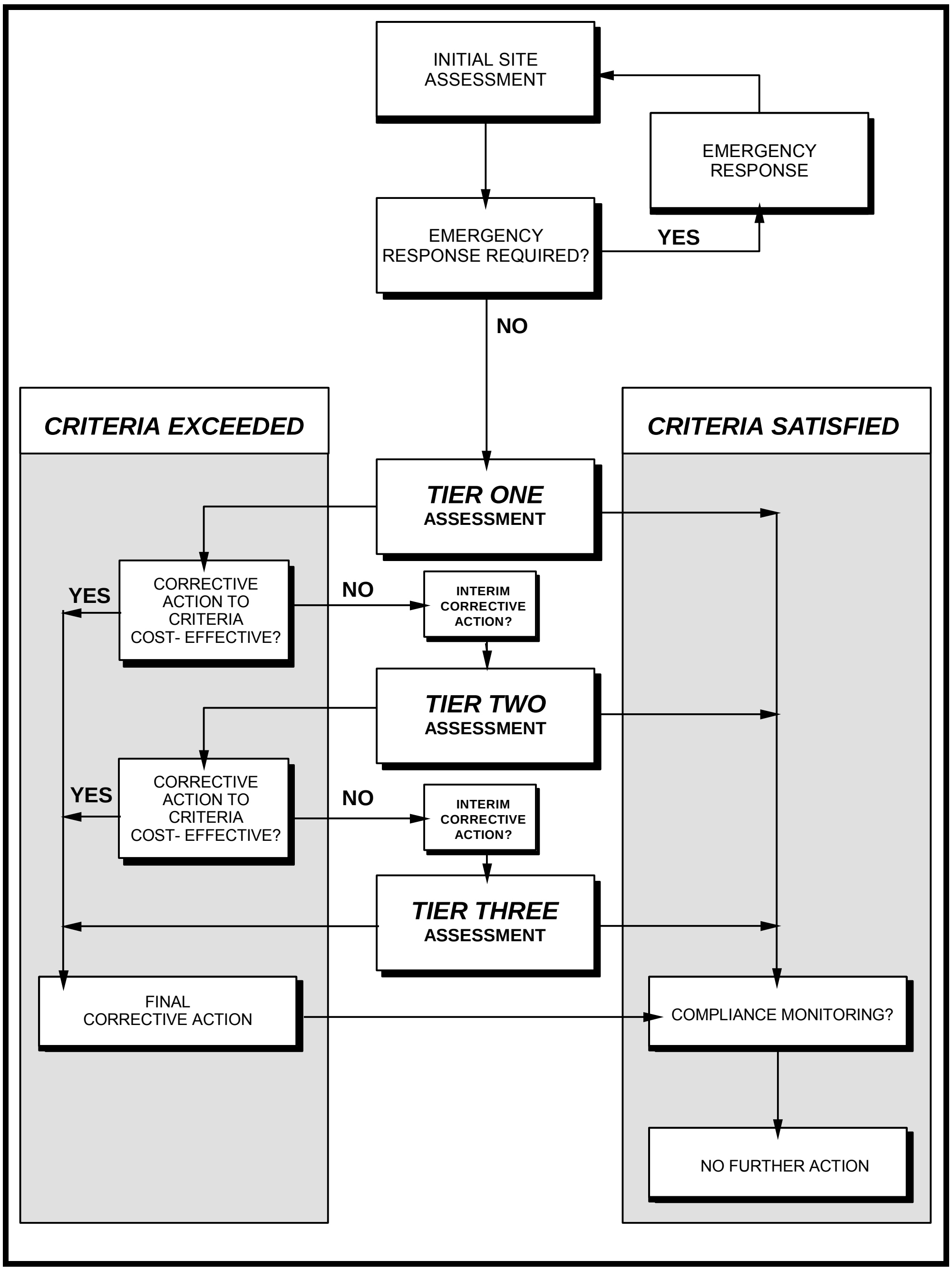
The Guideline reflects the European oil industry's desire for a consistent risk-based approach to dealing with its contaminated sites. Such an approach is necessary since the industry is responsible for a large number of sites across Europe. The industry firmly believes that the guiding principle behind the approach should be protection of human health and the environment.

Corrective action should only be applied to sites which are found to pose unacceptable actual or potential risks to human health and/or the environment. A risk-based approach allows the regulatory and regulated communities to focus their efforts on sites that pose actual risks, rather than drawing conclusions from the blanket application of non-site-specific criteria at all sites.

Contaminated oil industry sites vary widely in terms of their complexity, physical and chemical characteristics, and the potential risk they may pose to human health and the environment. The Guideline recognises this diversity and describes a three-tiered approach to decision-making in which site assessment, risk assessment and corrective action activities are appropriately tailored to site-specific conditions and hazards. This flexibility allows more focused and cost-effective solutions to be developed than have been used in the past, particularly those designed to achieve uniform standards and procedures. While the Guideline is aimed specifically at oil industry sites, its general principles should be applicable across a broad range of industrial sectors and activities.

Under the Guideline, site assessment becomes more detailed at each successive tier, and requires the progressive use of additional information and expertise. The approach is summarised schematically in **Figure 1**. It should be noted, however, that not all tiers have to be completed for a conclusion to be reached on the need for and scope of any corrective action. The tiered approach merely allows the level of analysis to be restricted to that needed to make an appropriate risk-based decision. Such an approach is consistent with the evolving contaminated land policies of several European governments and has the flexibility to be used by others.

Figure 1 General approach



This document contains information on the process to be used. A more detailed technical explanation of the methods to be used, and the Risk Based Screening Levels, will be published at a later date.

2. OVERVIEW

2.1. OBJECTIVES OF THE GUIDELINE

The objective of this Guideline is to provide a simple-to-use, rational system for addressing potentially contaminated oil industry sites in a manner which is protective of human health and the environment. It will allow risk-based decisions to be made in an efficient and cost-effective manner and can be used to prioritise remedial actions at numerous sites, where this is necessary.

The Guideline is designed to replace more traditional approaches to contaminated land assessment and remediation, in which investigation and corrective action activities have often taken place in isolation, with no clear linking of the two. Such approaches have tended to lack any detailed scientific evaluation of whether corrective action is necessary and what form this should take to achieve adequate protection of human health and the environment in the most cost-effective manner. The blanket and uniform application of generic standards has compounded the problems of this approach since, when an exceedence has been identified, remedial measures have often been implemented with little regard for the actual objective, or how they should be targeted most effectively.

The Guideline has been developed to provide a risk-based framework for consideration by European regulators and other interested parties across Europe as a scientifically defensible approach for dealing with contaminated land, specifically at oil industry sites. This is especially important at present since a number of countries are developing contaminated land policies which involve the use of risk assessment. The Guideline provides a common framework that could be applied on a Europe-wide basis via an "evergreen" framework which integrates "state of the art" risk assessment techniques into a flexible decision-making methodology.

It should be noted that, until recently, risk assessment of contaminated sites often focused on the "worst case" or "reasonable worst case". This was especially so in the USA, where protecting the hypothetical "Maximally Exposed Individual" (MEI) has proved costly to industry, and ultimately society, with minimal positive impacts for the public, regulatory and regulated community. This situation can be visualised by considering sites where both soil and groundwater are contaminated, for example with volatile organic compounds. The MEI is assumed to be someone who lives on the site and is exposed to the contamination via all plausible exposure pathways which, in reality, are unlikely to be experienced by one person. These include drinking groundwater from a garden well, eating vegetables grown in the garden, coming into dermal contact with contaminated media and inhaling the vapours (both indoors and outdoors) and showering in the same contaminated water. It is only recently that the extensive resources committed to protecting this individual have been viewed in terms of the overall benefits to society and the environment. Such benefits are often low or even indefinable compared with those that are achieved in other areas of environmental improvement. This resulted in the risk-based corrective action (RBCA) process being adopted in the US.

It is the European oil industry's belief that corrective action at contaminated sites should be based on the practical application of risk-based methods. Clearly, it is impracticable and unrealistic to attempt to protect this hypothetical individual at all costs.

2.2. BACKGROUND TO RISK ASSESSMENT

Risk assessment in regard to contaminated land has as its basis a principle published by the US National Academy of Sciences (NAS) in 1983. This principle identifies four elements of the risk assessment process, as follows:

- hazard identification, in which the main potential adverse health effects are identified. In practice, hazard identification has been replaced by the term "site characterisation" and involves examination of the site and collation of relevant data and information. The process is illustrated in **Figure 2**.
- exposure assessment, in which the potential intake levels/exposures for target populations are calculated;
- dose-response assessment, in which the relationship between dose level and adverse health effects of chemicals are defined; and
- risk characterisation, which combines the exposure and dose-response information to predict the likelihood of adverse health effects arising in the target population.

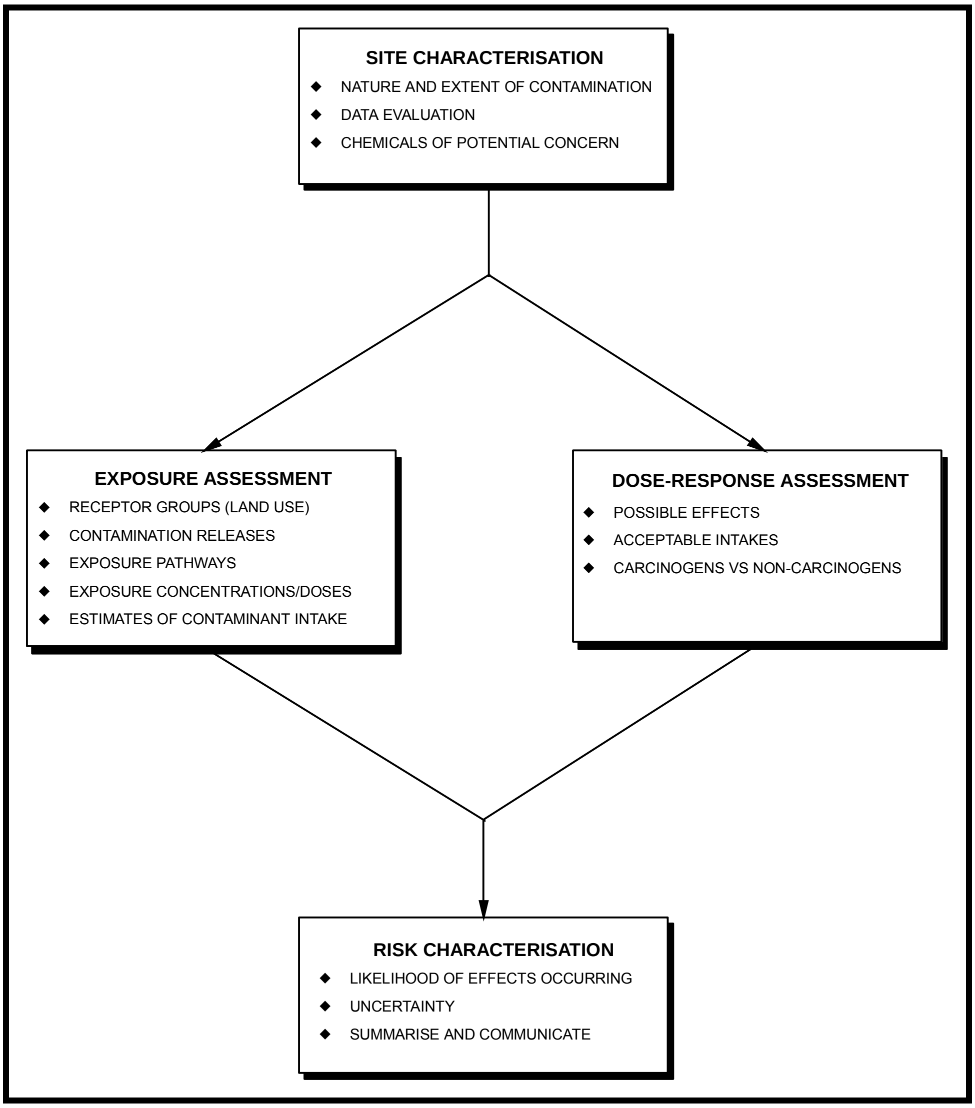
Fundamental to an understanding of risk assessment is the basic principle of toxicology, that "the dose makes the poison". This refers to the fact that every substance is toxic, no matter how benign it seems in everyday experience. The critical factors are the amounts which can be taken into the body before adverse effects occur and the probability of those effects occurring.

The purpose of a risk assessment is to carry out an evaluation of the possibility that toxic effects will occur, by quantitatively predicting exposure levels and then combining them with toxicity information. Well-established methods are available to predict the potential human exposure to substances present at contaminated sites, and suitable toxicity information (in the form of dose-response criteria) is available from authoritative sources, such as the World Health Organisation. The combination of predicted exposure levels with toxicity information provides an assessment of risk. In situations where it appears that there is a significant risk (i.e. the predicted exposure is in excess of the "tolerable" exposure), acceptable soil contaminant concentrations can be derived or the exposure setting changed to bring the potential exposure levels down to within the tolerability limits. It should be noted that such limits are themselves subject to considerable uncertainty and so usually err considerably on the side of safety.

Risk assessment is now seen by regulators and industry in many countries as the best way forward in managing potential contaminated land issues. It has been incorporated into government environmental regulations in the USA, Canada, Australia, New Zealand, the Netherlands and the UK and is being considered in many others. In its broadest sense, risk assessment in relation to contaminated land can be defined as:

> *"an evaluation of whether there is a potential for adverse effects to occur, based on factual knowledge about a site and scientific evidence concerning the environmental behaviour and toxicity of the chemicals present."*

Figure 2 Traditional risk assessment model



Risk assessment has developed rapidly since its initial use in addressing environmental issues in the USA in the mid-1980s. Historically, it was regarded as distinct from risk management, the latter being concerned with the implementation of measures designed to mitigate any issues identified by the former. This separation developed so that objective, scientific appraisals of risk could take place in isolation from issues such as economics or politics.

More recently it has been recognised that, while the separation of risk assessment and risk management makes sense philosophically, it can lead to problems in risk-based decision-making. This is because some sites present insignificant risk, whereas others may have the potential to present significant risk, and so merit a more detailed examination. Clearly, with perhaps hundreds of thousands of potentially contaminated sites worldwide, risk assessment has to be streamlined to allow low risk sites to be screened out at an early stage, and allow a more detailed investigation into sites which have the potential to pose higher risk.

The European oil industry believes that risk assessment is most cost-effectively applied within a tiered framework that is acceptable to both the regulators and regulated community. The amount of time and effort that is invested in assessing risk is therefore defined on a site by site basis, taking into account site conditions and the potential exposure pathways to the human and environmental receptors of concern. A tiered approach also allows the use of increasing amounts of site-specific data to replace the conservative generic assumptions that are initially made with less detailed site specific knowledge.

The risk-based approach to dealing with contaminated land has considerable advantages over the use of generic standards. It allows the assessment of site-specific conditions to determine whether or not there is a potentially unacceptable risk at a contaminated site and the need for, and scope of, any corrective action can subsequently be determined. Site-specific risk-based corrective action levels are typically less conservative than generic standards as they are calculated using site-specific data (the latter are designed to be applicable to the most sensitive of situations). As a result, corrective action is only carried out in situations where a need has been identified through a comprehensive evaluation of the associated risks, taking into account all local circumstances.

This Guideline outlines a tiered risk assessment framework that provides a logical and technically defensible means of evaluating potential risks at petroleum sites. It also offers additional advantages since pre-defined risk assessment methods can be reviewed by regulators and/or independent technical consultants, and form the basis for established acceptance procedures. The Guideline provides a framework into which new scientific information can be integrated as it becomes available, and allows country-specific requirements and assumptions to be incorporated.

The final, and perhaps most important benefit of the risk-based process is that it identifies the most important issues surrounding a site. This allows the exposure pathways of concern to be identified and any potential for exposure to be eliminated through institutional controls, natural attenuation and/or remedial techniques. The key is that the approach is flexible enough to facilitate the reduction or mitigation of potential site risks, as needed.

2.3. PROJECT SCOPE

In developing this Guideline, a thorough review of best practice in risk-based corrective action decision-making has been carried out. This has involved, primarily, a technical survey of the various risk assessment tools currently in use. In addition, the linking of data collection and risk assessment has been evaluated, as have risk-based approaches to corrective action.

A series of tasks were undertaken in support of this guideline development and were as follows:

Task 1	Model/Package/Approach Critical Review
Task 2	Exposure Pathway Assessment
Task 3	Site Investigation Data
Task 4	Master List of Chemicals and Toxicity Database
Task 5	Simulation Methods and Statistics
Task 6	European Exposure Assumption Database

Task 7 Ecological Risk Assessment
Task 8 Regulatory Impact Analysis

The results of these tasks provide information on:

- suitable technical approaches to risk-based corrective action and the applicability of already-existing models/packages/approaches;
- the exposure pathways that should be considered in a European contaminated land risk assessment;
- data needs for risk-based corrective action purposes;
- the nature of contamination at oil industry sites;
- the use of statistics in risk assessment;
- suitable input parameters for European risk assessments;
- methods for evaluating risk to non-human ecological receptors; and
- the regulatory situation *vis-a-vis* risk-based approaches to dealing with contaminated land.

They have allowed the development of an approach which incorporates the best parts of several others, tailored to the European situation.

2.4. REGULATORY ACCEPTABILITY

Many countries in Europe have either adopted risk-based approaches to contaminated land corrective action decision-making or are in the process of doing so. It is important that, within developing legislation, the opportunity for using innovative techniques is left open. This will ensure that advances in knowledge and scientific developments can be incorporated into existing frameworks. Individual regulators may wish to make their own policy decisions and establish their own "best practice" but it is in everyone's interests that reasoned scientific principles should be allowed to prevail when deciding on the correct approach at a particular site.

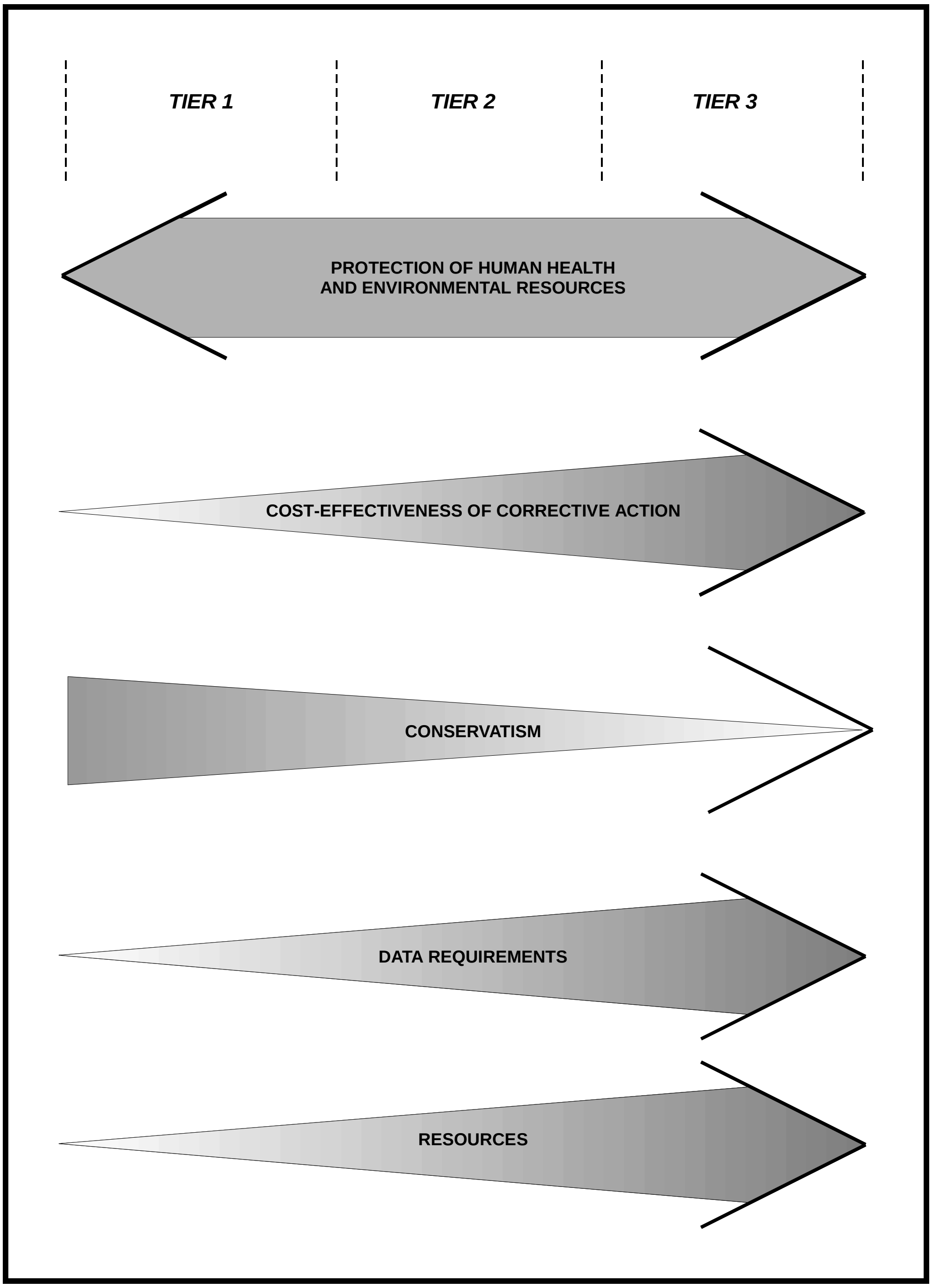
2.5. SUMMARY OF THE APPROACH

The approach developed for the European oil industry is of a tiered nature, based on ASTM Risk Based Corrective Action. It is summarised in **Figure 1** and a brief description of each of its elements is provided below, in advance of the remainder of this guideline, which describes it in detail.

The tiered approach to risk-based corrective action described in this Guideline facilitates the best use of both private and public sector time and resources at oil industry sites in Europe. It is justified on the grounds that many sites do not need a detailed risk assessment to be performed in order that they can be declared safe, provided that conservative assumptions are made and any increase in the level of accuracy would result in a decrease in the estimated level of risk.

Figure 3 presents a schematic representation of certain key features of the tiered approach. As shown in the figure, progression through the tiers results in greater investments of resources (time and money) in order to reach the increasing data and analytical requirements. At the same time, conservative "generic" assumptions are replaced by site-specific values, producing less stringent targets for increasingly cost-effective corrective action. Throughout the process, the level of protection of human health and the environment remains constant.

Figure 3 Summary of tiered site analysis



In broad terms the approach can progressively incorporate the following key steps, as required:

- Initial Assessment;
- Emergency Response Decision/Action;
- Tier 1 Assessment and Corrective Action Decision;
- Tier 2 Assessment and Corrective Action Decision;
- Tier 3 Assessment and Corrective Action Decision.

The outcome of each step can include tier upgrade, corrective action, compliance monitoring or a conclusion that no further action is required.

The first step, the "initial site assessment", involves the gathering of general data about the site. The assessor is required to identify the following:

- potential contaminant sources (e.g. equipment leaks)
- potential exposure pathways;
- obvious environmental impacts, if any;
- the presence of potentially impacted humans and environmental resources (e.g. workers, residents, surface water bodies, etc.);
- the current and proposed site land-use;
- the presence/absence of potable groundwater beneath the site; and
- conceptual site model(s).

This is followed by the collection of chemical data, via intrusive investigations, and a comparison of the data with Risk-Based Screening Levels (RBSLs) and other relevant criteria (ORCs). It is also appropriate at this early stage to assess whether an emergency response action is required.

RBSLs represent chemical concentrations in soil and groundwater that, in the vast majority of cases, do not pose a significant risk to human health. ORCs relate to existing exposure media that have also been sampled (e.g. indoor air) and they are legal standards, guidelines or aesthetic criteria. RBSLs are typically derived using conservative assumptions and contaminant migration models. They are of an "evergreen nature" and subject to change as new modelling approaches and input parameters are developed. RBSLs are therefore conservative values against which measured contaminant concentrations can be compared. Where measured concentrations are below these screening criteria it may be assumed that the identified contamination does not pose a significant risk.

If the Tier 1 criteria (RBSLs and ORCs) are satisfied, then normally no further action is required. If the criteria are not satisfied, then the possibility of corrective action should be reviewed for its cost-effectiveness. If it is clear that corrective action to achieve these levels would not be cost-effective, then the need for interim measures should be considered, before a Tier 2 assessment is carried out, involving the collection of additional data, if required. The decision regarding whether or not to carry out a Tier 2 assessment should include a comparison of the cost of achieving Tier 1 corrective action goals with the cost associated with completing a Tier 2 assessment, bearing in mind that the achievement of the Tier 2 site-specific goals should be significantly less costly to achieve than Tier 1 goals.

The Tier 2 assessment involves a refinement of the study to take into account more site-specific considerations with the collection of additional site investigation data if required. In regard to data interpretation, of particular importance may be the replacement of "worst-case" assumptions with more site-specific information. Different modelling techniques (which take into account chemical attenuation in the environment between source and receptor) may be employed or, alternatively, the models that were used to generate the RBSLs may be used, with appropriate refinement of the input values where site-specific data is available. It is recommended that the assessment takes place in a "forward manner" where quantitative risk estimates are generated for the site. The "forward calculation" of risk gives an overall perspective on the significance of potential risks to public health and the environment from measured chemical concentrations and is consistent with the "risk assessment" requirements of many European regulators.

Risk estimates are compared with appropriate acceptability criteria in order to determine the outcome of the Tier 2 assessment. This is in contrast to the Tier 1 analysis where measured contaminant concentrations were compared with RBSLs derived by taking an insignificant risk level and back-calculating a "safe" concentration. If corrective action target levels are needed, they may be developed using either the estimated risk levels or the same techniques as used in the original development of RBSLs, except that site-specific parameters are used in the equations. The new target levels, which incorporate site-specific assumptions and parameters, are termed Site Specific Target Levels (SSTLs).

If the acceptability criteria at Tier 2 are met, then no further action is required, except, perhaps, periodic monitoring for a finite period of time, if justified. If the criteria are exceeded by the site-specific risk estimates, the cost-effectiveness of achieving Tier 2 corrective action goals, which may include changes in land-use, exposure pathway control measures or Site Specific Target Levels (SSTLs), should be reviewed in relation to undertaking a Tier 3 assessment, bearing in mind that the achievement of Tier 3 site-specific goals will likely be less costly to achieve than Tier 2 goals. If corrective action is still not considered to be practical or cost-effective, a Tier 3 assessment should be carried out, although interim corrective action may still be needed. Such action could include obvious hot-spot removal or temporary containment measures and focuses on reducing risks which, while as yet not quantified accurately, are judged by the assessor as likely to need addressing following Tier 3. By carrying out such interim measures, any potential risk posed by the site while the Tier 3 assessment takes place, is avoided, or at least reduced. Alternatively, interim measures may not be driven by real risk but by aesthetic considerations and the adverse publicity that could accrue if action is not taken where contamination has been identified.

The Tier 3 assessment evaluates further the risks posed by the site and provides the information required to more effectively focus any corrective action required. It will often require more site-specific data, more sophisticated modelling (such as numerical fate/transport models and pharmaco-kinetic modelling) or a combination of the two. The Tier 3 assessment provides forward calculations of risk which are then compared with acceptability criteria to assess the need for corrective action, as at Tier 2. If the risks are found to be unacceptable, the options for corrective action should be reviewed and appropriate control measures put in place and/or a remedial scheme designed and implemented. If the risks are not significant, then the situation may need to be monitored for a finite period of time, to make sure that it does not deteriorate due to unforeseen circumstances.

It should be noted that throughout the assessment approach, a number of options are available under the heading of "corrective action" and can be summarised as follows:

- institutional controls (procedures or facilities that eliminate the possibility of exposure e.g. protective work practices or a restriction on use of the land);
- natural attenuation;
- bioremediation; and
- technology-based remedial methods (e.g. pump and treat, air sparging).

Overall, this guideline represents a framework in which reasoned, risk-based decision-making can take place, rather than a prescriptive "how to" guide. As a result, it is hoped that it will provoke a search for yet more innovative and cost-effective approaches and techniques, all focused on achieving risk reduction.

2.6. COMPARISON WITH ASTM RBCA STANDARD

The approach outlined in this document is very similar to ASTM's RBCA.* Key similarities are as follows:

- Each provides a consistent and rational approach to corrective action within own sphere of influence;
- Both incorporate risk assessment into all aspects of investigation and corrective action;
- Both use a tiered approach which balances conservatism with site specificity;
- Both focus corrective action decisions on the reduction of risk on a site specific basis;
- Initial screening against Risk Based Screening Levels (RBSLs);
- Calculation of Site Specific Target Levels (SSTLs) based on site specific compliance points;
- Share many common pathways and algorithms for estimating exposures;
- In many cases use common data sets for physical/chemical, toxicological characteristics.

However, there are certain differences between the two approaches, several of which are summarised in **Table 1**. These differences, in general, reflect the regulatory situation, history and present understanding of contaminated land issues in Europe, versus that in the USA.

The most important difference between the two approaches is that CONCAWE RBSLs are land-use specific and cover a wide range of pathways, with protection being afforded from all pathways considered for that land-use. Europe has long standing programmes of land-use planning, and most contaminated land policies are built around the concept of land-use. The ASTM approach selects specific pathways based on a Conceptual Site Model and then compares site measured values with pathway-specific RBSLs. The consideration of multiple pathway exposures is unlikely to result in a significant difference between the CONCAWE and ASTM

* ASTM (1995) Standard guide for risk-based corrective action applied at petroleum release sites. ASTM E-1739. Philadelphia PA: American Society for Testing and Materials

approaches since one pathway e.g. for a specific chemical and/or land-use or a particular carcinogenic compound (such as benzene) often dominates the risk.

Another important difference between the current approach and ASTM's RBCA is that CONCAWE Tier 1 RBSLs can be derived using Monte Carlo simulation techniques. This reflects the increasing use of such techniques worldwide and it allows for the explicit consideration of uncertainty. The alternative to Monte Carlo based RBSLs is values based on point estimate assumptions, ostensibly made on a "reasonable worst case" basis but providing unknown levels of conservatism. Such conservatism may be extremely high, due to compounding effects, or low, depending on the scenarios considered in the risk model.

A further difference between the two approaches is the opportunity to carry out "forward"[(1)] calculations of risk at Tiers 2 and 3. (Under the ASTM approach, these tiers involve changes to clean-up target levels only). It also allows the full use of statistics and spatial considerations (including geostatistics) in the decision-making process. A "forward" risk is consistent with European regulators' requirements for performing a risk calculation in support of contaminated land decision-making.

Minor differences between the two approaches include the use of European exposure/toxicity assumptions, the inclusion of a child receptor and inclusion of a risk-based methodology for dealing with Total Petroleum Hydrocarbons (TPH). The latter reflects, primarily, recent developments in the USA connected with this issue (these occurred following publication of the ASTM document); the former is necessary in order to reflect current European practice in risk assessment.

Additional differences in the detail of some of the risk models and acceptability criteria will be described in a separate technical report.

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1 "Forward" means using the measured soil and groundwater contaminant concentrations to calculate actual risk levels to the identified receptors, at the points of exposure.
"Backward" means taking defined acceptable risk levels at points of exposure, and back-calculating soil contaminant levels which would achieve that level of risk.

Table 1 Comparison of CONCAWE STF-27 draft guideline and ASTM E1739-95

ISSUE AREA	CONCAWE	ASTM	JUSTIFICATION/COMMENT
Quantify Uncertainty	Monte Carlo can be built into Tier 1	no probability until Tier 3	• avoidance of RME (Reasonable Maximally Exposed Individual) • more balanced and transparent approach to conservatism
Pathways	All ASTM + food chain + shower	soil ingestion/absorption inhalation groundwater ingestion surface water recreation/habitat	• precedent in Europe - UK (CLEA), Netherlands (HESP, CSOIL) • completeness of the exposure assessment
Additive exposure for various pathways	add exposure from all pathways in Tier 1	no summing of pathways	• reflects credible exposure scenario • balanced approach to conservatism allows summing, although generally one pathway tends to predominate
Pathway Selection	land use driven at Tier 1	Conceptual Site Model Driven at Tier 1	• strong European policies toward land use planning • precedent in UK, Belgium, Netherlands and others
Forward Risk Calculation	forward risk calcula-tion an option for Tier 2 and Tier 3	no forward risk calculation	• improve understanding of risk basis for targets • can consider additive risk from multiple compounds exceeding their RBSL • European Regulators want risk assessment
Exposure Assumptions	European based when available, some USEPA	largely USEPA based	• more specific to European situation
Toxicity Values	WHO/UK/ Netherlands/USEPA	USEPA	• more specific to European situation
Receptors	adult or child	adult	• reflects different exposure assumptions for children • regulatory precedent in UK and Netherlands
TPH	included - guidance following the TPHCWG	not included but involved with the TPHCWG	• regulatory emphasis in Europe on TPH-based targets

3. INITIAL SITE ASSESSMENT

The initial assessment of a contaminated oil industry site involves the collection of data concerning site conditions in order to aid in the Tier 1 assessment. It is also an early opportunity to assess the need for carrying out any emergency measures. The individual components are described below.

3.1. DATA COLLECTION

The initial site assessment provides the building blocks upon which all other works at the site are based. A robust desk study, incorporating a good understanding of the site's history/operations and its environmental setting, will allow a focused data collection exercise to be planned and implemented. The desk study (which can include a questionnaire sent to site personnel, if available) should be combined with a site reconnaissance visit to confirm or support its findings.

Key operational history information to collate and assess includes the following:

- site size and age;
- products stored;
- tank numbers, volumes, age, throughput and testing records;
- secondary containment detail;
- modes of product transfer (pipelines, loading gantries);
- drainage system information;
- interceptor configuration and maintenance history;
- wastewater treatment plant details;
- hardstanding distribution and condition;
- location of below ground utility service lines and other preferential contaminant migration pathways (e.g. culverts);
- product spillage and leakage history;
- chemical storage / additive facilities
- production area detail; and
- solid/hazardous waste management practices.

For larger/older sites in particular it will be appropriate to collect local historic topographic maps and aerial photographs of the facility to cross-check historical detail provided by site records.

An environmental setting assessment places the site within its local context. Key information to obtain here includes:

- land-use (on-site and adjacent areas, past, present and proposed future);
- regional and, if available, local geology and hydrogeology;
- proximity to and use of surface water bodies which may receive site-derived contamination and their use;

- local resource potential of groundwater and surface water bodies (e.g. potable supply, other supply purposes) including location of downgradient wells;
- the location of sensitive ecological habitats (defined according to EC Directive 79/409/EEC or EC Directive 92/43); and
- data on local foundations and cellars.

Sources of information include local and regional geological, hydrogeological, aquifer vulnerability and topographic maps of an appropriate scale, along with site records (e.g. geotechnical and general site investigation). These can be supplemented by site specific information prompted by a questionnaire and detailed inspection during the site reconnaissance visit.

The purpose of the environmental setting assessment is to identify: 1) the location of humans and environmental resources ("receptors") that could be impacted by the site; and 2) potentially significant exposure pathways. The latter should include a consideration of the possibility of preferential contaminant migration pathways, such as utility conduits.

3.2. ASSESSMENT OF NEED FOR IMMEDIATE ACTION

At a very small proportion of sites, it may become obvious during initial site reconnaissance and/or Tier 1 intrusive investigations, that there is an immediate potential threat of harm to human health or the environment. Examples include issues such as the ingress of large quantities of free product in adjacent waterways or off-site drainage systems, or significant vapour concentrations within buildings. If such threats exist, an action plan will need to be developed immediately to address such issues without waiting for the completion of the tiered sequence of tasks. Professional judgement will be needed on the urgency of response. **Table 2** shows examples of issues requiring emergency action and possible responses, although it should be noted that the table is for illustrative purposes only.

Table 2 Examples of issues requiring emergency response actions

Criterion / scenario	Possible Emergency Response Action
Overpowering odour indicating the possible presence of explosive levels or concentrations of vapours that could cause acute health effects.	Evacuate occupants and immediate vicinity of site. Check vapour concentrations using a PID and/or LEL detector. If suspicions are confirmed, then begin abatement measures such as subsurface ventilation, or building pressurisation.
Visual signs of off-site contaminant migration (e.g. oil seepage, surface water plumes)	Minimize further impact using containment measures. Recover free product. Assess the need to restrict area access.
Substantial product loss (e.g. fractured pipe, substantial dip losses in storage tanks)	Minimize further impact using containment measures. Recover free product. Assess the need to restrict area access.
Visual signs of ecological harm (e.g. damaged vegetation, dead fish)	Minimize further impact using containment measures.
Third parties affected (e.g. nearby wells impacted, preferential contaminant migration along electrical conduits, through sewers)	Assess impacts using drinking water criteria. Minimize further impact using containment measures. Notify affected third parties. Assess the need to restrict area access.

3.3. DEVELOPMENT OF CONCEPTUAL SITE MODEL

The data collected during the initial site assessment should be used to develop a "conceptual site model" (CSM) that will be refined as the analysis proceeds. The CSM is a description of how potential chemical sources at the site could contribute to increased levels of risk in potentially exposed receptors. It is a qualitative evaluation of the sources, exposure pathways and receptors identified during the desk study and site reconnaissance visit and can be used to test assumptions and field data to produce a complete view of the site-specific situation. The most important potential human exposure pathways that can exist at contaminated sites are as follows (depending on land-use):

- accidental soil/dust ingestion (indoors and outdoors)
- skin contact with soil/dust (indoors and outdoors)
- inhalation of vapours from soil sources (indoors and outdoors)
- inhalation of vapours from groundwater sources (indoors and outdoors)
- inhalation of vapours from free product
- leaching of chemicals from soil or free product to groundwater or surface waters
- domestic use of groundwater or surface waters (potentially leading to ingestion and inhalation of contaminants)
- consumption of home-grown fruits and vegetables

Where appropriate, the site should be divided into discrete areas, each with its own CSM, in addition to an overall CSM for the site as a whole. Flow charts and schematics can be used to illustrate the processes considered in the CSM.

Early development of the CSM and constant reassessment in the light of investigative results can have a profound influence on the investigation and sampling activities. This can enhance the latter's cost-effectiveness by making sure that samples are taken from the areas that are most likely to be contaminated and from the media that are most relevant to those contaminant migration/exposure pathways likely to pose a significant risk (this is especially important for Tiers 2 and 3). It can also guide the sampling of off-site receptor locations that may have already been impacted by the migration of contaminants.

The CSM's focus is on which pathways for a given site are complete. A complete pathway exists only if there is a source of sufficient strength, a pathway for migration of Contaminants of Concern (COC) from source to receptor, **and** an exposure point for the receptor. The process of progressing from Tier 1 to Tier 2 or Tier 2 to Tier 3 involves a more complete analysis of whether these pathways are complete and should be retained in the CSM.

For simplicity, Tier 1 RBSLs are based largely on landuse, with a given landuse calling up a set of default pathways. The CSM should challenge whether these pathways exist at the site; if not, the contribution of that pathway may be removed from the RBSL. This, in effect, is a simple Tier 2 analysis.

4. TIER ONE ASSESSMENT

4.1. INTRODUCTION

The Tier 1 assessment involves the collection of data concerning site conditions, the interpretation of chemical data by reference to suitable Risk Based Screening Levels (RBSLs) and other relevant criteria (ORCs) and an evaluation of the overall results. The individual components of the assessment are described below.

The Tier 1 data collection exercise relies on the conceptual site model to ascertain the distribution and character of existing chemical contamination. A balance must be struck between the provision of sufficient information to allow an appropriate Tier 1 evaluation and the minimising of detail which can, if required, be collected during subsequent tiers. In general, the amount of information necessary for the Tier 1 assessment is generally less than that collected for Tier 2 and certainly Tier 3 assessments. At some sites, however, the benefits of collecting sufficient information during the initial site assessment to allow subsequent Tier 2 assessment without a need for further site works may be considerable (e.g. due to site access issues).

4.2. SAMPLING AND ANALYSIS

Most Tier 1 assessments should include the sampling of on-site soils and shallow groundwater, if present. Soil vapour surveying may be used to screen a site to help pinpoint potential "hot-spot" areas which hopefully will have already been highlighted by the desk study and site reconnaissance. The preferred option at most sites is to bias the sampling programme towards identifying the maximum levels of on-site contamination by focusing on most likely source areas (e.g. locations of old spills). In rare cases where site information is absent (e.g. an old derelict site or site area long since demolished) systematic sampling may have to be applied. In such cases a statistically appropriate number of samples must be collected.

The Tier 1 intrusive site investigation may be limited to within the site boundary because the assessment is based on assumed on-site receptor scenarios. Occasionally, however, it may be necessary to sample nearby off-site wells/water courses and local buildings/basements. This is especially important with regard to the identification of immediate hazards requiring an emergency response (see below) and it should be guided by the initial site reconnaissance. To some degree the extent of migration can also be assessed by including down hydraulic gradient boundary locations in the sampling plan.

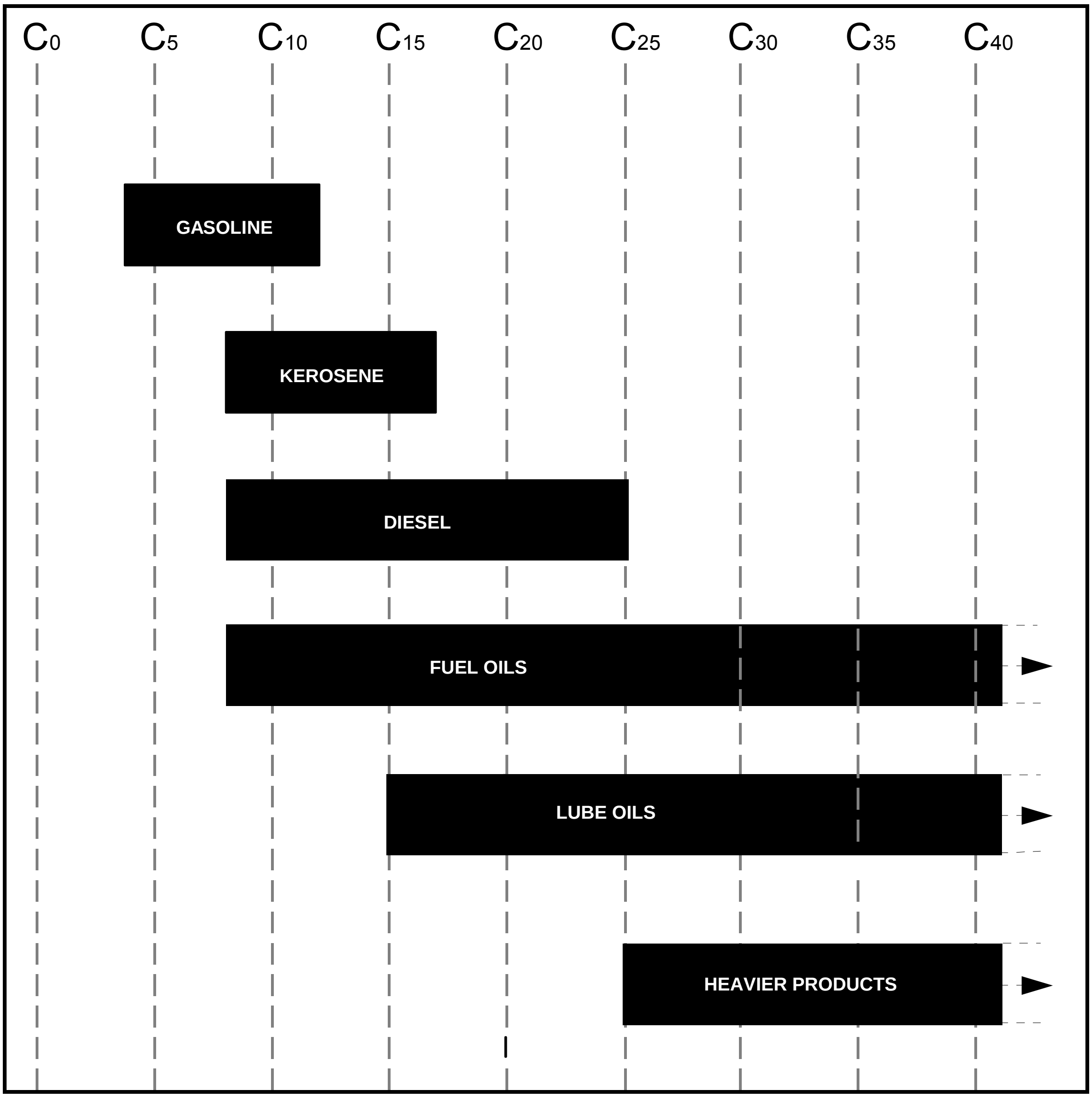
The laboratory analysis of samples should initially focus on chemicals known to have been used or stored on-site which are relevant to the particular medium being evaluated. Soil samples may be sent to a laboratory for detailed gas chromatography (GC) analysis, while vapour samples from a utility conduit may be analysed by a portable explosimeter, where the objective is to evaluate the potential for immediate hazard (it should be noted that this can take place before the collection of Tier 1 samples). An example list of chemicals is provided in **Table 3**, along with the reasons for their likely evaluation at petroleum industry sites. It is good practice to include a wide range of suspected contaminants at the Tier 1 stage, with progressively fewer being needed at subsequent levels of analysis. To this end, data pertaining to site history, especially any information regarding product usage, leaks and completed or ongoing corrective action, should be used. It is important that all key hazardous chemicals which have been stored or used on-site are included for analysis at this stage because a site which passes the Tier 1 assessment should not require any additional evaluation.

Table 3 Example list of compounds that are likely to be encountered at petroleum industry sites

Compound	Reason for inclusion
Benzene	Carcinogenic constituent of light-end fuels (e.g., gasoline)
Benzo(a)anthracene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Benzo(a)pyrene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Benzo(b)fluoranthene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Benzo(k)fluoranthene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Total petroleum hydrocarbons	Measure of total oil content of soils
Chrysene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Dibenzo(a,h)anthracene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Ethylbenzene	Non-carcinogenic constituent of light-end fuels (e.g., gasoline)
Indeno(1,2,3-cd)pyrene	Carcinogenic constituent of mid-range fuels (e.g., diesel)
Methyl-tertiary-butyl-ether	Non-carcinogenic gasoline additive
Tetraethyl lead	Non-carcinogenic gasoline additive
Toluene	Non-carcinogenic constituent of light-end fuels (e.g., gasoline)
Xylene	Non-carcinogenic constituent of light-end fuels (e.g., gasoline)

It should be noted that any analysis of Total Petroleum Hydrocarbons (TPH) should focus on either: 1) establishing concentrations of specific groupings of compounds, or 2) the identity of the TPH mixture (e.g. weathered diesel). This is because petroleum products are composed of a multitude of chemicals, which vary depending on factors such as product type and age. **Figure 4** illustrates the diversity of chemicals found in petroleum products, in terms of the carbon numbers of specific products. TPH measurements which meet neither of the above objectives are less useful for risk assessment purposes but can still be utilised in a qualitative manner to assist in the identification of the boundaries of contamination and the location of hot-spots. Samples from such areas could subsequently be taken and subjected to more complex analysis.

Figure 4 Carbon number ranges of petroleum products



4.3. INTERPRETATION OF DATA

4.3.1. Introduction

The data collected during Tier 1 are interpreted by reference to Risk-Based Screening Levels (RBSLs) and other relevant criteria (ORCs). RBSLs are used to screen chemical concentrations in on-site soil and groundwater while ORCs are used to interpret data for additional media that have been sampled, for example, off-site well water.

4.3.2. Comparison of Data with RBSLs

The comparison of data with RBSLs is a relatively straightforward exercise in which measured on-site soil and groundwater concentrations are evaluated, based on the specific land-use designation, and whether or not there is potable groundwater underlying the site. RBSLs are typically calculated using conservative assumptions applicable to the country in which the site is situated and using the sum of the exposure pathways that could co-occur under a specific land-use scenario.

For simplicity, soil RBSLs are land-use specific (i.e. different RBSLs are set for different land-uses) and can be applied with a minimum of background knowledge on the risk assessment of contaminated sites. Groundwater RBSLs are based on the conservative (worst-case) assumption, i.e. the site is located on an existing or potential drinking water supply utilised by a residence with a domestic well. Exposure could therefore occur both via the ingestion of contaminated groundwater and via the inhalation of vapours from the water. It should be noted at this stage that the RBSLs only take into account human health risk and do not address aesthetic, ecological and other criteria. Thus these factors will need to be considered separately.

If analysis of the conceptual site model shows that any of the default pathways are not complete, then the contribution of that pathway to the RBSL may be removed. The main focus of RBSLs is the prevention of long-term (chronic) dose levels from repeated exposure to chemicals in soil and groundwater. This is of primary importance at contaminated sites since the risks of chronic effects are generally more common than those of short-term (acute) effects. Any site at which chemical concentrations are less than the appropriate RBSLs can be assumed to pose no significant risk of either acute or chronic effects.

Soil RBSLs will be provided for surficial (taken to be <1 m depth) and deeper soils (>1 m depth). RBSLs for TPH and specific product types will also be provided. Soil RBSLs will be developed for the following land-uses:

- residential (with and without gardens);
- commercial (with and without landscaping);
- on-going petroleum industry;
- recreational areas; and
- allotments.

Groundwater RBSLs are also being developed, along with soil concentrations which would give rise to the groundwater RBSLs due to leaching. The lowest of the latter and the land-use specific soil RBSLs should be used for sites at which potable groundwater is present. It may also be necessary, at such sites, to consider the possibility of additive exposures from soil and groundwater contamination.

These RBSLs will be highly conservative and err considerably on the side of caution. This is a result of the methodology and assumptions used in their derivation.

In order to use the RBSLs the assessor must establish:

1) the current and proposed site land-use;
2) inventory of completed pathways for the site;
3) whether potable groundwater is present beneath the site; and
4) whether the assumptions made in deriving the RBSLs are potentially under-conservative in relation to site-specific conditions (this is most unlikely, but not impossible).

The RBSLs relate to various land-uses and incorporate exposure assumptions specific to these land-uses. As a result, it is essential that the correct values are used in the comparison exercise. Assertions regarding future land-use must be supported by legally binding instruments such as deed restrictions, which prevent or manage certain types of development.

If a targeted intrusive investigation has been carried out (as would normally be the case), the maximum detected chemical concentrations should be compared with the RBSLs, on the grounds that if there is an insignificant risk from these, then there is an insignificant risk from the entire site. If random data have been collected, statistical techniques can be used. It should be noted that the use of maximum values from targeted investigations places considerable importance on the quality of the data collection activities.

At sites where there is more than one chemical present, the possibility of additive toxic effects can be considered, although this is generally part of a more refined Tier 2 or 3 analysis. It may also be important to consider background concentrations of chemicals in soil and air, along with potential up-gradient sources for groundwater, to enable the assessment to focus on site-related contamination only.

4.3.3. Limitations

Although the comparison of measured concentrations with RBSLs represents a suitable Tier 1 screening tool, there are several limitations which must be considered in order to decide whether they are to be relied on to make site-specific risk-based corrective action decisions at a particular site. These are as follows:

- RBSLs do not explicitly cover risk issues related to multiple compounds, surface water, free product or agricultural land-use. As a result, these must be confirmed as being absent or evaluated as part of a follow-on Tier 2 assessment.
- RBSLs do not consider risks to ecological receptors. As a result, sensitive ecological habitats must be confirmed as being absent or an ecological risk assessment developed as part of a Tier 2 assessment.
- The assumptions used in generating the example RBSLs are conservative in almost all cases. However, as mentioned above, there may be rare occasions where such assumptions are under-conservative and a check is therefore necessary as to their applicability to the site in question.

- RBSLs do not address the risk of damage to materials through corrosion, geotechnical issues such as ground stability, environmental impacts from ongoing industrial processes, flooding risk, construction worker safety or aesthetic issues (e.g., soil staining). These must be dealt with separately, where appropriate.

Neither the RBSLs nor the information in the associated technical report should be viewed as a definitive list of standards. They are based on current knowledge and assumptions concerning exposure parameters and toxicology and, consequently, should be viewed as an "evergreen" set of values that is continually updated whenever new methodologies and parameters are developed. Where required, fate and transport estimations are based on conservative models.

It should be noted that certain regulators have their own standards that may need to be used in place of RBSLs as part of a Tier 1 assessment. For example, the Netherlands has published "Intervention Values", which, if exceeded, trigger further risk assessment to determine the urgency of response at contaminated sites. In the UK, Guideline Values are being developed which will fulfil roughly the same role as the RBSLs described above. Such values are derived using certain assumptions and models which may not be appropriate at all sites - this is an important aspect that must be considered in trying to reconcile between two apparently conflicting values for the same compound.

4.3.4. Comparison of Data with Other Relevant Criteria (ORCs)

At certain sites, data may have been collected from off-site wells, local basements/buildings and local water courses. These data can be compared with suitable criteria for the particular contaminant of concern. For example, the comparison of off-site well concentrations with legal standards or drinking water guidelines may indicate whether a potential risk already exists via the off-site groundwater migration pathway, while the use of odour thresholds can enable the existence of a potential nuisance to be assessed. Examples of ORCs are provided in **Table 4**.

Table 4 Other Relevant Criteria (ORCs) - Examples

Compound	WHO Drinking water standard (?g/l)	Occupational Exposure Limit - Air (ACGIH) [b]		WHO Air Quality Guideline	Odour Threshold [c]		Lower Explosion
		ppm	mg/m^3	(mg/m^3)	ppm	mg/m^3	Limit (%)
Benzene	10	10 [d]	32 [d]		1	3.26	1.4
Ethylbenzene	300	100	434		0.092	0.4	1.2
Toluene	700	50	188	8[a]	0.156	0.6	1.27
Xylene	500	100	434		0.069	0.3	1.0
Benzo(a)pyrene	0.7						

a Time-weighted average (averaging time = 24 hours)

b ACGIH - American Conference of Governmental and Industrial Hygienists

c 50% detection threshold (lowest value taken from Verschueren, 1983)

d EU OEL likely to become 1 ppm (3.2 mg/m^3) in 2000

4.4. EVALUATION OF TIER 1 RESULTS

If the measured on-site chemical concentrations exceed the RBSLs and the RBSLs are appropriate to the site in question, the possibility of corrective action should be reviewed in relation to its cost-effectiveness. The review should focus on the following alternatives:

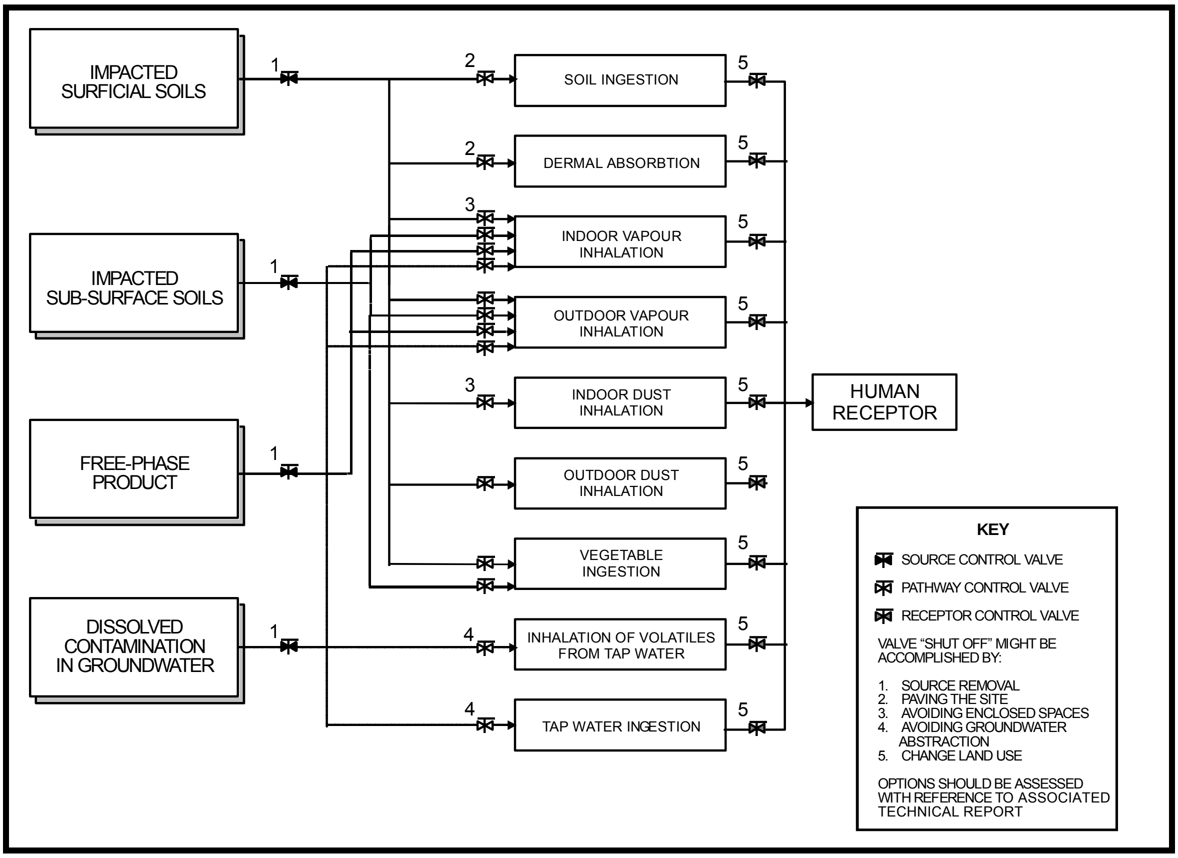
1) reducing the concentrations to below RBSLs;
2) controlling certain exposure pathways (by referring to Tier 1 pathway contribution tables); or
3) changes in land-use, backed up by deed restrictions or other institutional controls (a more detailed review of the options available for corrective action is provided in **Section 7**).

If any of these measures would be more cost-effective than a Tier 2 assessment, bearing in mind that the latter may point to substantially less costly corrective action being needed then they may be carried out. If, however, they are judged to be inappropriate, then the process should proceed to Tier 2. If any measured receptor point concentrations exceed ORCs, it is possible that this would trigger corrective action.

A useful tool in the development of corrective action goals is a diagram such as that in **Figure 5**. This illustrates the relationship between contaminant sources, exposure pathways and receptors and how, by applying corrective action measures to the source, pathway or receptor, risks can be reduced to acceptable levels. In terms of controlling pathways, a valve symbol denotes where such action can take place - all the assessor needs to do is establish the best way of shutting off the valve, which will break the source-pathway-target link.

If the on-site chemical concentrations do not exceed the RBSLs, the assessment finishes, and the site can be considered to represent no significant risk and normally no further action is required. Compliance monitoring may be implemented, subject to the views of the regulatory authority, to confirm that current conditions persist or improve with time.

Figure 5 Example pathway control measures



5. TIER TWO ASSESSMENT

5.1. INTRODUCTION

The Tier 2 assessment involves a more detailed evaluation of the site focusing on exposure pathways that have caused exceedence of RBSLs and addressing other issues identified at Tier 1, such as land use. This may require the collection of more data and/or the completion of more sophisticated risk assessment.

Tier 2 provides the opportunity for the assessor to consider contaminant fate and transport in more detail than is the case at Tier 1. This is achieved by the replacement of conservative or default assumptions with site-specific information and the use of more sophisticated chemical fate and transport models. In these ways, the Tier 2 assessment provides a less conservative (more realistic) examination of the issues surrounding a site and therefore a more cost-effective set of corrective action goals, if needed.

It is important to note that both Tier 1 and Tier 2 corrective action goals are based on achieving similar levels of human health and environmental resource protection; however, in moving to Tier 2 the assessor is able to develop more cost-effective action plans because the conservative assumptions made in Tier 1 are replaced with more realistic site-specific assumptions.

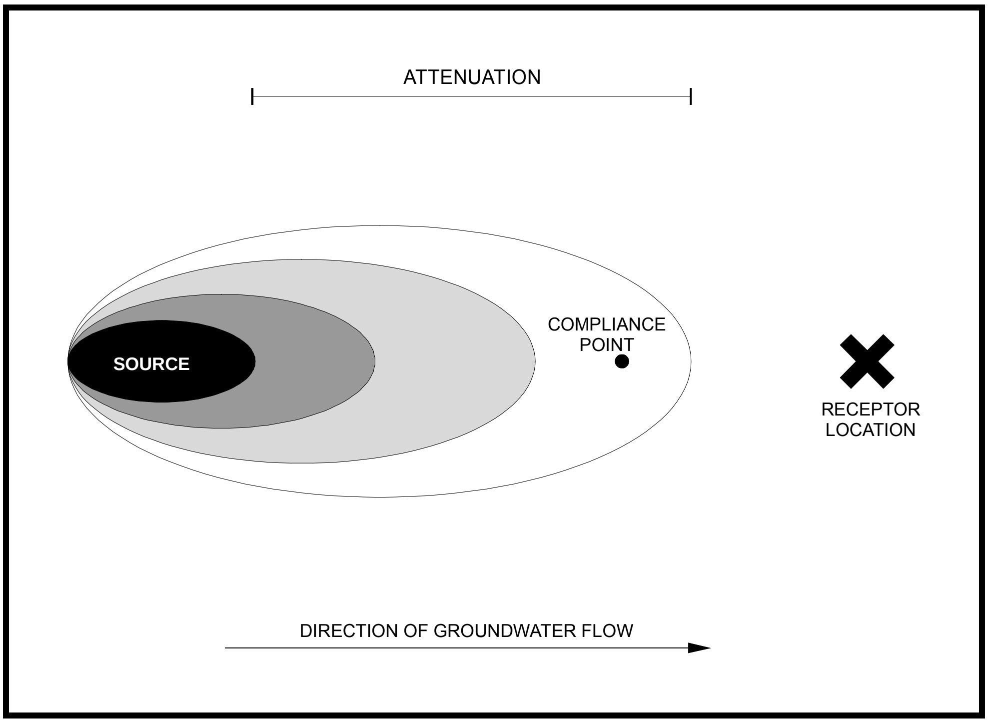
5.2. ISSUES OF CONCERN

The first step in a Tier 2 assessment is to identify the issues of concern requiring further analysis. This is accomplished by revisiting the CSM and reviewing which pathways are complete and contribute to receptor exposure. Incomplete pathways or Contaminants of Concern which do not contribute to risk can be eliminated from further analysis. Tier 2 assessment will include the sources, chemicals and exposure pathways which caused the exceedence of the RBSLs in Tier 1, along with any other exposure scenarios not covered at Tier 1 (e.g. agricultural land-use).

The chemical sources could include known or assumed areas of high concentration (hot-spots) or contaminated groundwater which contains the chemicals that exceeded the RBSLs. The human exposure pathways include all those which made a significant contribution to the RBSLs which were exceeded in Tier 1, identified by means of pathway contribution tables.

An important aspect of Tier 2 is the consideration of potential exposure at "compliance points", as opposed to anywhere in an environmental medium. Such points include property boundaries or locations between source areas and reasonable potential receptors, or they could be receptor locations themselves. Corrective action goals for source areas are then based on the demonstrated and predicted attenuation (reduction in concentration with distance) of compounds that migrate away from the source area. **Figure 6** illustrates this concept.

Figure 6 Natural attenuation of contaminants dissolved in groundwater



5.3. DATA COLLECTION

Tier 2 data collection activities are designed to build upon the information collected as part of Tier 1 in order that the site assessment can focus on the most important issues. The Tier 1 data set should be re-appraised and summary tables produced which highlight the chemical and physical characteristics of the various environmental media, within all relevant site areas and depth zones. In cases where it is believed the data set is suitably robust to facilitate an adequate Tier 2 assessment then this should proceed. If this is not the case then an appropriate Tier 2 site investigation programme should be planned to fulfil the additional data needs.

Tier 2 investigations could be directed towards better characterising the magnitude and distribution of contamination along the migration pathway(s) identified to be of concern. This may involve the collection of geological, hydrogeological and chemical data to replace conservative assumptions made in the previous tier. The amount of Tier 2 data required could also depend on factors such as the degree of site contamination (the extent to which Tier 1 investigation data failed the RBSLs), the suitability of the generic assumptions used at Tier 1, site environmental sensitivity, and the proposed land-use.

During the Tier 2 data collection activities, every effort should be made to collect samples from exposure or compliance points as such locations represent points at which potential receptors could actually become exposed. Amongst other things, such data may assist in the calibration of chemical fate and transport models, if required. In many cases it can be used to eliminate the need for, or to check the validity of, sophisticated pathway-specific modelling by providing actual exposure data. However, it must be remembered that such measurements are only "snapshots" in time and that, although the detection of high concentrations may indicate a potential problem, the interpretation of low contaminant concentrations is much more difficult. An assessment needs to take into account at least the physical-chemical properties of the particular contaminants and appropriate toxicity data so that the significance of such low concentrations can be determined.

5.4. INTERPRETATION OF DATA

5.4.1. Introduction

The interpretation of data at Tier 2 takes the form of

1) site-specific risk assessment,
2) the development of Site-Specific Target Levels (SSTLs) and/or
3) comparison of measured or predicted concentrations with ORCs or RBSLs
4) comparison of measured or predicted compliance point concentrations with ORCs or RBSLs.

Where estimated risks exceed acceptable levels, or where the measured concentrations exceed ORCs or RBSLs, Site-Specific Target Levels can be developed to aid in the setting of Tier 2 corrective action goals. Tier 2 focuses on all chemicals detected at the site at concentrations which exceed the Tier 1 RBSLs, as discussed above.

5.4.2. Site-Specific Risk Assessment

The Tier 2 site-specific risk assessment should take place in a "forward manner", in which quantitative risk estimates are generated for the site and compared with appropriate acceptability criteria. This allows the statistical treatment of data, if required, and it should enable a clear view of the presence or absence of a significant risk at the site (often required by regulators). Examples of acceptability criteria for a Tier 2 risk assessment are currently under development - these should normally be the same as those used in the derivation of RBSLs.

The Tier 2 risk assessment techniques involve the use of either: 1) the algorithms used to generate RBSLs or 2) other models and approaches. In either case, site-specific data should be used in the place of conservative assumptions, wherever possible. Within the Tier 2 assessment it is also possible to evaluate whether a potential risk exists by predicting contaminant concentrations at the off-site receptor or compliance point, and comparing these to the RBSLs.

The models are used to predict attenuation of contaminants away from the source area. They are based on interpolating and extrapolating site-specific data through the use of conservative "screening" mathematical models. In general the better the site investigation data the more accurate the modelling results. These models are characterised by the following:

- the models are relatively simplistic, and are often algebraic or semi-analytical expressions;

- model input is limited to practically attainable site-specific data, or easily estimated quantities (e.g. soil porosity, soil bulk density);
- site-specific validation/calibration studies are not necessary provided worst-case assumptions are used in setting the input parameters;
- source depletion due to physical removal mechanisms (e.g. leaching) can be considered;
- biodegradation can be considered provided either: 1) site-specific data is available to demonstrate its occurrence; or 2) documented evidence is available from other, similar sites;
- the models are based on descriptions of relevant physical/chemical phenomena. Any mechanisms that are neglected result in predictions that are conservative relative to those likely to occur.

For above-ground exposure pathways, the chemical data which form the input to a Tier 2 risk assessment should be health-conservative estimates of the concentrations present across the relevant exposure area (e.g. garden). These are typically either maximum detected values or 95% upper confidence limits of arithmetic mean values, calculated using algebraic or geostatistical techniques. Alternatively, certain risk assessment software can accept whole data sets or probability distributions of contaminant concentrations. For groundwater modelling, the maximum detected on-site concentration (soil or groundwater) should normally be used as the source concentration in the model, in order to be conservative.

5.4.3. Comparison of Data with Other Relevant Criteria (ORCs)

If additional data have been collected from off-site wells, local basements/buildings and local water courses as part of a Tier 2 assessment, they can be compared with ORCs, as at Tier 1. For example, the comparison of off-site measured groundwater concentrations with RBSLs will indicate whether a potential health hazard exists via this migration pathway at the time of measurement.

5.4.4. Assessing the Risk from Free Product

The risk from free product should be addressed. These allow the modelling of indoor air and groundwater (if present) impacts, based on known product characteristics. Groundwater quality data obtained from the site could also be used to assess the effects, if any, on groundwater. Again, "real" data are preferred over modelled contaminant concentrations, where they are available.

5.4.5. Assessing the Risk to Surface Water

The risk to surface water can be assessed by measuring contaminant concentrations in lakes, rivers, etc., or modelling them using computer software available for this purpose.

5.4.6. Ecological Risk Assessment

An ecological risk assessment is the process of evaluating the likelihood that adverse ecological effects will occur. If an ecological risk assessment is deemed necessary, a tiered approach is recommended to ensure the cost-effective protection of ecological resources, mirroring the approach taken to protecting human health.

5.5. EVALUATION OF TIER 2 RESULTS

If the site-specific risk assessment acceptability criteria are met and there are no exceedences of ORCs then no further action is required, except, perhaps, periodic monitoring for a finite period of time. If the criteria are exceeded, SSTLs can be derived from the results of the risk assessment. Following this, the cost-effectiveness of achieving Tier 2 corrective action goals, which may include SSTLs, should be reviewed, bearing in mind that Tier 3 site-specific goals will likely be less costly to achieve than Tier 2 goals. If corrective action is still not considered to be cost-effective, a Tier 3 assessment should be carried out, although interim corrective action may be needed (this could include hot-spot removal, localised containment or institutional controls). A review of the options available for corrective action is provided in **Section 7**.

Corrective action goals could include source removal or the blocking of individual exposure pathways based on the results of the risk assessment. In the case of the former, SSTLs should be developed from the predicted attenuation of contaminants away from the source area. For example, if the risk assessment model predicts exposure/compliance point groundwater concentrations which are 100 times lower than the measured on-site concentrations (and the relationship between on-site and off-site concentrations is linear), then the SSTL for on-site groundwater should be 100 times greater than the relevant RBSL or ORC (e.g., drinking water standard). Measured exposure/compliance point concentrations can be used to corroborate the model's predictions.

It should be noted that, while a Tier 3 assessment may represent the best way forward at a site, there may be interim corrective measures that could be carried out while this is going on. Such action could include obvious hot-spot removal or temporary containment measures that focus on reducing risks which, while as yet not quantified accurately, are judged by the assessor to be likely to need addressing following Tier 3. By carrying out such interim measures, the potential level of risk posed by the site is reduced while the Tier 3 assessment takes place. Alternatively, interim measures may not be driven by real risk but by aesthetic considerations or the adverse publicity that may accrue if action is not taken. In some cases, the implementation of corrective action can exacerbate the risks associated with the contaminants identified. Therefore, the potential benefits of carrying out interim corrective action should be considered in the light of the potential risks (and associated costs) before deciding to proceed.

6. TIER THREE ASSESSMENT

6.1. INTRODUCTION

The Tier 3 assessment involves the collection of more site-specific data, if necessary, and a further evaluation of the potential risks from site-related contamination using advanced techniques including, for example, numerical fate/transport models and pharmaco-kinetic considerations. In some cases this can result in a conclusion being reached that no corrective action is required with the likely exception of a finite period of monitoring. In others, the on-site concentrations may still be found to pose a significant risk and corrective action goals need to be developed. These could include the calculation of, and remediation to, Tier 3 SSTLs, which are normally higher (less conservative) than their Tier 2 counterparts.

It is important to note that both Tier 2 and Tier 3 corrective action goals are based on achieving similar levels of human health and environmental resource protection. However, in moving to Tier 3 the assessor is able to develop more cost-effective action plans because certain conservative assumptions and modelling techniques used in Tier 2 are replaced with site specific data and more realistic approaches.

6.2. ISSUES OF CONCERN

The first step in a Tier 3 assessment is to identify the issues of concern requiring further analysis. These could include sources, chemicals, exposure pathways and receptors, as indicated by the results of the Tier 2 assessment.

In most cases it would be expected that source area hot-spots including soil, groundwater and free phase contamination will have been adequately characterised during Tier 2. However for the principal contaminant migration pathways additional media specific chemical and physical property data may need to be collected. The exposure pathways assessed should include all those which make a significant contribution to the Tier 2 estimated risk levels - pathway contribution tables can be used for this purpose.

6.3. DATA COLLECTION

Field investigation data requirements for Tier 3 assessment should be defined on a site-specific basis. It is not appropriate to give even indicative requirements since this tier of assessment will be very focused on one or more key aspects.

In advance of any Tier 3 site investigation which involves the collection of additional media samples for chemical analysis and/or physical property testing, geostatistical analysis of the existing data set could be considered. This allows data gaps to be identified and an appropriate sampling plan to be developed to fill such data gaps. Geostatistics incorporates procedures to describe and evaluate clustered (hot-spot) and non-random sampling regimes. The mathematical procedures of geostatistics allow estimates of a given parameter at unsampled locations to be made within known limits. This allows quantitative assessment and statistical validation of proposed (Tier 3) sampling plans.

6.4. INTERPRETATION OF DATA

6.4.1. Introduction

The interpretation of data in Tier 3 takes the form of site-specific risk assessment, the further development of SSTLs and/or the comparison of measured receptor point or compliance point concentrations with ORCs and RBSLs. It generally focuses on all chemicals detected at the site which contribute to the exceedence of Tier 2 risk acceptability criteria although it may also be necessary to consider others where additive effects are possible.

6.4.2. Site-Specific Risk Assessment

The Tier 3 risk assessment approaches may involve the use of Tier 2 techniques, with added refinements made, or the utilisation of additional techniques, as follows:

- revised treatment of non-detect values;
- calibration of models with measured data;
- numerical modelling of groundwater pathways;
- revisions to toxicity criteria; and
- site-specific bioavailability/leachability data.

Clearly, there is considerably more flexibility in exposure assessment than in toxicity assessment, since the latter is often set by regulators. In certain circumstances, however, industry-derived dose-response criteria may be felt to be more appropriate than other published values. Where this is the case, the use of such values must be justified to the relevant authorities and their agreement obtained.

6.4.3. Comparison of Data with Other Relevant Criteria (ORCs)

If additional data have been collected from off-site wells, local basements/buildings and local water courses as part of a Tier 3 assessment, they can be compared with RBSLs or ORCs, as at Tier 1. For example, the comparison of off-site measured groundwater concentrations with RBSLs will indicate whether a potential health hazard exists via this migration pathway.

6.5. EVALUATION OF TIER 3 RESULTS

If the site-specific risk assessment acceptability criteria are met and there are no exceedences of ORCs or RBSLs then no further action is required, except a possible need for periodic monitoring for a finite period of time. If the criteria are exceeded, the cost-effectiveness of achieving Tier 3 corrective action goals, which could include SSTLs should be reviewed. A review of the options available for corrective action is provided in **Section 7**; the concept of Best Practical Environmental Option (BPEO) is a useful guiding principle.

7. CORRECTIVE ACTION MEASURES

7.1. INTRODUCTION

This section provides a summary of the range of corrective action measures that are available for contaminated sites representing the Risk Management options. There are many options available under the heading of "corrective action" at such sites. These include the following:

- traditional remediation processes that reduce contaminant concentrations;
- exposure pathway elimination methods, such as capping and hydraulic containment;
- land-use restrictions (administrative and institutional controls - these are especially important at larger facilities); and
- monitoring of natural attenuation between sources and receptors (for the purpose of validating the conclusion to take no further action).

All of these options are equally valid within the risk-based corrective action framework, provided they are implemented correctly, as they are all capable of reducing risks to acceptable levels.

It should be noted that the measures described in this section should only be utilised in connection with the tiered assessment approach described above. It should also be noted that other measures may become available and be developed as "best practice" in the remediation of contaminated sites as risk-based corrective action evolves.

7.2. SELECTION OF MOST APPROPRIATE CORRECTIVE ACTION TECHNIQUES

Following the identification of an unacceptable risk associated with site-related contamination, a number of risk management strategies may be considered. The works may vary from simple risk mitigation measures to large-scale site remediation. The management tool used in the selection of the most appropriate corrective action approach for a site is a technical (engineering) feasibility study, incorporating design and costing.

It is also necessary when comparing corrective action options to consider short-term risks to health and the environment during their implementation, such as exposure due to vapours and dust, and accident hazards to site personnel. Clearly, a corrective action programme must not, in addressing one set of risks, create others that negate the gains to health and the environment that remediation was intended to bring about.

It is inherent within the tiered approach that potential corrective action options and approaches are evaluated, and their merit revisited as analysis proceeds (i.e. as part of assessing the need for tier-specific corrective action, whether interim or final). A technical (engineering) feasibility study should be carried out to assess the site specific practicalities associated with undertaking one or more potential corrective action measure(s), which also forms part of the cost benefit analysis.

Once the selection of one or more appropriate options has been made a detailed design can be drawn up and budget cost estimates made. In cases where highly technical solutions may be required, simple bench scale or field pilot studies (i.e. pilot plant scale testing) may be required to better assess the feasibility of a particular scheme prior to full scale design and costing (e.g. for dual phase extraction or bioremediation).

7.3. EXAMPLE CORRECTIVE ACTION TECHNIQUES

The following techniques represent the principle methods by which corrective action at oil industry sites can be achieved, whether as an interim measure or a long term solution:

- ongoing monitoring of the natural attenuation of contaminated media (in particular in cases where source removal has been achieved and/or where natural processes (e.g. biodegradation) are expected to reduce the contaminant levels over time);
- contractual instruments or physical barriers limiting the use of property or land to avoid a potentially unacceptable exposure to current or future site users

  includes fencing-off contaminated areas, restricting access to subsoils and restricting site land-use;

- physical isolation measures for existing buildings or their incorporation into the design of new buildings during site redevelopment

  includes vapour exclusion membranes, removal of ducting, passive venting techniques;

- installation of specialist physical isolation barriers to restrict exposure/migration pathways at existing or redeveloped sites

  includes the capping of contaminated areas where direct exposure pathways drive the risk assessment or where the leaching of soil contaminants to groundwater via rainfall infiltration is a concern;

- construction of physical barriers or collection systems to restrict contaminant migration to surface and or groundwater

  includes cut-off walls or collection drains, vitrification, stabilisation;

- in situ treatment of contaminated materials to reduce the source term

  may include vacuum extraction for volatiles and semi-volatiles; air sparging, or bioremediation;

- receptor point corrective action

  includes the treatment of contaminated water as it is abstracted from a groundwater supply well;

- removal and disposal/treatment of contaminated soils

  includes ex situ bioremediation, landfilling, incineration, soil washing, thermal desorption

- a combination of the above.

7.4. MONITORING AND POST-CORRECTIVE ACTION REQUIREMENTS

Following the implementation of corrective action measures, a site monitoring system should be considered as a part of the corrective action assurance process. For example, at those sites where estimated risks are acceptable, but where significant residual contamination is known to exist, a requirement to monitor may be set by the regulatory authority. The purpose and duration of any such activity would be negotiated on a site specific basis and should depend upon the sensitivity of a particular site setting. If conditions change in the future then further corrective action measures may be necessary

Monitoring can take one of two principal forms. Firstly, validation monitoring is designed to ensure that contaminated material has been removed or treated to an acceptable degree leaving residual concentrations at acceptable levels. This is usually performed at the time of (or immediately after) the remedial programme of works. Secondly, longer term monitoring is often implemented to prove that the site condition, post-corrective action, does not represent an ongoing risk to the wider environment. It is important to pre-define the period of time for which monitoring is required.

8. GLOSSARY

Acceptability criteria	RBSLs, SSTLs or IRLs
Acute	Short term, not chronic.
Air sparging	*In-situ* volatilisation of dissolved or sorbed-phase organic compounds by the injection of air.
Algorithm	Procedural model or rule for calculation.
Analytical data	Data pertaining to the chemicals for which a sample is analysed.
Aquifer	A water-bearing bed or strata, either by virtue of its porosity or because it is pervious.
Arithmetic mean	The standard mean. The sum of a set of observations divided by the number of observations.
Attenuation	See "Natural Attenuation"
Backward	"Backward" means taking defined acceptable risk levels at points of exposure, and back-calculating soil contaminant levels which would achieve that level of risk.
Biased data	Data collected in a non-random manner.
Biased sampling	The taking of samples in a non-random manner.
Bioavailability	The degree to which chemicals present in a soil matrix may be absorbed or metabolised by a human or ecological receptor
Biodegradation	The breakdown of a substance or chemical by living organisms, usually bacteria.
Bioremediation	Breakdown and removal of contaminants by microbial action.
Capping	Placing a layer of material over an area of contamination to remove exposure pathways and/or prevent infiltration.
Carcinogenic	Capable of increasing the incidence of cancer.
Chronic	Of a persistent, recurring or long-term nature, or delayed in onset.
Compliance point	Negotiated location where target concentrations are to be achieved.
Compound	Chemical which contains more than one chemical element.
Concentration	Amount of chemical per amount of medium in which it exists.
Conservative	Erring on the side of safety.
Contaminant migration pathway	The mechanism by which a contaminant moves in the environment from source to target.
Contaminant	That which contaminates.
Contaminate	To render impure by contact or mixture; to corrupt, defile, pollute, sully, taint, infect.

Contamination	Pollution, impurity.
Corrective action	Any activity conducted in order to address an actual or perceived contamination problem.
Deed restriction	Legal method for preventing particular types of developments on a specific site.
Dose	The amount of a chemical which enters the body of an individual, expressed in the form of mass per unit body weight per unit time (e.g. mg/kg-day).
Dose-response relationship	A numerical expression of a chemical's dose-response relationship that is used in risk assessments. The two toxicity criteria used in this assessment are reference doses (for non-carcinogenic effects) and slope factors (for carcinogenic effects).
Ecological receptor	Habitat or species (non-human) that is potentially exposed to site-related contamination.
Ecological risk assessment	The process of evaluating the likelihood that adverse ecological effects may occur due to exposure to one or more stressors.
Exposure	The opportunity to receive a dose of a chemical.
Exposure assessment	The process of establishing whether, and how much, exposure will occur between a receptor and contamination.
Exposure assumption	An assumption made to aid in the process of exposure assessment.
Exposure pathway	The course a chemical takes from a source to a receptor. Each exposure pathway includes a source, a transport medium (or media) an exposure point and an exposure route.
Extrapolation	The action or method of finding, by calculation, other terms, from the known terms of a series.
Fate and transport model	A mathematical model used to describe and simulate the movement of a chemical in the environment.
Forward	"Forward" means using the measured soil and groundwater contaminant concentrations to calculate actual risk levels to the identified receptors, at the points of exposure.
Free product	Petroleum product (e.g. gasoline, diesel) which is present in either its original or weathered state at a concentration above the residual saturation level.
Generic	Applied to a large group or class of objects; general.
Generic assumptions	Simplifying assumptions, often highly conservative, made in the place of actual data and designed to apply widely.
Generic standards	Chemical concentrations, often conservative, which are designed to be protective of public health and environment in the majority, or all, situations.
Geostatistics	Statistical methods specifically related to characterising geological conditions.

Groundwater	Water occupying openings, cavities, pores and spaces in rocks, beneath the topographic ground level.
Guidelines	Non-enforceable statements of suitable approaches for achieving specified aims.
Hardstanding	Concrete or tarmac covering.
Hazard	Inherently dangerous quality of a substance, procedure or event.
Hazardous	Dangerous.
Hot-spot	Area containing a higher concentration of contaminant(s) than the surrounding area.
Insignificant risk	A risk which is so small as to be ignored.
Insignificant risk level (IRL)	A measure of risk which has broad public or regulatory acceptance (e.g. via legislation).
Intake	Same as dose.
Intrusive investigation	Procedures incorporating techniques such as boring and trenching to facilitate the investigation of subsurface conditions.
Land-use	That use to which a site is or will be put.
Maximally exposed individual (MEI)	Hypothetical individual who has a combination of characteristics (body weight, soil ingestion rate, etc.) such that the total exposure is unlikely to be exceeded by any other individual.
Medium	Air, water, soil and biota (plant and animal life).
Model	Idealised mathematical expression of the relationship between two or more factors (variables).
Monitoring	The gathering of data over time.
Monte Carlo analysis	Method for calculating the range of solutions to an equation, when the input variables can be characterised by probability density functions (PDFs).
Natural attenuation	Reduction in contaminant concentrations as a result of naturally occurring processes, such as dilution, evaporation and biodegradation.
Non-detect	Not capable of being detected by a specific laboratory instrument at specific settings.
Other relevant criteria (ORCs)	Officially recognised chemical concentrations in environmental media for the protection of specific adverse effects (e.g. odour thresholds, drinking water standards).
Pathway	The mechanism by which a contaminant travels from source to target in the environment.
Petroleum products	Gasolines, kerosenes, diesels, fuel oils, lube oils, etc.
pH	The logarithm of the reciprocal of the hydrogen ion concentration in solution - a measure of acidity and alkalinity.

Pharmaco-kinetic	Pertaining to the internal physiological/biochemical responses to a chemical dose.
Risk-based screening level (RBSL)	Chemical concentration in a specific environmental medium that can be used to make a judgement on the absence of a significant risk.
Reasonable worst case	An estimate of the plausible maximum (or minimum) value that an exposure assumption can achieve.
Receptor	Potentially-exposed organism.
Reference dose	Dose-response parameter for non-carcinogenic effects, equal to "safe" level of exposure.
Remediation	The completion of practical measures with agreed end-points for the purposes of rendering a contaminated site suitable for the use to which it is desired to be put.
Residual contamination	Contamination remaining on a site following corrective action.
Risk	The nature and probability of occurrence of an unwanted, adverse effect on human life or health, or on the environment.
Risk assessment	The process of establishing, to the extent possible, the existence, nature and significance of a risk.
Risk estimate	A quantitative or qualitative statement as to the level of risk, with no attempt made to interpret its meaning.
Risk management	The process of interpreting and controlling assessed levels of risk.
Screening	Simple and often highly conservative analysis.
Sensitive	Readily and acutely affected by some particular influence.
Significant risk	A risk which is considered worthy of concern and/or remedial action.
Significant risk level	A quantitative expression of what constitutes a significant risk.
Site history	Inventory of the operations and activities that have taken place on a site in the past.
Site investigation	Assessment of the condition of a site, including past and ongoing procedures and subsurface conditions.
Site-specific target level (SSTL)	A chemical concentration derived on a site-specific basis which does not pose a significant risk.
Soil vapour	Airborne chemicals present in the soil that may or may not be due to contamination.
Solubility	Upper limit on the dissolved concentration of a chemical in a particular liquid (usually water) at a given temperature.
Source	The activity or entity from which a chemical is released for potential human exposure.
Subsoil	A layer of shattered and partly weathered rock between the soil proper and the bedrock.

Surface water	Rivers and streams, lakes and reservoirs and tidal estuaries.
Target organ	The site where the toxic injury manifests itself in terms of dysfunction or overt disease.
Total petroleum hydrocarbons (TPH)	The sum of all petroleum-related compounds present in a sample, according to a specific analytical technique.
Toxic effect	Any change in an organism which results in impairment of functional capacity of the organism (as determined by anatomical, physiological, biochemical or behavioural parameters); causes decrements in the organism's ability to maintain its normal function; or enhances the susceptibility of the organisms to the deleterious effects of other environmental influences.
Toxicity	The potential of a substance to act as a poison. The capacity to cause injury to a living organism defined with reference to the quantity of substance administered or absorbed, the way in which the substance is administered and distributed in time, the type and severity of injury etc.
Toxicology	The study of the adverse effects of chemicals on organisms.
Tumour	A swelling; a mass of abnormal tissue which resembles the normal tissues in structure, but which fulfils no useful function and which grows at the expense of the body.
Unacceptable risk	A risk that is high enough to cause concern.
Upper confidence limit (UCL)	The upper value that delimits the confidence interval of a mean value.
Vacuum extraction	Removal of contaminants by creating a vapour flow through the soils by applying a vacuum.