Quantitative Risk Assessment for Contaminated Land

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1. Introduction

Changes in environmental legislation have had a major impact on how the long-term impacts of oil and chemical spills are assessed and controlled.

Clean-up of contaminated land and groundwater in the UK is governed by Part IIA of the Environmental Protection Act. Whilst this was implemented some time ago, there is still a degree of misunderstanding among remediation contractors of how the act affects potential liabilities resulting from land contamination. It is no longer acceptable to rely solely on reference tables to determine clean-up targets. The degree of remediation required at a contaminated site should generally be determined using a risk-based approach to underpin decision-making and regulatory approval. The principals of risk assessment apply to environmental, human health ecological and building receptors.

Implementation of the Landfill Directive has resulted in increased landfill disposal costs. As Government policies move away from a traditional dig and dump approach, on-site remediation technologies are becoming more commercially viable.

These changes present clean-up contractors with a number of challenges and opportunities. Whilst implementation of on-site remedial technologies is increasingly favoured, the selection of inappropriate remedial targets or remedial processes can result in potential financial or legal liabilities. The assessment of 'how clean is clean' is therefore crucial to designing an appropriate clean-up strategy. However, applying risk assessment methodologies to spill sites can be challenging, particularly as fuel oils comprise a mixture of many different compounds. After a spill occurs, a number of processes such as volatilization and biodegradation can leave an environment contaminated by petroleum residues of extreme chemical complexity. Yet sound, defensible and practical decisions are required on how to manage the risks to human health from exposure to petroleum hydrocarbons in soil.

2. Regulatory Context

UK policy for assessment of risks arising from contaminated land is clearly set out in a series of reports published by DEFRA, the Environment Agency and SEPA. Risk assessment involves use of a site specific, risk based approach according to the principles established in Part IIA of the Environmental Protection Act 1990 (the Contaminated Land Regime).

The regime sets the definition of contaminated land within the context of the "suitable for use" approach. It is based on the principles of risk assessment, including the concept of "pollutant linkage" – a linkage between a **contaminant**, and a **receptor**, by means of a **pathway**.

The Environment Agency has recently published its Model Procedures for the Management of Land Contamination (CLR11), which set out the basis by which contaminated sites should be assessed and decisions for remedial actions made.

3. Basic Principles of Risk Assessment

Determination of appropriate remedial targets requires an understanding of Quantitative Risk Assessment (QRA) and effective liaison with the Regulators. When designing a remedial programme it is not generally necessary to think in terms of achieving a total clean-up, but to identify the risk that the contamination poses to any receptors, be these humans, Controlled Waters, buildings or ecosystems. This is effectively a **risk management** approach rather than simply aiming to remove all contaminants regardless of whether they pose a problem. At the same time, it not acceptable to leave a site alone because 'looks OK'. The processes involved in identifying, assessing and judging risks should be transparent and presentable in a logical framework.

The starting point for an assessment of risk at a contaminated land or spill site is understanding the **"pollutant linkage".** This requires the identification three components:

• A **Source** (contaminant) – a substance that is in, on or under the land and has the potential to cause **harm** or to cause **pollution of controlled waters**;

• A **Receptor** – something that could be adversely affected by a contaminant, such as people, an ecological system, property, or a water body; and

• A **Pathway** – a route or means by which a receptor can be exposed to, or affected by, a contaminant.

A risk only exists when all three components are present. For example, a leak of a moderate quantity of diesel (source) from an underground pipe may not present an identifiable risk in a clay soil area, even if there is a water well (receptor) in the vicinity, because there is no pathway through which the contaminant can migrate to impact a receptor. The same leak occurring over a Chalk aquifer may present a significant risk due to pathways created by fractures in the Chalk. When the combination of contaminant–pathway–receptor is present this is described as a **pollutant linkage**.

Each pollutant linkage needs to be separately identified, understood and dealt with if appropriate. This is normally rationalised in the form of a **Conceptual Model**. The conceptual model is the main focus of preliminary risk assessment, and the model is subsequently refined or revised as more information and understanding is obtained through the risk assessment process. These principles apply to risk assessment for both Human Health and Controlled Waters, although the detailed risk assessment methodology varies considerably.

Risk assessments are undertaken using a **Tiered Approach**, each tier involving an increasing level of detail and complexity. The three tiers used in CLR11 are:

I. **Preliminary risk assessment (Qualitative Risk Assessment);**
II. **Generic quantitative risk assessment ;**
III. **Detailed quantitative risk assessment** (this also involves a number of Tiered assessments).

Depending on the outcome of a risk assessment, it may not be necessary to continue to the next tier. Judgement may sometimes be needed as to the cost of detailed risk assessment against the benefits of remedial work. Once the risks have been assessed, and if action to reduce or control the risks is considered necessary, the next part of the process is the appraisal of options to deal with the risks, followed by the implementation of appropriate action.

Preliminary risk assessment . Preliminary risk assessments are undertaken to develop an initial conceptual model of the site and establish whether there are potentially unacceptable risks. If potential pollutant linkages are established it may be necessary to progress to either generic quantitative risk assessment, detailed (site specific) risk assessment; or remedial work.

Professional judgment plays an important part in this process, but it is important that decisions can be justified within a logical framework.

Generic quantitative risk assessment. Generic quantitative risk assessments are used to establish whether **generic assessment criteria** are appropriate for assessing the risks and, if so, to apply them to establish whether there are actual or potential unacceptable risks. Generic Soil Guideline Values must be applicable across a range of soil types and site conditions and relate to the complete range of human activities that could take place on a site. These factors make it difficult to derive generally applicable criteria, sometimes resulting in impracticable or over-conservative values.

Generic Risk assessment criteria in common use include:

- CLEA Soil Guideline Values (SGVs). (discussed below)
- The ICRCL guideline values. DEFRA have formally withdrawn this guidance. The source information is still available from DEFRA on request to aid understanding of historical decisions on the remediation of contaminated sites but it should not be used in the assessment of new sites. All new decisions should be based on CLEA 2002,

- Dutch Guideline Values. The Dutch values are generally inappropriate as they are based on suitability for use; the intention is to allow the return of contaminated land to any potential use, rather than tailoring the level of remediation to the specific site.
- US Soil Screening Levels. These should be used with care, particularly for carcinogenic and non-threshold contaminants, as the US approach differs from the UK.

The recommendation from this process may be that risks are within acceptable bounds and that no further work is required; to progress to a detailed quantitative risk assessment; or to proceed to remedial work.

Detailed quantitative risk assessment. The purpose of detailed quantitative risk assessment is to establish **site-specific data** to decide whether there are unacceptable risks. It may be used as the sole method for assessment of risks, or it may be used to refine earlier assessments using generic assessment criteria. During this stage the assessor will normally use a computer software–based tool to estimate and evaluate the risk. The key objective will be to establish, for each contaminant of concern, a concentration limit below which the presence of that contaminant in the ground does not present a risk to a receptor(s). This concentration is generally referred to as the **remedial target.**

4. Human Health Risk Assessment Related to Contaminated Land

4.1. The CLEA Methodology (Contaminated Land Exposure Assessment Model)

The requirements and methodologies for establishing a human health risk linkage in the UK are based around the CLEA model and associated CLR publications. Soil is only one of the sources of contaminant exposure, and its effect needs to be kept in proportion with the total exposure from all sources.

The CLEA guidance includes a series of generic assessment criteria (SGVs) against which actual contamination levels at a given site can be assessed. The guidance is gradually being updated with new toxicology (TOX) reports for common soil contaminants and new SGVs. With respect to hydrocarbon based risk assessments, TOX reports have been published for benzene, toluene, ethylbenzene, xylenes, napththalene and benzo[a]pyrene. SGVs have been published for toluene and ethylbenzene.

Site specific quantitative risk assessment models have been developed within the CLEA framework and these are discussed below.

4.2. Comparison & Selection of Risk Assessment Tools

A brief comparison is made below between four widely used tools for assessment of risks to human health from contaminated land. This is not an exhaustive list and other models may also be considered. Extensive reference is made to the Environment Agency Contaminated Land Assessment Model Fact Sheets. Emphasis is given to factors affecting assessment of indoor vapour inhalation, which is particularly relevant to spill sites.

Regardless of which risk assessment model is used, assessments should take into account:

- the likely total intake of, or exposure to, the substance or substances which form the pollutant, from all sources including that from the pollutant linkage in question.
- the relative contribution of the pollutant linkage in question to the likely aggregate intake of, or exposure to, the relevant substance or substances.
- the duration of intake or exposure resulting from the pollutant linkage in question.

Assessment of whether an intake or exposure is unacceptable is independent of the number of people who might be affected. Toxicological properties should be taken to include carcinogenic, mutagenic, teratogenic, pathogenic, endocrine-disrupting and other similar properties.

A key consideration within human health risk assessments is to distinguish between `threshold' and non-threshold compounds. In the UK, substances are classified according to whether they are threshold substances or non-threshold substances, rather than whether or not cancer is the endpoint. This is because a substance may be carcinogenic, but still have a threshold below which no observed adverse effect occurs.

4.2.1. Contaminated Land Assessment Model (CLEA)

As discussed above, the CLEA methodology sets out the basis for human health risk assessment in the UK. It is a probabilistic computer tool that has been used to derive the first suite of UK long-term human health generic assessment criteria for contaminated soil. CLEA 2002 was issued as an accompaniment to CLR 10, which provides the technical and scientific basis and algorithms that underpin it.

The Environment Agency has recently released the CLEA UK software (currently the `Beta' version for evaluation and comment). This allows the development of generic assessment criteria and site-specific assessment criteria. CLEA UK overcomes a major limitation of the CLEA 2002 software by allowing users to derive assessment criteria for contaminants for which no SGV or TOX report data are available.

CLEA considers only human health receptors. Whilst UK guidance directs use of the CLEA methodology, CLEA does not estimate human exposure via contaminated groundwater; therefore, an alternative approach is required for this scenario.

4.2.2. Framework for Deriving Numeric Targets to Minimise The Adverse Human Health Effects of Long-Term Exposure to Contaminants in Soil (SNIFFER)

This is a paper based risk assessment tool for deriving site-specific assessment criteria (SSAC), developed primarily by SEPA.

This framework provides a deterministic methodology for deriving human health assessment criteria for chronic exposure to contaminants in soil.

The indoor inhalation pathway is very simple and allows for dilution only.

4.2.3. Risk-Based Corrective Action (RBCA) Tool Kit for Chemical Releases RBCA Tool Kit

The RBCA Tool Kit was developed by the American Society for Testing and Materials (ASTM). RBCA can be used to calculate risk levels and/or cleanup standards for soil and groundwater and to evaluate risk to both human health and the environment. This includes the calculation of exposure concentrations and average daily intake of contaminants by people.

An integrated toxicological and physico-chemical parameter database of chemicals is provided in the Tool Kit. These include aliphatic and aromatic carbon chain lengths specified in the TPH Criteria Working Group (TPHCWG) methodology.

The Tool Kit includes analytical fate and transport models for air, groundwater and soil exposure pathways, enabling evaluation of surface soil, subsurface soil, air, groundwater and surface water. However, contaminant concentrations can only be specified for soil and groundwater.

A wide range of exposure pathways and scenarios are integrated in the software, including inhalation of groundwater vapour.

The RBCA Tool Kit is a deterministic model (i.e. it uses a single value for each exposure parameter). The model does not allow probabilistic human health risk evaluation.

4.2.4. Risk-Integrated Software for Clean-ups (RISC)

RISC was developed by BP Oil International Ltd.

RISC is a probabilistic model based on the RBCA methodology described above, with additional pathways, fate and transport information and contaminant information. RISC can be used to assess human exposure to contaminants from soil and groundwater. Groundwater and surface water receptors can also be considered. Measured soil, groundwater and air concentrations may be input directly into the programme to assess their risk, or used as input to run the fate and transport models.

A study published by the Environment Agency assessed several soil vapour transport models in relation to the CLEA framework. The RISC model was recommended as the closest to satisfying requirements for adaptation of the CLEA methodology.

5. Quantitative Risk Assessment for Groundwater

The Environment Agency (EA) has a duty to monitor and protect controlled waters. Moreover, the Contaminated Land Regime Part IIA of the Environmental Protection Act (April 2000) provides the EA and local authorities powers of prosecution should pollution resulting in significant harm to humans or groundwater be caused or knowingly permitted. In particular the EA places a great emphasis on the protection of controlled waters from pollution, adopting a tiered approach for determining the required remedial targets. The tiered risk assessment uses the “source-pathway-receptor” model whereby it is required to:

- Identify the source of contamination including preliminary assessment of the contaminant spatial distribution and concentration, together with their physical and chemical properties.
- Determine and characterise the potential environmental receptors.
- Identify the transport and exposure pathways of contaminants to potential environmental (water-based) receptors.

5.1. Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Groundwater Resources

The overall methodology to determine the level of remedial action required to protect water resources is outlined in the Environment Agency R&D Publication 20 (1999) “Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Groundwater Resources” (commonly referred to as ‘P20’). This uses a tiered approach to assess the risk on the basis of the data available and the validity of the proposed conceptual model.

Within the P20 model, TIER 1 quantitative risk assessment considers whether the concentration of contaminants dissolved in the ‘pore water’ in the contaminated soil (or sediment) is sufficient to impact on the receptor, ignoring dilution, dispersion and attenuation along the pathway. The pore water hydrocarbon contaminant concentrations are based on soil/water partitioning equations.

TIER 2 assumes that the observed groundwater concentration below the site is compared directly to the target concentration. The compliance point (i.e. receptor) is taken as the groundwater below the site or a nearby surface water stream. The model therefore assumes that contaminants may undergo some dilution prior to reaching the compliance point.

TIER 3 takes account of the potential attenuation as contaminants move off-site to the receptor. In this Tier, an analytical contaminant transport model is used to predict the contaminant concentration down gradient of the site as a result of attenuation. The remedial target is derived by multiplying the target concentration at the receptor by the dilution and attenuation factors.

TIER 4 is similar to the TIER 3 assessments, but requires a very detailed understanding of hydrogeological setting of the site. In reality, few spill sites will warrant a TIER 4 assessment, as the time and cost required to obtain sufficient data can generally be better spent on remedial works.

5.2. Available Tools for Groundwater Quantitative Risk Assessment

5.2.1. R&D 20, Remedial Targets Worksheets

The P20 methodology can be applied through Excel based spreadsheets that can be freely downloaded from the EA website. This is a deterministic methodology, so can result in over conservative remedial targets being established.

5.2.2. CONSIM

This is a probabilistic computer model, closely based on R&D 20. The key advantage of ConSim is that it allows for probabilistic risk determination.

5.2.3. RBCA and RISC

Both of these models can be used to determine risk to groundwater receptors, but must be adapted to take into account UK policy.

6. The Problem of Hydrocarbon Risk Assessment

Once released to the environment in a spill or leak, petroleum constituents partition, to differing extents, between the oil phase and the air, soil and water phases of the environment. Physical, chemical and biological processes ‘weather’ or age the spilled product, resulting in additional changes in composition and complexity.

Understanding the toxicology of environmental contaminants in soil is essential if the risks to human health are to be managed responsibly. The toxicological evaluation of petroleum hydrocarbons is particularly difficult because these substances are present in the environment as complex mixtures, containing many hundreds of individual compounds, each with their own toxicological properties. Similarly, it is impractical to analyse for individual compounds when present in complex mixtures. Hence a scientifically sound and practical approach to managing risk is required that is protective of human health.

The Environment Agency has recently published a report outlining the UK Approach for Evaluating Human Health Risks from Petroleum Hydrocarbons in Soils. The basis of the framework is the United States Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) approach, which is already used extensively within the UK, particularly for groundwater risk assessment. Quantitative Risk Assessment for hydrocarbon contaminated sites requires that the hydrocarbons in the soil (or groundwater) are considered as a number of individual fractions, based on the number of carbon atoms. Furthermore, the hydrocarbon fractions are differentiated into aliphatic and aromatic compounds. The Environment Agency proposes to add three further fractions onto that of the original TPHCWG methodology. In total there would be 16 fractions.

The UK approach also assumes additivity of toxicological effects across all fractions, unless there are scientific data to the contrary.

In addition to the use of hydrocarbon fractions, indicator compounds have been identified that should be assessed concurrently. Indicator compounds are the most toxic compounds and most prevalent in the petroleum hydrocarbon-contaminated environment. Indicator compounds include threshold and non-threshold contaminants.

7. Practical Implications for the Contractor/ Consultant

7.1. Liason with the Regulatory Bodies

It is advisable to involve the appropriate Regulatory body (Environment Agency, Local Authority) at an early stage to ensure that they agree with the risk assessment methodology and that remedial targets are agreed before remediation commences.

7.2. Analysis

The analytical regime is crucial to determining appropriate remedial targets. This is particularly important for fuel spills. For TPH analyses, the relative concentrations of different hydrocarbon fractions must be determined and the bandings used must correlate with those used in the risk assessment. Differentiation into aliphatic and aromatic components of a mixture is important but involves a significant additional cost.

Physical soil characterisation may be required in addition to chemical analysis.

The Environment Agency now requires that all soil analyses conform to the MCERTS performance standard analyses where reports are submitted for regulatory purposes.

7.3. Remediation

The remediation programme should include appropriate validation sampling to ensure that remedial targets have been met.

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