Executive Summary Report
Risk Assessment
Comparison Study

April 2004

Prepared for:

Network for Industrially Contaminated Land in Europe (NICOLE)
Industrial Sub-Group (ISG)

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Statement of Use:

This Executive Summary Report provides a synopsis of the Risk Assessment Comparison Study prepared by Arcadis Geraghty & Miller International for the NICOLE Industrial Sub-Group. The synopsis is intended to present a summary of the purpose, methodology and findings of the full study. The study is applicable to EU Risk Assessors or regulatory personnel responsible for managing contaminated land issues.

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NICOLE - Risk Assessment Comparisons Study (AGMI Rpt No 916830024_02)
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1. INTRODUCTION

NICOLE began in 1996 from a 4th European Union (EU) Framework Initiative. Since then, it has been involved in providing technical support for EU members developing Site Specific Risk Assessment programs for managing contaminated land. In March 2002, NICOLE published a discussion paper on the role of risk assessment in sustainable land management. One of the questions posed in this document is in regard to Risk Assessment models and the differences between them.

In early 2002, the Industrial Sub-Group (ISG) of NICOLE contracted with Arcadis Geraghty & Miller International Inc ("Arcadis GMI"), to undertake a study to examine the human health risk assessment models being used in Europe.

Eleven members of the ISG have provided the funding for this project and NICOLE has provided additional funding. A list of participating companies and organisations is presented below:

Akzo Nobel	NICOLE
BNFL	PowerGen
BP	SecondSite Property
Fortum	Shell
ICI	Solvay
JM Bostad	TotalFinaElf

1.1. Acknowledgements

The authors of this report would like to acknowledge the contribution made to the project by Mr. Lawrence Houlden former Project Director for ArcadisGMI. We would also like to thank Frank Swartjes and Christa Cornelis of the Review Panel for their many helpful comments and support during the project. Finally, we would like to thank NICOLE and the ISG sponsors for giving us the opportunity to undertake this study.

1.2. Report Format

This Executive Summary Report, presents the condensed results of the "NICOLE / ISG – Risk Assessment Comparison Study" completed by Arcadis GMI and submitted to NICOLE (main Technical Report). The Executive Summary Report is structured in the following format:

1. Introduction
2. Study Aims and Objectives
3. Methodology
4. Review of EU Risk Assessment practice
5. Screening of Risk Systems
6. Generic Test Site
7. Output and Results
8. Summary of Case Studies
9. Conclusions and Recommendations
10. References

2. STUDY AIMS AND OBJECTIVES

As stated earlier, the aim of the study was to critically appraise the human health risk assessment models / systems commonly used in the different countries of Europe.

The specific objectives of the study were:

- To increase the awareness and understanding of model variability for Risk Assessors applying the models;
- To provide confidence to Risk Managers relying on model output to facilitate environmental decision making.

2.1. Scope of Work

The focus of the study is on site-specific human health risk assessment and consists of 4 phases of work.

Phase 1. Risk Assessment "System" Identification to review risk assessment practice in Europe and identify which risk assessment systems are employed.

Phase 2. System Screening to compare risk assessment packages with respect to their capability of assessing various pathways *i.e.* indoor air, dermal contact, ingestion etc. and to examine differences in output presentation between the models.

Phase 3. An evaluation of model data requirements and algorithms employed using a Generic Test Site.

Phase 4. An examination of the differences in model predictions using data from 5 practical test sites.

2.2. Limitations

Each system has been discussed within the remit of the project resulting in its development, taking into account existing or pending legislative requirements together with consideration of the socio-economic status of the origin state. This project aims to make meaningful comparisons between systems that purport to provide a similar capability. To this end not all of the systems selected can be compared for every factor considered.

In undertaking this comparison study, Arcadis GMI has only used the version of software packages that were available at the time. We have not obtained access to any of the packages at the software coding level and are using the systems as they exist on the market.

Some of the risk assessment systems incorporate a stochastic or probabilistic modelling capability. These features of those systems are not tested, except where a deterministic capability does not exist; however attention is drawn to the capability existing.

3. METHODOLOGY

A phased approach was developed that began with an initial examination of risk assessment "practice" across Europe including comment on legislative tools, generic guidelines or the existence of site specific risk assessment guidelines. This is followed by a series of systematic reviews and screens to focus the level of comparison from generic elements that are more widespread down to site-specific elements that are fewer.

Figure 1 illustrates the process adopted and a description of the process is provided below.

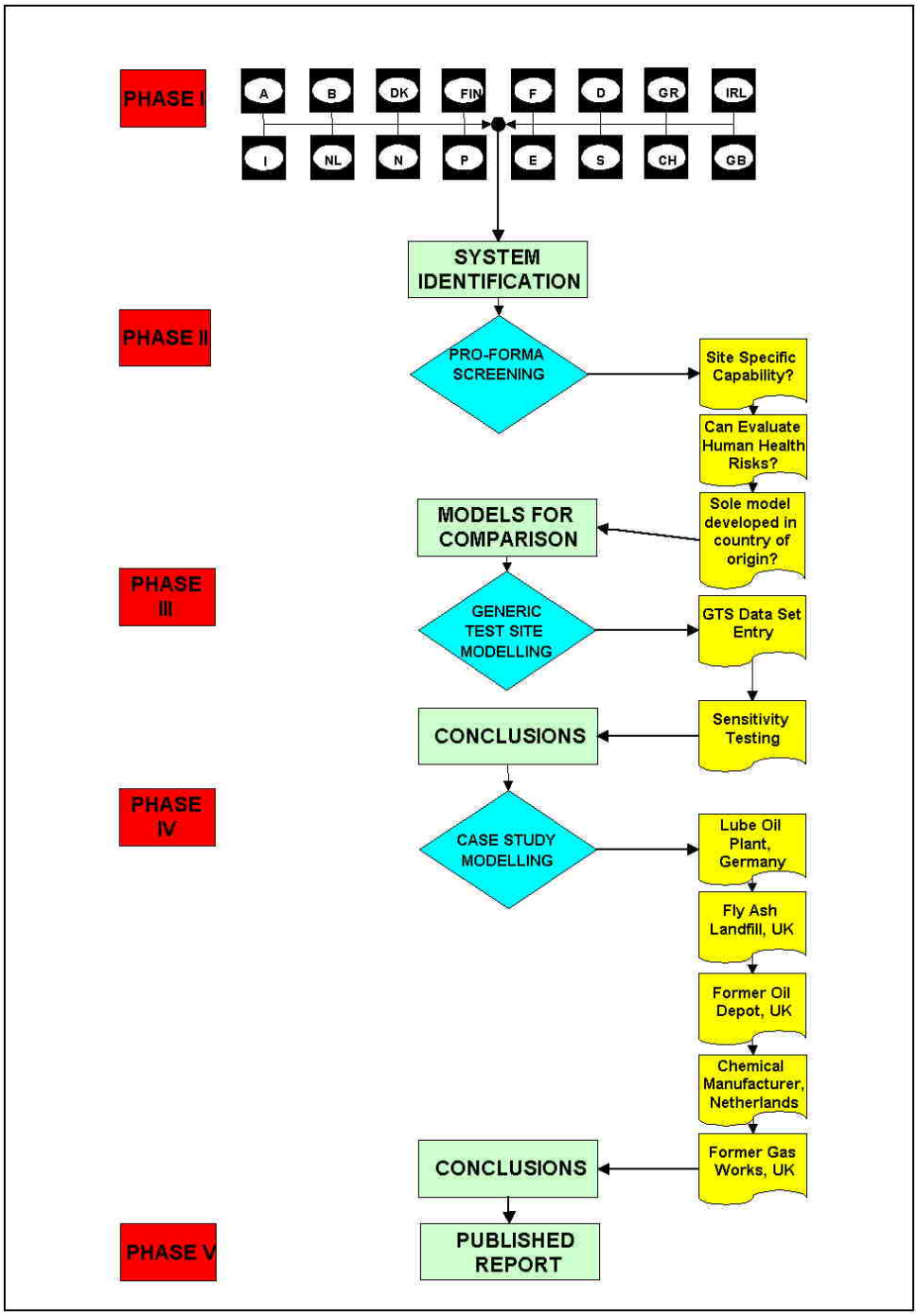

Figure 1 – Methodology

3.1. Phase I –Risk Assessment "System" Identification

In Phase I, a review of existing literature that overviews contaminated land risk assessment in Europe was undertaken. The second element of the review comprises an examination of the legislative management of contaminated land in European countries with the aim of identifying the appropriate means of assessing potential risks in each country. This phase concludes with the determination of a list of risk assessment "systems" for consideration at Phase II including methodologies, guidance documents, screening tools and software tools all of which assist in decision making.

3.2. Phase II – System Screening

In Phase II, each system was evaluated against a pro-forma questionnaire that questioned the system's functionality in terms of capability, *i.e.*, what types of exposure pathways it considers, whether it incorporates fate and transport models and what outputs are produced. The end product of Phase II was a list of systems suitable for further quantitative testing at Phase III based on the following criteria:

- Can the system be used for site specific risk assessment?
- Can the system quantify human health risk?
- Is this the sole system developed in the country of origin?

3.3. Phase III – Generic Test Site (GTS)

This Phase of the project tested the capabilities of each system against a generic data set with the aim of identifying similarities and differences between:

- Data entry requirements;
- Environmental fate and transport algorithms;
- Human health exposure algorithms;
- Risk calculation equations.

Phase III comprised the development of a Conceptual Site Model (CSM), which involved the development of a consistent data set for testing between the relevant systems, the assessment of the source pathway receptor linkages in the CSM using the applicable risk assessment systems and the testing of sensitivity of outputs to changes in parameter inputs.

3.4. Phase IV – Case Study Test Sites

The aim of Phase IV was to draw out and expand upon the conclusions made at Phase III using real site data sets. Five Case Study Test Sites were used for this assessment:

1. Former Lube Oil Plant
2. Former Gasworks Site
3. Fly Ash Landfill
4. Active Chemicals Manufacturing Site
5. Former Retail Petrol Filling Station

Each of the sites was assessed for a range of applicable source-pathway-receptor linkages. Not all exposure pathways are active at any one site, therefore a range of different types of site and different types of contaminants of concern were selected in order to explore as many of the previously investigated pathways as possible. The sites selected represent "typical" sites, but they have also been

selected on the grounds that they comply with a number of the assumptions adopted for the environmental fate and transport models. The sites are relatively easily conceptualised, but include natural variations that may potentially result in larger variations in results. Furthermore, the sites were selected on the grounds that they have good data coverage, which may often be missing at similar sites.

4. REVIEW OF LITERATURE & EUROPEAN RISK ASSESSMENT PRACTICE

Risk assessment is widely recognised as a key concept in the management of contaminated land, however the uptake of use by contaminated land investigators and the tools available to assist in the assessment are at differing levels of development in the countries of Europe. The complete main Technical Report to NICOLE presents a review of existing literature relevant to this project in terms of aims, objectives, methodology of study and conclusions drawn. The review is not exhaustive, but has singled out several key reports and enables this project to build upon the results of the research discussed.

4.1. Ferguson and Kasamas (editors) (1999)

The Concerted Action on Risk Assessment for Contaminated Sites in Europe (CARACAS) commissioned a two-volume desk reference book addressing the aims of risk assessment and the variety between risk assessment practises in the 16 CARACAS countries.

Volume 1 reviews the fundamental concepts of risk assessment and various technical aspects of risk assessment in greater detail (Ferguson *et al*., 1998).

Volume 2 presents a commentary on the status and evolution of risk assessment practice in each of the 16 countries affiliated with CARACAS. The appendices to Volume 2 present some useful comparative matrices of risk assessment use in separate CARACAS countries (Ferguson and Kasamas, 1999).

4.2. Zaleski and Gephart (2000)

In recognition of the need to use site specific data in exposure assessment modelling, NICOLE commissioned the development of the Exposure Factors Sourcebook. Human “lifestyle” factors are needed to calculate predicted maximum doses for risk assessment, and in defining acceptable doses in remedial target derivation. Therefore the factors are fundamental to human health risk assessment.

4.3. Whittaker *et al.* (2001)

A research project was commissioned by the Environment Agency of England and Wales (EA), with the aim of producing a methodology for benchmarking models for use in conjunction with the EA’s *Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources* (R&D Publication 20 – Marsland and Carey, 1999). To assist in the benchmarking process, four case studies were used as test sites to assess performance and allow comparison of results. The report concluded that the four software tools have a similar approach to modelling groundwater flow and contaminant transport, while a number of significant differences were also highlighted, including:

1) Three of the four systems applied first-order decay to both the dissolved and sorbed phases, leading to a higher degradation rate than for dissolved phase degradation alone; and
2) Where the leachate flux is not insignificant with respect to the receiving groundwater flux, errors in contaminant travel times may arise for RBCA Toolkit and the RTW.

4.4. Rikken *et al.* (2001)

The aim of this study was to evaluate the models used in the CSOIL human exposure model by comparing with a group of alternative human exposure models. The study begins with a comparison of CSOIL with the European Union System for the Evaluation of Substances (EUSES); this is followed by comparison with the Contaminated Land Exposure Assessment (CLEA) system from the UK, the Umwelt Menschen Schadstoffe (UMS) system from Germany and the US-EPA CalTox system. Comparison is limited to assessing risks from soil impacts and because of the aim to compare with CSOIL, the pathways are limited to those included in CSOIL however, specific focus is given to the modelling of volatiles in indoor air and metal uptake in plants.

4.5. Evans *et al.* (2002)

The Environment Agency of England and Wales (EA) commissioned a research project to evaluate soil vapour intrusion models for use in the Contaminated Land Exposure Assessment (CLEA) system. One of the key objectives of the study was to undertake a review of the characteristics of the identified soil vapour models. Ten systems were included in the initial screening with a short list of five chosen for further assessment against the case study site data. Of the five systems compared, the system deemed most suitable for inclusion in the CLEA system was the Johnson and Ettinger sub-model (as used in the RISC v3.09 package).

4.6. Swartjes (2002)

The study aimed to compare the dose calculations of a variety of contaminants for generic scenarios, using risk assessment systems from seven European countries (Denmark, UK, The Netherlands, France, Sweden, Italy, Belgium/Flanders). Three aims of the comparative study were identified:

- Investigate variations in calculated human exposure level for different systems;
- Investigate variation in default input parameters for different systems; and
- Evaluating differences in calculated exposure via different major exposure routes on the basis of differences between system concepts and input parameters.

Both a generic data set of input parameters and a system-specific (default) data set of input parameters were tested. To demonstrate variability, results were plotted as variations from the common median for each output of concern. An overview of the system-specific default values was completed for the main input parameters and a qualitative evaluation of differences between the system outputs was completed.

A wide range of system calculation results was reported. The greatest degree of variability was reported where fate and transport models were incorporated into the assessment, particularly in the case of vapour migration.

4.7. European Risk System Review

A literature review was undertaken for the first fifteen member countries of the European Union. In addition, two non-EU countries, Norway and Switzerland were included. The reviews were conducted using information available via Internet searching, obtaining policy information detailed in manuals, direct communication with regulators and consultation with professionals working in the industry in different countries.

Where information could not be obtained at source, the CARACAS reports (see section 4.1) provided the basis for the reviews. It is acknowledged that policies could have changed in the time elapsed since the publication of the CARACAS reports.

Reviews were completed for the following countries: Austria; Belgium; Denmark; Finland; France; Germany; Greece; Ireland; Italy; Luxembourg; Netherlands; Norway; Portugal; Spain; Sweden; Switzerland; and the United Kingdom. The individual reviews are presented in the full report to NICOLE.

4.8. Proprietary Systems

There are several risk assessment systems that have been developed commercially, rather than specifically to support the approach to contaminated land of a particular country or region. Many of these are in widespread use throughout Europe (and globally), including countries that have not yet developed their own methodology. We included four of these systems in the comparison study:

RBCA Toolkit
The Risk Based Corrective Action (RBCA) methodology developed by the American Society for Testing and Materials (ASTM, 1995) is a human health risk assessment tool (ASTM Designation E1739-95). Groundwater Services Inc (Houston, Texas, USA) developed the methodology into a software package.

RISC
The Risk Integrated Software for Clean-ups (RISC) was developed by BP (Spence and BP, 2001) and is a Windows based package for the multi-media risk assessment of contaminated land.

Risk Assessment Model (RAM)
Environmental Simulations International Ltd has developed this proprietary system. The aim of the model is to assess the potential risks to water resources in line with the P20 methodology developed in the UK.

ConSim
A commercially available software package developed by Golder Associates on behalf of the Environment Agency of England and Wales. The software is designed to assess the potential risks to water resource receptors from impacted soil and groundwater sources.

4.9. Conclusions

The development and acceptance of risk assessment as a tool for the management of contaminated land is growing, however the level of development varies considerably. Furthermore it can vary considerably between different regions of a country.

In many instances the development of a specific risk assessment system has been undertaken to directly address a legislative requirement. However in other countries where risk assessment is

widely used an array of different modelling software packages could be used, provided that the models are suitable for the exposure scenario in question. In both cases the systems available are being used, and it is these systems that were to be compared in later phases of this study.

The following list represents the conclusion of Phase I and includes all the systems identified and considered applicable for review in Phase II:

System Name	Origin		System Name	Origin
CLEA	UK (England & Wales)		RISC	Commercial
ConSim	UK (England & Wales)		Risc-Human	Netherlands
Giuditta	Italy (Milano)		ROME	Italy
JAGG	Denmark		SFT 99:06	Norway
P20-RTW	UK (England & Wales)		SNIFFER	UK (Scotland & NI)
RAM	UK (Commercial)		UMS	Germany
RBCA Toolkit	Commercial		Vlier-Humaan	Belgium (Flanders)
Report 4639	Sweden			

5. SYSTEM SCREENING

In Phase II of the study, the selected systems were evaluated to determine the extent of their capabilities and to evaluate their applicability for use in testing with the Generic Test Site (Phase III) and Case Study Test Sites (Phase IV) thereby fulfilling the aims and objectives of the study. The following tasks were completed:

5.1. Pro-forma Screening

The questionnaire included enquiries relating to general capability (*e.g.* whether it can quantify human health risk or undertake fate and transport modelling) before assessing what specific types of exposure pathways are included and the system's ability to model environmental fate and transport. System support capabilities were also evaluated, for example, does the system include databases, and some comment on user friendliness of the software was made. The questionnaires used in the Phase II study are located in the main Technical Report to NICOLE.

5.2. Matrix

The results of the pro-forma screening were entered into a matrix of risk assessment system against key risk system capabilities; presented as Table 1 in this Executive Summary.

Table 1 presents a rapid means of assessing the capabilities of the model and establishes which potentially key elements of a risk assessment can be assessed with each system.

5.3. Criteria for System Screening

To select appropriate systems for further comparison in Phases III and IV, a set of three screening criteria were defined:

1. **Can the system be used for site-specific risk assessment?**
   By site specific it is intended that the user can enter the majority of required parameters. In this step any system primarily developed for setting initial screening values was removed from the assessment process.
2. **Can the system quantify human health risk?**
   Each risk assessment system was evaluated to determine if it is capable of calculating either a receptor point concentration or a dose concentration for use in further risk assessment.
3. **Is this the sole system developed in the country of origin?**
   This criterion was intended to limit duplication of effort and to ensure that the comparisons were as direct as possible. Where two or models have been developed for similar or identical purposes, only one system was selected.

The results of the application of the criteria are presented in Table 2.

Table 1
Summary of Risk System Capabilities

Pro-forma Reference	Model	Software package	Human health risk assessment	Compliance risk assessment	Ecological risk assessment	Back calculations	Soil models	Groundwater models	Vapour transport models	Air mixing models	Surface water mixing models	Presence of NAPL	Probabilistic capability	Exposure Assessment Models									Chemical properties database	Toxicological properties database	Geological properties database	Compliance Criteria database	Default values	English language	Help system
														Soil			Air		Groundwater				Surface water							
														Direct contact	Vegetable uptake	Inhalation of particulates	Inhalation indoor air	Inhalation outdoor air	Direct contact	Vegetable uptake	Shower model	Irrigation model								
1	CLEA	●	●			●	●		●	●			●	●	●	●	●	●						●	●	●		●	●	●
2	ConSim	●		●			●	●					●											●		●	●		●	●
3	Giuditta	●	●	●		●	●	●	●	●	●			●		●	●	●						●	●		●	●	●	●
4	JAGG	●		●			●	●	●	●														●		●	●	●		●
5	P20-RTW	●		●		●	●	●																					●	●
6	RAM	●		●		●	●	●					●																●	●
7	RBCA Toolkit	●	●	●		●	●	●	●	●	●			●		●	●	●	●				●	●	●	●	●	●	●	●
8	Report 4639		●	●	●		●		●	●	●			●	●	●	●		●				●	●	●		●	●	●	●
9	RISC	●	●	●		●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●
10	Risc-Human	●	●	●			●	●	●	●				●	●	●	●	●	●		●			●	●	●	●	●	●	●
11	ROME	●	●	●		●	●	●	●	●	●	●		●		●	●	●					●	●	●		●	●	●	●
12	SFT 99:06		●	●	●	●	●		●	●	●			●	●	●	●		●				●	●	●		●	●	●	●
13	SNIFFER		●			●	●		●	●				●	●	●	●	●										●	●	
14	UMS	●	●				●		●					●	●	●	●	●						●	●			●	●	●
15	Vlier-Humaan	●	●	●			●	●	●	●				●	●	●	●	●	●		●			●	●		●	●		●

Notes:

Software Package – Risk System software is available

Human Health Risk Assessment – Risk System considers the risk posed to human receptors

Compliance Risk Assessment – Risk System considers the modelling of contaminant levels to set compliance criteria

Ecological Risk Assessment – Risk System considers the risk posed to environmental receptors

Back Calculations – Risk System back calculates risk posed to receptors to produce target contaminant levels at the source

Soil Models – Risk System models contamination from a soil source

Groundwater Models – Risk System models contamination from a groundwater source

Vapour Transport Models – Risk System considers transport of vapour within the risk system

Air Mixing Models – Risk System considers air mixing within the risk system

Surface Water Mixing Models – Risk System considered mixing of surface waters within the risk system

Presence of NAPL – Risk System considers the presence of low and high density free phase product (model dependant)

Probabilistic Capability – Risk System allows the use of stochastic input concentrations and exposures parameters giving a resultant, statistically evaluated risk.

Chemical Properties Database – Risk System contains a chemical properties database

Toxicological Properties Database - Risk System contains a toxicological properties database

Geological Properties Database- Risk System contains a geological properties database

Compliance Criteria Database- Risk System contains a compliance criteria properties database

Default Values- Risk System contains default values

English Language- Risk System is available in English

Help System- Risk System contains a help system

Exposure Assessment Models:

Soil (Direct Contact) – Direct human contact with contaminated soil

Soil (Vegetable Uptake) – Uptake of contaminants into vegetable grown on contaminated soil

Soil (Inhalation of Particulates) – Human inhalation of contaminated soil particulates

Inhalation of Indoor Air – Human inhalation of vapours in indoor air. Where the Risk System considers soil models vapour transport from soil to air is a pathway and/or where the Risk System considers groundwater models vapour transport from groundwater to air is a pathway

Inhalation of Outdoor Air - Human inhalation of vapours in outdoor air. Where the Risk System considers soil models vapour transport from soil to air is a pathway and/or where the Risk System considers groundwater models vapour transport from groundwater to air is a pathway

Groundwater (Direct Contact) - Direct human contact with contaminated groundwater

Groundwater (Vegetable Uptake - Uptake of contaminants into vegetable grown with contaminated groundwater

Groundwater (Shower Model) - Direct human contact with contaminated groundwater used for a shower

Groundwater (Irrigation Model) - Uptake of contaminants into vegetable grown irrigated with contaminated groundwater

Surface Water – Transport of contamination from soil and/or groundwater to surface water

5.4. Final System Selection

Table 2 presents a matrix of Risk Assessment System against Phase II Screening Criteria. The screening criteria were applied broadly on the basis of the results from the Phase II Pro-forma Questionnaire resulting in a list of systems for inclusion in the Phase III and Phase IV testing. The systems selected for further comparison are:

- CLEA
- JAGG
- P20-RTW
- RBCA Toolkit
- RISC
- Risc-Human
- ROME
- SFT 99:06
- UMS
- Vlier-Humaan

Table 2
Risk System v's. Screening Criteria Matrix

System Name	Origin	Can the system be used for site specific risk assessment?	Can the system quantify human health risk?	Is this the sole model developed in the country of origin?	System included in study?
CLEA	UK (England & Wales)	No (See note 1)	Yes	No	Yes (see note 1)
ConSim	UK (England & Wales)	Yes	No	No	No (See note 2)
Giuditta	Italy (Milan)	Yes	Yes	No	No (See note 3)
JAGG	Denmark	Yes	No	Yes	Yes (See note 4)
P20-RTW	UK (England & Wales)	Yes	No	No	Yes (See note 4)
RAM	UK (Commercial)	Yes	Yes	No	No (See note 5)
RBCA Toolkit	Commercial	Yes	Yes	commercial package	Yes
Report 4639	Sweden	Yes	Yes	Yes	No (See note 6)
RISC	Commercial	Yes	Yes	commercial package	Yes
Risc-Human	Netherlands	Yes	Yes	No	Yes
ROME	Italy	Yes	Yes	No	Yes (See note 3)
SFT 99:06	Norway	Yes	Yes	Yes	Yes
SNIFFER	UK (Scotland & NI)	Yes	No	No	No (See note 7)
UMS	Germany	Yes	Yes	Yes	Yes
Vlier-Humaan	Belgium (Flanders)	Yes	Yes	Yes	Yes

Notes:

1 CLEA is not currently intended for use as a fully site specific risk assessment model, however the methodology is the key guidance in the UK.
2 ConSim is a stochastic groundwater fate and transport model and is intended for use under the P20 methodology, P20-RTW is recognised as the preferred package within the UK regulatory environment.
3 ROME is considered in preference to Giuditta as it has been developed by ANPA (National Agency for Protection of the Environment).
4 JAGG and P20-RTW do not assess risks to human health, however receptor point concentrations are generated for comparison to other models and would be compared to quality standards.
5 RAM is based on the P20 methodology, RTW is recognised as the preferred package within the UK regulatory environment.
6 The Norwegian and Swedish models are similar. Report 4639 describes the model used to derive generic guidelines, though it has since been ascertained that it is also frequently used to calculate site specific risk based guidelines.
7 At the time of system evaluation SNIFFER was not available in software format, is used in implementing the same legislation as CLEA and reflects the guidance in the CLEA reports CLR9 and CLR10.

6. GENERIC TEST SITE (GTS)

The environment is inherently difficult to simplify into a conceptual site model. A single set of potential input values was defined in order to remove the subjectivity of site characterisation and produce standard approach. Sensitivity testing of the input parameters created further evidence as to how potential variations could arise from site conceptualisation.

The GTS study involved undertaking a number of tasks to assess general differences within the risk assessment systems and to identify those differences in the systems that could impact upon interpretation of the results. The tasks listed below are discussed in detail in the main Technical Report.

Task 1. Define the Conceptual Site Model

The conceptual site model for the Generic Test Site is a series of defined source-pathway-receptor linkages selected to enable comparison in terms of both applicability on most real sites and what is appropriate for comparison.

Task 2. Define Methodology for the Results Comparison

The defined risk assessment systems are capable of producing a vast array of information relating to the types of assessment required. This task determined how the results of each system would be used in order to make direct comparison of the systems.

Task 3. Define the Parameter Inputs

Standardised parameters were developed to ensure that the comparison between the system outputs is valid. In many cases the algorithms are based on similar theories, but require different parameters to achieve the same overall input. In these instances the parameters were isolated and given values to produce equivalent inputs. The final input data set ensures that potential output differences due to variations in inputs were minimised.

Task 4. Undertake Model Simulations and Review Results

Each selected source-pathway-receptor linkage was assessed using all of the applicable defined systems. The output was collated and compared and differences explained in terms of the variations that exist in modelling approach, hard-wired parameters and differences in algorithm interpretation.

Task 5. Undertake Sensitivity Analysis and Review Results

The sensitivity of key input parameters was tested and the variation in the output was compared to the variation in the inputs. The results of the testing were compiled and comparisons made in the light of the findings of the original model simulations.

6.1. GTS Conceptual Site Model

The Conceptual Site Model for the GTS is a series of source-pathway-receptor linkages that provide effective and reasonable comparison between output results.

6.1.1. Sources

The GTS data set considers three sources:

- **Shallow Soil,** *e.g.* leak from an above ground storage tank;
- **Deep Soil**, *e.g.* from buried waste or leaking underground storage;
- **Groundwater,** *e.g.* as a result of landfill leachate.

In order to assess potential risks posed by the sources, contaminants of concern must be defined and characterised. Contaminants potentially present in a source can be broadly split into two categories:

1. Threshold contaminants (*e.g.* non-carcinogens) – there is a limit below which negative health effects are not likely to occur.

2. Non-threshold contaminants (*e.g.* carcinogens) - there is no theoretical reason why a single molecular exposure should not result in a tumour or mutation.

With consideration of the above factors in mind, and the practical requirement to include substances that could be considered common soil and groundwater contaminants on a contaminated land site, the following contaminants of concern were selected:

1. Atrazine
2. Benzene
3. Benzo(a)pyrene
4. Cadmium
5. Trichloroethene

6.1.2. Pathways

The pathway in a source-pathway-receptor linkage is the means by which the impact characterised at the source affects the defined receptor. A distinction is made between direct and indirect pathways. The former is a pathway that occurs direct from source to receptor and includes such pathways as ingestion and dermal contact. The latter, indirect pathways, require some form of transport to occur from the source to the receptor point before exposure can occur, for example volatilisation and vapour transport are required before a receptor can inhale the vapours. Therefore indoor air inhalation is considered an indirect pathway.

6.1.3. Receptors

The focus of the study was human health risk assessment and therefore the receptors included in the study are human health receptors only. Human health receptors are often differentiated only as far as being either an adult or a child receptor. Further refinement of this can involve consideration of whether the receptor is exposed under a residential or industrial scenario, specific age groups or include consideration of target organs in the body, which are more or less affected depending on the type of contaminant of concern.

6.1.4. Linkages in the GTS

It was not the intention of the study to develop a conceptual site model (CSM) that reflected a potentially real situation, as this approach would have omitted several key pathways. Instead, the CSM comprises a series of individual source-pathway-receptor linkages.

Figure 2 illustrates the range of receptor point concentrations, dose concentrations and quantified risk levels that have been developed through the study. Figures 3a and b are schematic representations (in cross-section) of the linkages included in the GTS.

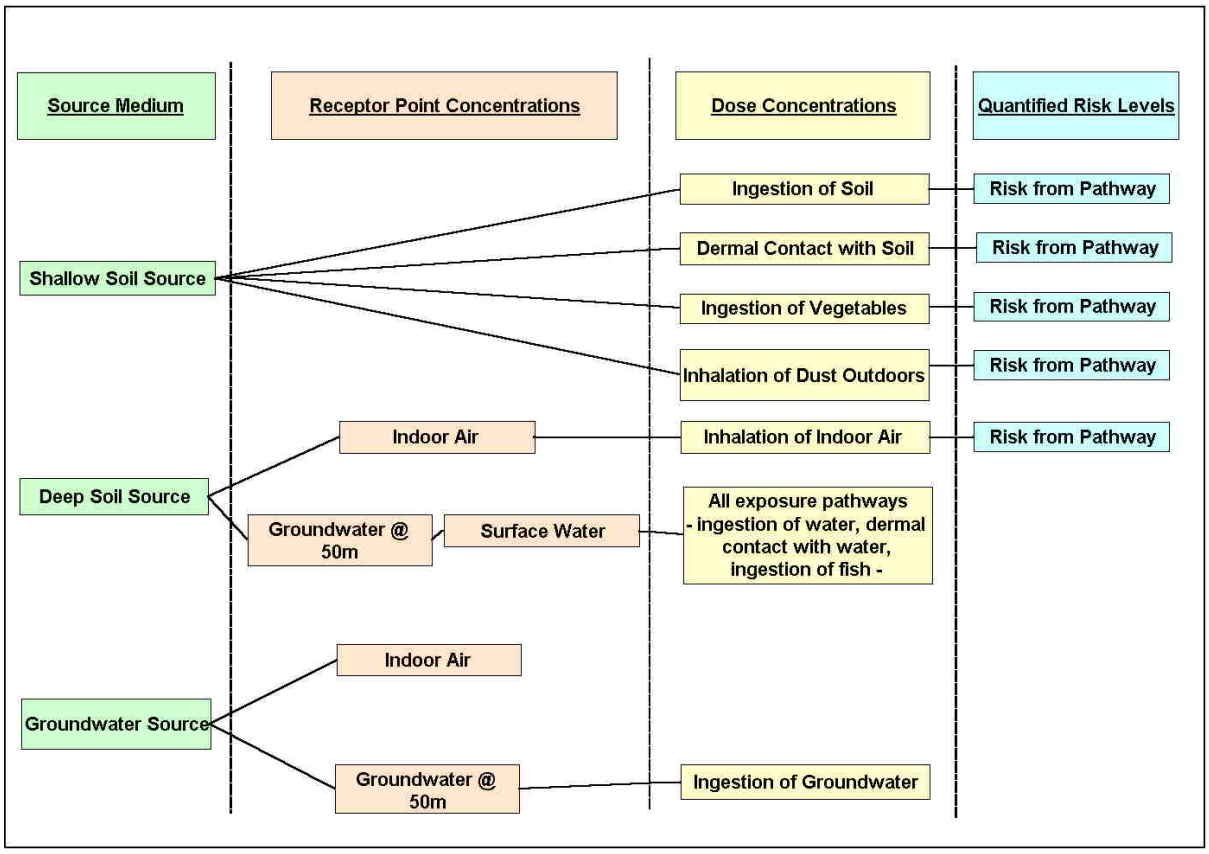

Figure 2. Source-Pathway-Receptor Linkages

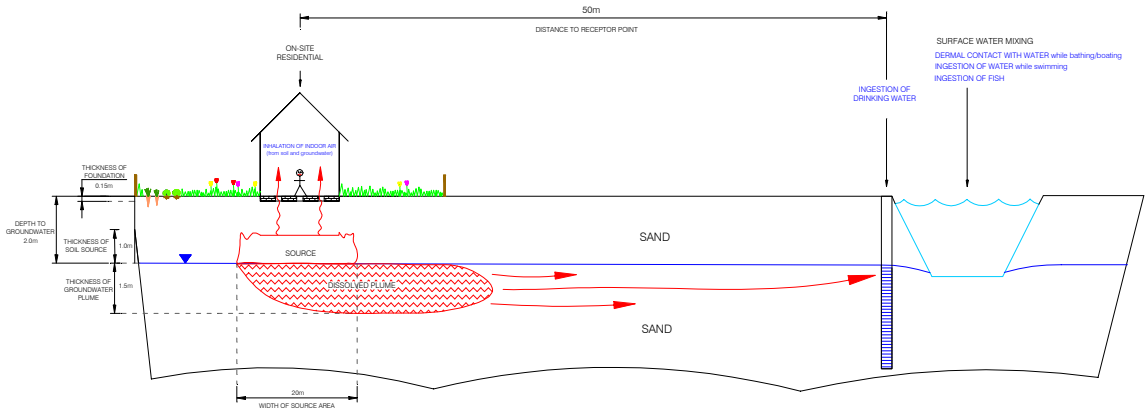

Figure 3a. Generic conceptual model for a deep soil source.

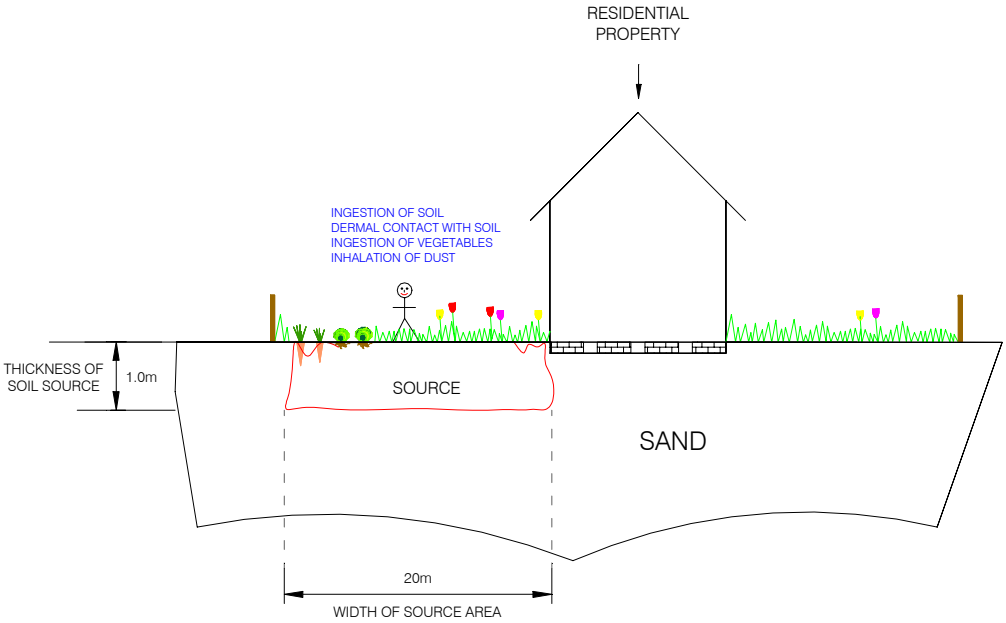

Figure 3b. Generic conceptual model for a shallow soil source.

6.2. Results Comparison Methodology

In order to allow efficient comparison of results between the systems, a consistent technical basis from which results can be generated and compared was produced. Output was generated at three distinct levels for comparison in this study:

- Receptor Point Concentrations;
- Dose Concentrations; and
- Quantified Risk Levels.

6.2.1. Receptor Point Concentration Comparisons

Fate and transport models are included in a number of the risk assessment systems to quantify the environmental pathway and generate Receptor Point Concentrations. The models fall into three types:

1. Vapour intrusion models - Receptor point concentrations have been derived in indoor air spaces from the Deep Soil and Groundwater sources into residential properties.

2. Groundwater fate and transport models - Receptor point concentrations have been derived at hypothetical groundwater monitoring wells at a distance of 50m from the site from the Deep Soil and Groundwater sources.

3. Surface water mixing models - Receptor point concentrations have been derived for a hypothetical surface water receptor at 50m from the site that includes the effects of dilution and mixing in the surface watercourse. This fate and transport model is used in conjunction with the deep soil to groundwater model.

In total there are 5 output data sets for comparison at the ***Receptor Point Concentration*** level.

6.2.2. Dose Concentration Comparisons

The calculation of dose concentrations requires an input source concentration. The following exposure scenarios were included in the GTS:

1. Direct Exposure Pathways from Shallow Soil
   The direct exposure pathways include ingestion of impacted soil, dermal contact with impacted soil, ingestion of vegetables grown in impacted soil and inhalation of dust generated from impacted soil.

2. Indirect Exposure Pathways from Deep Soil
   The indirect exposure pathways were derived from receptor point concentrations using the Deep Soil source, and include inhalation of vapours in an on-site indoor air space. Also included were the exposure pathways associated with surface water receptors, for example dermal contact through bathing.

3. Indirect Exposure Pathways from Groundwater
   The indirect exposure pathways use receptor point concentrations derived using the Groundwater source and include ingestion of groundwater at a point 50m from the site.

Therefore the GTS resulted in 7 output data sets for comparison at the ***Dose Concentration*** level and included exposure models both with and without modelled source concentrations.

The adult receptor was selected in preference to the child receptor, as it is more uniformly defined between the systems, therefore the results are subject to less differences due to hard-wired parameters. A full discussion of the selection process is given in the main Technical Report.

6.2.3. Quantified Risk Level Comparisons

Where an exposure pathway is assessed to provide a dose, it is logical to compare this dose with some form of acceptable dose to determine if a risk is presented. This is a difficult aspect to compare between the systems as the differences between the models often reflect differences in national policy on assessment of health effects.

The main comparisons and conclusions with respect to the Quantified Risk Levels relate to what each of the individual systems do, *i.e.* what are their capabilities and what are the characteristics of the outputs produced?

The Quantified Risk Level comparisons focussed on the following:

- Output presentation
- Approach to Averaging Times
- Approach to Toxicity

6.2.4. Sensitivity Testing

To test the sensitivity of the systems to variations in parameter changes away from the GTS dataset, the array of input parameters were divided into four categories:

Physical Input Parameters
The key input variable that affects the calculation of receptor point concentrations were modified to ascertain the variation in the results compared to the GTS results. Parameter changes only affect

those models used for calculating indoor air concentrations and groundwater concentrations. The following variables were included:

Indoor Air Concentrations:	Crack fraction; Pressure Difference; Building Height; Ventilation Rate.
Groundwater Concentrations:	Infiltration Rate; Groundwater Velocity; Degradation Rate.

Chemical Input Parameters

The GTS results were compared to the equivalent results where the chemical input parameters specified in the GTS were replaced by the default chemical input parameters presented in the systems. The specific pathways that this was carried out for are as follows:

- The receptor point concentrations for Benzene for the "Soil to Indoor Air" and "Soil to Groundwater at 50m" pathways;
- The dose concentrations for benzene and cadmium for the "dermal contact with soil" and "ingestion of vegetables" pathways.

Toxicological Input Parameters

The GTS results were compared to the equivalent results where the toxicological input parameters specified in the GTS were replaced by the default toxicological input parameters presented in the systems. The specific pathways that were tested are as follows:

- All exposure pathways using benzene (non-threshold substance);
- All exposure pathways using TCE (threshold substance).

Exposure Input Parameters

The GTS results were compared to the equivalent results where the exposure factor input parameters specified in the GTS were replaced by the default exposure factor input parameters presented in the systems. The dose concentrations for benzene and TCE were tested for the following specific pathways:

- Ingestion of Soil;
- Inhalation of Indoor Air;
- Ingestion of Vegetables.

6.3. Input Parameters

6.3.1. Environmental Parameter Selection

Where fate and transport models are used, a range of parameters is required to describe the environment. These fall into the following categories:

- Source Dimensions;
- Unsaturated Zones Parameters;
- Saturated Zone Parameters;
- Building Parameters for Slab-on-grade House;
- Dust Parameters
- Receptor Point – Distance to monitoring wells;
- Surface Water – Properties of surface water receptor

6.3.2. Exposure Parameter Selection

A list of key exposure input parameters is presented in Table 3 below.

Table 3
Key Exposure Parameters for the Generic Test Site

	GTS VALUES			SYMBOL used in the considered software							
EXPSOSURE PARAMETERS	**ADULT**	**CHILD**	**UNIT**	**CLEA**	**RBCA Toolkit**	**RISC**	**Risc-Human**	**ROME**	**SFT 99:06**	**UMS**	**Vlier-Humaan**
Body weight	70	20	kg	BW	BW	BW	Wa/c	BW	KV	BW	W
Lifetime (≡averaging time for carcinogens)	70	70	years		Atc	LT		AT		*	
Averaging time for non carcinogens	30	5	years	AT^{NB}	Atn			AT		*	
Exposure duration	30	5	years	ED^{NB}	ED	ED	lfta/lftc	ED	*	*	*
INGESTION OF SOIL											
Exposure frequency soil ingestion	180	180	days/year	EF_{oral}	EF	EF	Tdoa/c	EF	f_{exping}	EFR	Calculated
Ingestion rate of soil	30	150	mg/day	SDR	Irs	IR	Ida/c	IR	DI_{is}	IR_s	AID
DERMAL CONTACT WITH SOIL											
Exposure frequency dermal contact	180	180	days/year	EF_{dermal}	EF_D			EF	f_{expder}	EFR	
Exposure time	2	2	hours/day	t_{event}			Tdoa/c			*	Noc/a
Skin surface area	18,400	6,800	cm^2	A_{skin}	SA	SA	Aexpa/co	SA		SS	Aexpoad/c
Fraction skin exposed	0.2065	0.5882	-			*		F_S			
Soil to skin adherence factor	0.2	0.2	mg/cm^2	AF	M	AF	DAEa/c	SL		F_{sc}	DAE
INGESTION OF DRINKING WATER											
Average daily intake of drinking water	2	2	l/day		IRw	IR_{iw}			DI_{iw}		
Exposure frequency drinking water	350	350	days/year		EF	EF			$f_{expwater}$		
INHALATION OF INDOOR AIR											
Exposure frequency in indoor air	350	350	events/year		EF	EF	Tdia/c	EF	$f_{expdust}$ $f_{expsoil}$	EFR	Nic/a
Inhalation rate indoors	0.83	0.	m^3/hour			InhR	Ava/c	Bi	PH_{IA}	IR_{Atem}	Va
Time indoors	16	16	hours/day			ET	Tdia/c	*		*	
Lung retention factor	0.75	0.75	-			LRF					
INHALATION OF DUST (OUTDOORS)											
Exposure time	2	2	hours/day	RV			Tdoa/c	*		*	Noc/a
Dust inhalation rate outdoors	2	0.7	m^3/hour	(EF_{inh} , *)				Bo	PH_{OD}	IR_{Atem}	
Lung retention factor	0.75	0.75	-				fr		LR	RetF	frc
INGESTION OF VEGETABLES											
Average daily ingestion of vegetables	0.475	0.23	kg/day	CR		$IR_{vr/va}$	Qvl/va a/c		DI_{ig}	IR_v	Qfv
Exposure frequency for ingestion of vegetables	350	350	days/year	EF_{oral}		EF			f_{expveg}	*	
Fraction split of vegetables consumed	50:50	50:50	-				Fl/Ft a/c		f_{leaf}:f_{stem}	*	fl/r
Fraction of consumed veg. grown in contaminated soil	0.1	0.1	-	HF		FI			f_h	EA_v	ffv
INGESTION OF FISH											
Daily consumption of fish	0.055	0.015	kg/day		IR_{fish}				DI_{if}		
Exposure frequency for consumption of fish	350	350	days/year						$f_{expfish}$		
Fraction of consumed fish from contaminated water	0.5	0.5	-		FI_{fish}				f_f		
SURFACE WATER EXPOSURE											
Swimming exposure time	2	3	hours/event		Etswim	ET					
Swimming frequency	30	30	events/year		Evswim	EF					
Ingestion of surface water	0.05	0.5	L/day		IR_{swim}	IR					
Skin surface area for swimming	18,400	6,800	cm^2		Saswim	SA					

Notes:

NB ‘Age classes’ used in CLEA; lifetime of 70 years, but not used for averaging; ‘adult’ 16-59 years of age (class 17); ‘child’ 0-6 years of age (class 1-6)

Parameter not required within model, or not required within model for pathways assessed

* Parameter has no symbol

6.3.3. Toxicity

A listing of the toxicological properties for each contaminant is presented in Table 4. A discussion of how the calculations for non-threshold and threshold risk levels are approached is given in the main Technical Report.

Table 4
Toxicological Properties

	UNIT	Atrazine	Benzene	Benzo(a)pyrene	Cadmium	TCE
THRESHOLD PROPERTIES						
Toxic Reference Dose Oral/Dermal	mg/kg-day	0.035	-	-	0.001	0.006
Toxic Reference Dose Inhalation	mg/kg-day	0.035	-	-	0.001	0.006
Toxic Inhalation Concentration	mg/m^3	0.123	-	-	$3.5x10^{-3}$	0.021
NON-THRESHOLD PROPERTIES						
Oral/Dermal Slope Factor	$\frac{1}{(mg/kgday)}$	-	0.029	7.3	-	-
Inhalation Slope Factor	$\frac{1}{(mg/kgday)}$	-	0.029	6.1	-	-
Carcinogenic Reference Dose Oral/Dermal	mg/kg-day	-	$3.45x10^{-4}$	$1.37x10^{-6}$	-	-
Carcinogenic Reference Dose Inhalation	mg/kg-day	-	$3.45\ x10^{-4}$	$1.64\ x10^{-6}$	-	-
Carcinogenic Inhalation Concentration	mg/m^3	-	$1.21\ x10^{-3}$	$5.74\ x10^{-6}$	-	-
Carcinogenic Inhalation Unit Risk Factor	$\frac{1}{(\mu g/m^3)}$	-	$8.29\ x10^{-6}$	$1.74\ x10^{-3}$	-	-

Notes:
TCE Trichloroethene
- Data not required
The toxicity data is based on the defaults in the ROME software as initial software problems prevented data changes in this package.

7. OUTPUT AND RESULTS

Five key results datasets have been discussed within this executive summary. These include dose concentrations from the ingestion of soil; dermal contact with soil; and ingestion of vegetables grown in contaminated soil; and receptor point concentrations for indoor air from a soil source and groundwater from a groundwater source. For more detailed discussions of the results and for the results from additional source-pathway-receptor linkages the reader is directed to the main Technical Report.

7.1. Soil Ingestion

Figure 4 presents the results of predicted doses for the soil ingestion pathway.

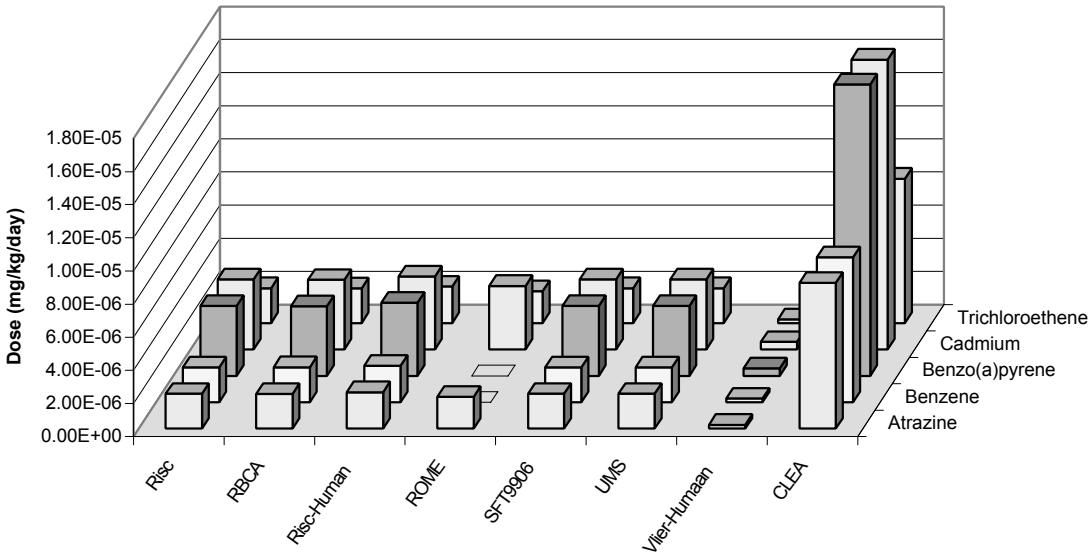

Figure 4. Model prediction of soil dose for contaminants in the GTS.

All the systems use very similar algorithms for the ingestion of soil pathway and consequently the predicted dose concentrations for the GTS testing are correspondingly similar. The key differences are as follows.

- *CLEA* predicts doses approximately four times greater than the other systems. This result is attributable to the hardwired default exposure parameters used in the current CLEA software that are different to the GTS parameter values.

- *Vlier-Humaan* predicts doses approximately ten times smaller than the other systems. This result is also attributable to hardwired default parameters in the software.

It should be noted that ROME does not present Dose Concentrations as results. The results presented in Figure 4 are calculated by hand, however this is only possible for threshold substances.

7.2. Dermal Contact

The results of this pathway assessment are presented on Figure 5. The systems evaluated produced a more varied response for this pathway assessment and can be divided into 3 groups based on the similarities and differences in underlying principles.

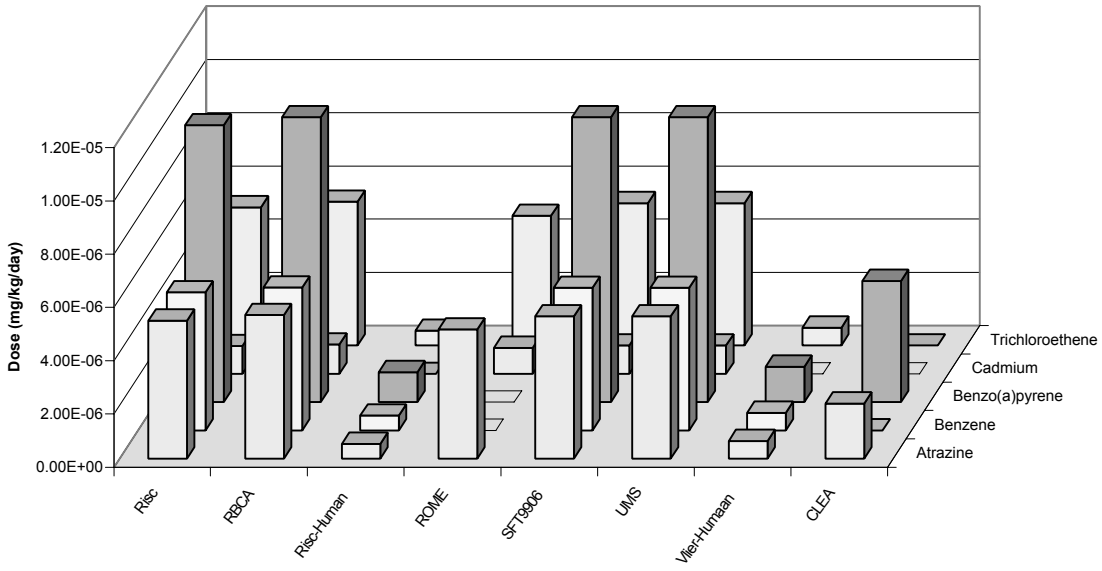

Figure 5. Model predictions for Dermal Contact.

Group I - RISC, RBCA, ROME, SFT and UMS
These systems contain algorithms based on the fraction of contamination absorbed through the skin, defined as 0.1 in the GTS. RISC and UMS include additional factors, which were set to unity in the GTS.

Group II - Risc-Human and Vlier-Humaan
These systems calculate dermal doses that are dependent on exposure time. The algorithms used are similar, however there are hard-wired parameters in Vlier-Humaan including the "adherence factor" and the "absorption rate".

Group III - CLEA
The dermal contact algorithm in CLEA is also absorption-rate dependent, but also includes a mass-balance to account for the variability in the volatility of different compounds. The doses for the most volatile compounds considered, *i.e.* benzene and trichloroethene, are orders of magnitude smaller than for the other systems, reflecting the fact that these compounds volatilise at a rate that results in a short residence time on the skin and therefore less absorption.

7.3. Ingestion of Vegetables

Dose concentrations for the "ingestion of vegetables" pathway are based on consideration of a two-step process: i) transfer of contaminants from the soil into the vegetables (root and stem) using a Bio-Concentration Factor (BCF); and ii) consumption of a specified proportion of contaminated vegetables. In the GTS dataset, the vegetables consumed were assumed to comprise 50% root vegetables and 50% stem/leaf vegetables. Figure 6 presents the predicted dose concentrations for this pathway.

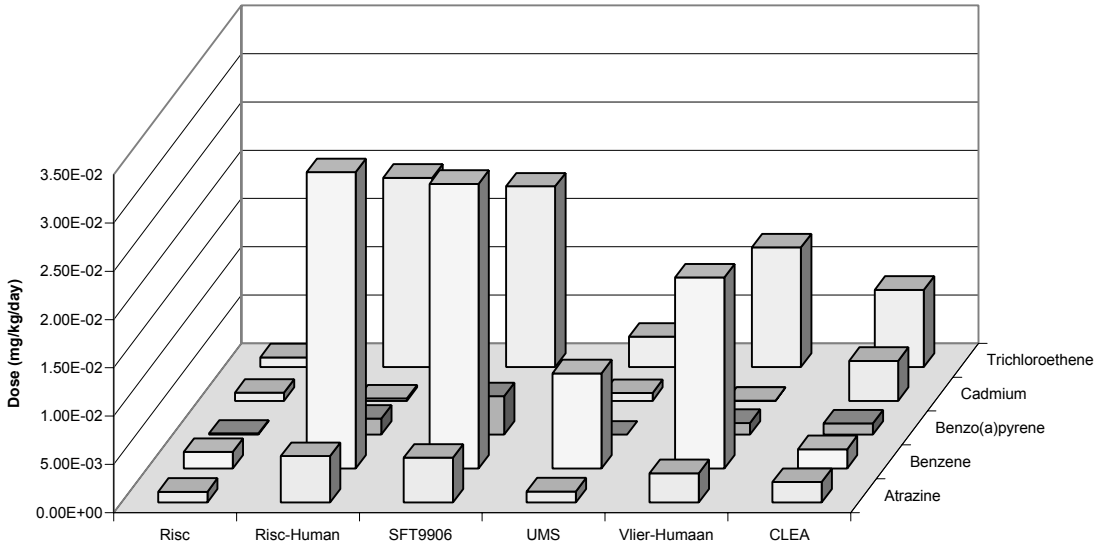

Figure 6. Model predictions for vegetable uptake pathway.

The algorithms to calculate BCFs and vegetable intake are generally similar, however, several differences relating to hard-wired parameters and additional correction factors were identified and are outlined below:

- RISC generally predicts lower doses compared with the other systems because the algorithm includes a BCF correction factor to account for structural differences between barley shoots (the test medium used in the source document) and those vegetables typically consumed in the home.

- UMS combines BCFs for root and stem vegetables into a single algorithm. There is an additional factor of 50% to account for vegetables prepared in the kitchen being washed prior to eating.

- Vlier-Humaan used a slightly higher F_{oc} value than the GTS due to the restricted allowable input range; has an additional factor included accounting for soil pH when calculating dose concentrations for metals; and has a hard-wired ingestion rate that is lower than the GTS dataset.

- CLEA splits vegetables into six groups, as opposed to two in the other systems. BCFs are defined in a similar way, however the factor to calculate porewater concentration is not allowed to exceed unity. This reduces the predicted benzene and trichloroethene doses in comparison to other systems. The cadmium BCFs for root and stem vegetables are hard-wired in CLEA at values higher than the GTS, explaining why the dose is higher than for the other systems. The ingestion rate and fraction of homegrown vegetables consumed are probabilistic parameters in CLEA, making direct comparison with the remaining systems difficult.

7.4. Receptor Point Concentration in Indoor Air from Impacted Soil

A wide range of results was found for this pathway, most notably the UMS system was found to predict a much greater indoor air concentration in comparison to the other indoor air models. UMS fixes the indoor air concentration at 1% of the predicted soil gas concentration. Indoor air concentrations (Receptor Point Concentrations) are presented on Figures 7a and 7b. The UMS results are excluded from the graphs below in order to accentuate remaining differences. Explanations of the key differences encountered are provided in the following text.

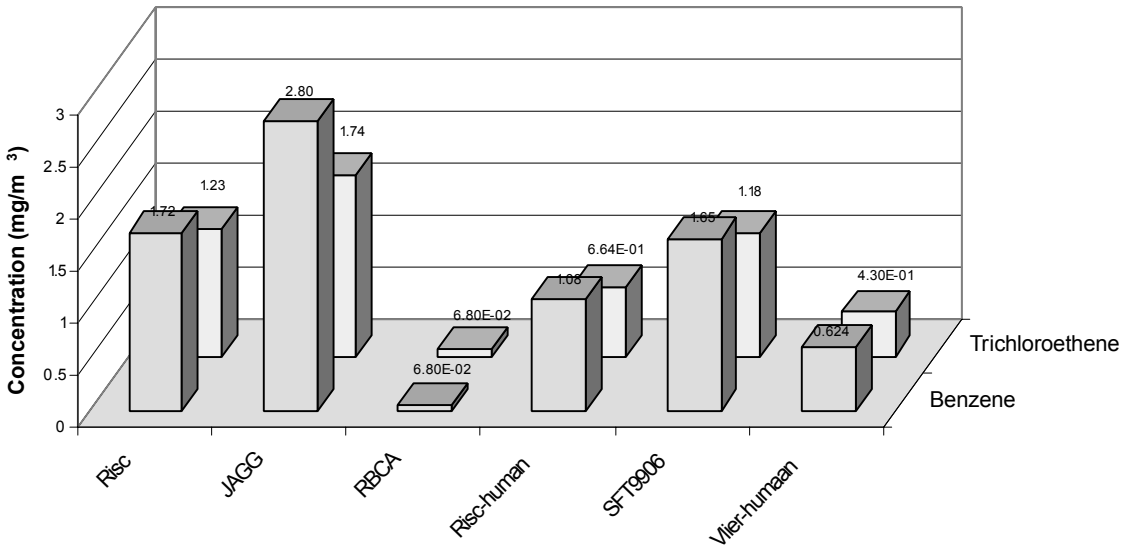

Figure 7a. Indoor air predictions for TCE and Benzene.

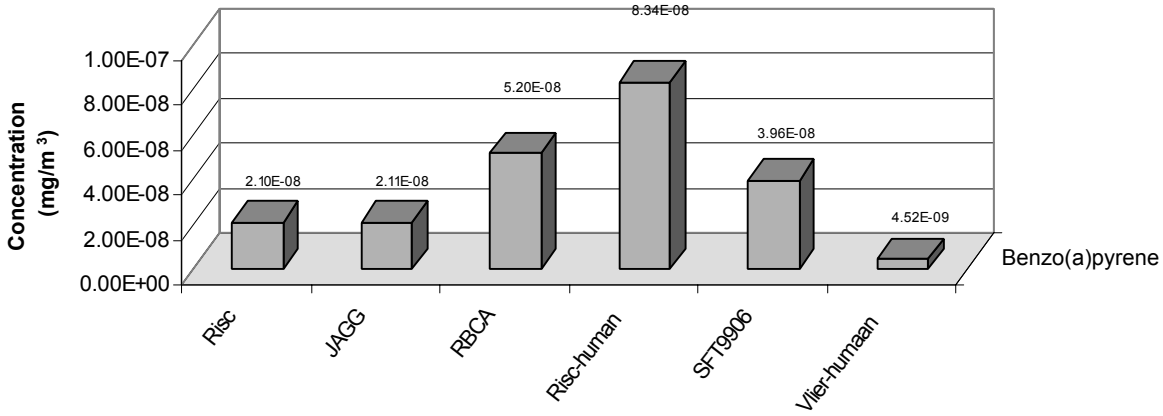

Figure 7b. Indoor air predictions for Benzo(a)pyrene.

In order to aid description, the systems have been divided into four groups based on the way in which this pathway is modelled.

Group I - RISC and RBCA

Both systems have indoor air models based on the Johnson and Ettinger algorithm for predicting vapour intrusion rates. However, RBCA incorporates two alternative expressions for the volatilisation factor from subsurface soils to enclosed spaces. The first algorithm models an infinite source and the second models a finite source assuming that volatilisation occurs at a constant rate over the defined exposure period. Only the first algorithm is incorporated into RISC. For the more volatile compounds, *i.e.* benzene and TCE, the finite source algorithm is adopted, leading to a difference between RBCA and RISC. For less volatile compounds, *e.g.* benzo(a)pyrene, RBCA adopts the infinite source algorithm, giving RBCA similar predicted indoor air concentrations to RISC.

Group II - Risc-Human and Vlier-Humaan

In Risc-Human and Vlier-Humaan the algorithms used to calculate soil air concentrations and flux to the house foundation are similar.

However, Risc-Human is not specifically designed to model a house without a basement or crawl space, which is the construction type modelled in the GTS scenario, this has been taken into account via modified input parameters in Risc-Human. Furthermore, when modelling the indoor air pathway Risc-Human automatically calculates both an indoor air concentration and an outdoor air concentration and adopts the maximum as the receptor point concentration. In GTS results, Risc-Human adopted the predicted outdoor air concentration for atrazine and benzo(a)pyrene, as a consequence these concentrations were not comparable between Risc-Human and the other systems, including Vlier-Humaan, which uses the predicted indoor air concentration for all compounds.

Minor differences also occur due to hardwiring in Vlier-Humaan, including F_{oc} and the depth to the soil source from the surface.

Group I vs. Group II

The major difference between the Group I and Group II systems is that Group I systems predict the indoor air concentration by modelling an intrusion rate through cracks in a concrete foundation for both diffusive and advective mechanisms (based on the Johnson and Ettinger algorithms) and Group II systems model an intrusion rate through pores in a concrete foundation for diffusion only (based on CSOIL algorithms).

Group III - SFT99:06

The Norwegian system applies a dilution factor to the pore air concentration to calculate the indoor air concentration. The user is required to input an intrusion rate of pore air into the building. This intrusion rate was taken to be the same as the intrusion rate calculated within the RISC software.

Group IV - JAGG

The JAGG system calculates air transport through cracks according to Baker, Sharples & Ward. Flow through a concrete deck is calculated by means of a “Cubic law”. This algorithm is significantly different to the Johnson and Ettinger algorithm and appears to give a more conservative prediction for volatile compounds whilst still giving results of the same order of magnitude. The JAGG system also includes a complex method for calculating the crack fraction, however the calculated crack fraction in JAGG was manipulated to equal the crack fraction for other systems.

7.4.1. Groundwater Concentrations at 50m from Groundwater Source

This comparison examines the maximum predicted groundwater concentrations at 50m as a result of the migration of an impacted groundwater source. The results of the modelling are presented as Figure 8.

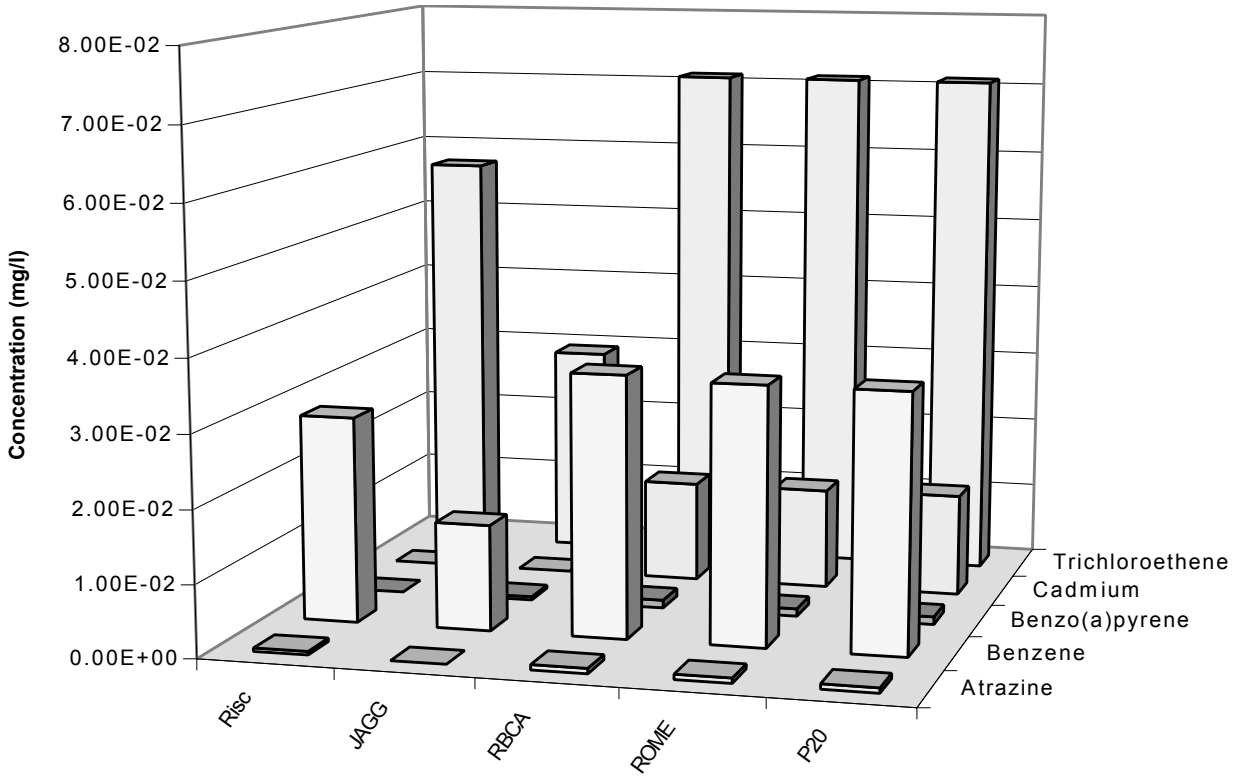

Figure 8. Predicted groundwater receptor point concentrations.

The key differences between the predicted receptor point concentrations are described below:

RBCA, P20 and ROME
These systems predicted receptor point concentrations that are in general agreement with each other. In each case, the algorithm modelling groundwater transport to a receptor point, which includes attenuation and dispersion in three dimensions, are similar. They all assume an infinite source and steady state conditions.

RISC
The predicted receptor point concentrations from RISC are lower than P20, RBCA and ROME, however the algorithm used to model contaminant fate and transport is identical. Two factors contribute to the production of lower receptor point concentrations: 1) specification of the hypothetical "receptor well" characteristics is an input variable in the RISC model. In the GTS testing the default values were used, however this leads to a dilution effect being included in the receptor point calculation (correcting for this accounts for approximately 50% of the difference between RISC and the other systems); and 2) the groundwater model in RISC is semi analytical being numerical in time and analytical in space. The solution of the algorithm is therefore different from the other models.

JAGG
The system does not allow the user to enter the distance to the receptor point. The concentration of contaminants is usually calculated for a point at a distance from the pollution source that corresponds to one year of groundwater flow, limited to a maximum of 100m. However, interim results are presented in the model for a range of distances, including 50m.

In a similar manner to which maximum groundwater concentrations can be predicted at 50m from a groundwater source, concentrations can be predicted as a result of leaching (via infiltration) of a soil source and subsequent groundwater migration. The latter scenario represents a more complex case and is included in the main Technical Report.

7.5. Phase III Risk Calculations

The different ways in which the systems report the risks makes it difficult to draw comparisons between the actual risk levels:

- RBCA, ROME and RISC derive a separate risk level for each of the individual pathways included for assessment.
- Risc-Human and Vlier-Humaan each report one risk level, based on all of the active pathways included for assessment.
- UMS reports three risk levels, one for ingestion, one for dermal contact and one for inhalation.
- CLEA presents one risk level for each model run; the user must select one intake pathway for the health criteria on which the risk level is based and separate models must be run if different health criteria are defined for each intake pathway.

The risk calculations can be split into two broad categories:

1) Threshold contaminants (*e.g.* non-carcinogens)
2) Non-threshold contaminants (*e.g.* carcinogens)

The differences in the ways in which threshold and non-threshold compounds are handled by the various systems are discussed in the main Technical Report.

The risk levels are highly dependent on the definition of health criteria (TDDs, slope factors etc), which is specific to the nation in which the software is being used, therefore it is not considered appropriate to draw any conclusions on differences in risk levels that are based on an “arbitrary” standardised set of health criteria.

7.6. Phase III Sensitivity Testing

It was not part of the scope of this project to undertake comprehensive sensitivity testing. However, a number of key parameters were selected to demonstrate the sensitivity of the systems to varying input parameters, and to highlight the influence of default parameters, such as exposure factors and chemical data.

To test the sensitivity of the systems, the input parameters were divided into four categories:

Physical Input Parameters:	Crack fraction (or concrete porosity)
	Pressure difference
	Building Height
	Ventilation Rate

	Infiltration Rate Groundwater Flow Velocity Degradation Rate
Chemical Input Parameters:	Variation from the GTS when using default Chemical Databases. • Dermal Contact Dose Concentrations • Ingestion of Vegetables Dose Concentrations • Indoor Air Receptor Point Concentrations • Groundwater Receptor Point Concentrations
Exposure Input Parameters:	Variation from the GTS when using default Exposure Databases • Ingestion of Soil • Inhalation of Indoor Air • Ingestion of vegetables
Toxicological Input Parameters:	Variation from GTS when using default Toxicological Databases • Dermal Contact with Soil • Ingestion of Soil • Ingestion of Vegetables • Inhalation of Outdoor Dust • Inhalation of Indoor Air from impacted Soil.

7.6.1. Sensitivity Testing Findings

A full discussion of the results is presented in the main Technical Report, however a brief description of the findings is presented here.

Physical Parameters

The testing generally proved that the systems are consistently sensitive to variations in selected parameters. The most interesting finding occurred when examining the effects of changing the groundwater velocity in the soil to groundwater migration models. The testing highlighted that the linkage between the soil leaching term and the groundwater migration term can have a significant effect on the resultant receptor point concentrations.

Chemical, Exposure and Toxicological Defaults

Testing of these parameter changes highlighted the need to understand the source of data input to any risk assessment system as the results indicated that major changes in receptor point concentrations and dose concentrations are produced when defaults are relied upon. Risk levels were also developed for this component of the project. The levels were derived based on the default toxicity data within each model. In practice this data is highly country specific, and therefore system specific, often being built into regulatory guidance, these defaults would not ordinarily be changed.

8. PHASE IV - SUMMARY OF CASE STUDY ASSESSMENT

Phase IV of this Risk Comparisons Study comprises the use of real site data to produce outputs for comparison. The sponsors of the project provided the information for five Case Study Test Sites. Each site was reviewed and the likely critical pathways for assessment were defined. The risk assessments carried out were not intended to be assessments for any likely legal purpose, moreover the intention was to explore the findings of the Phase III testing by isolating specific linkages.

8.1. Test Site 1

Site Description	**Former Lube Oil Blending Plant**	
Characteristics	Geology	Sand with localised silts and clays overlying gravelly sand, overlying clay with sand layers.
	Groundwater	12 to 15m below ground level.
Conceptual Site Model		
Sources	Contaminants of Concern	Tetrachloroethene
		Trichloroethene
		Cis-1,2 Dichloroethene
		Vinyl Chloride
	Impacted Medium	Groundwater
Pathways	Groundwater Migration	
	Volatilisation to Indoor Air	
Receptors	Groundwater Quality @ 57.5m	
	Groundwater Quality @ 120m	
	Groundwater Quality @ 600m (canal)	
	Indoor air @ 57.5m	
	Residential (Child and Adult)	
Models	JAGG	
	P20-RTW	
	RBCA	
	RISC	
	ROME	
Model Input Data	Hydraulic Conductivity	40 m/day (site data)
	Hydraulic Gradient	0.009 (site data)
	Effective Porosity	0.2 (site data)
	Chemical Properties	Default databases
	Toxicological Properties	Default databases
	Exposure Factors	Default databases
Model Output Data	Groundwater Receptor Point Concentrations – All models	
	- Comparison of predicted concentrations with measured concentrations	
	Indoor Air Receptor Point Concentrations – RISC only	
	Indoor Air Dose Concentrations – RISC only	

8.1.1. Summary of Results

Comparison of the predicted groundwater receptor point concentrations showed that the models produce similar results at all three receptor points. The closer the receptor point the greater the correlation between systems. The models predicted receptor point concentrations that were in reasonable agreement with the measured concentrations however the models tend to over estimate the concentrations that have been measured and the over-estimation effect increases with distance from the source.

Only RISC is capable of predicting indoor air concentrations from a distant groundwater impact originating from the site.

8.2. Test Site 2

Site Description	**Former Gas Works**	
Characteristics	Site Status	Residential property (with assumed vegetable ingestion)
	Geology	Sandy soils
	Groundwater	Minor Aquifer (not assessed)
Conceptual Site Model		
Sources	Contaminants of Concern	Benzo(a)pyrene
		Cadmium
		Free Cyanide
		Naphthalene
	Impacted Medium	Shallow soils
Pathways	Direct ingestion of soil	
	Dermal contact with soil	
	Ingestion of vegetables grown on-site	
Receptors	Residential – Adult only	
Models	CLEA	
	RBCA	
	RISC	
	Risc-Human	
	SFT99:06	
	UMS	
	Vlier-Humaan	
Model Input Data	Contaminant Concentrations	Site data
	Air and Water content - Vadose Zone	Site data
	Porosity, F_{oc}, bulk density	Literature based, from site data
	pH	7.75 (site data)
	Chemical Properties	Default databases
	Toxicological Properties	Default databases
	Exposure Factors	Default databases
Model Output Data	Soil ingestion dose concentrations	
	Dermal contact dose concentrations	
	Ingestion of vegetables dose concentrations	

8.2.1. Summary of Results

Comparison of the ingestion of soil and dermal contact results indicates that the systems predict a similar pattern for each contaminant for this pathway with results varying by less than an order of magnitude in all cases. The variations seen are largely attributable to differences in the definition of exposure factors between the systems, with differences in chemical databases also influencing the dermal contact results. The main findings of note, outside of differences in default databases, are: 1) Cadmium is not considered to be a contaminant of concern for dermal contact pathways in RBCA, Risc-Human, UMS, Vlier-Humaan and CLEA; 2) the difference in averaging times used in the assessment of benzo(a)pyrene (non-threshold substance).

Differences in dose concentrations for vegetable ingestion could be largely attributable to the differing mechanisms of assessment used in the systems, however no single model repeatedly predicted the maximum or minimum result, indicating that defaults are very influential in the results.

8.3. Test Site 3

Site Description	**Former Fly Ash Landfill**	
Characteristics	Site Status	Agricultural Land (residential redevelopment)
	Geology	Pulverised Fuel Ash (PFA), overlying river terrace sands and gravels, overlying mudstone.
	Groundwater	Minor Aquifer (not assessed)
Conceptual Site Model		
Sources	Contaminants of Concern	Arsenic
		Cadmium
		Chromium VI
	Impacted Medium	Shallow Soils
Pathways	Direct ingestion of soil	
	Dermal contact with soil	
	Ingestion of vegetables grown on-site	
	Inhalation of dust	
Receptors	Residential (Child and Adult)	
Models	CLEA	
	RBCA	
	RISC	
	Risc-Human	
	SFT99:06	
	UMS	
	Vlier-Humaan	
Model Input Data	Contaminant Concentrations	Site data
	Air and Water content - Vadose Zone	Site data
	Porosity, F_{oc}, bulk density	Literature based, from site data
	pH	8.99 (site data)
	Chemical Properties	Default databases
	Toxicological Properties	Default databases
	Exposure Factors	Default databases
Model Output Data	Soil ingestion dose concentrations	
	Dermal contact dose concentrations	
	Ingestion of vegetables dose concentrations	
	Inhalation of dust dose concentrations	

8.3.1. Summary of Results

All of the contaminants of concern can be treated as threshold and non-threshold substances. Doses have been converted where necessary to allow presentation of comparable results.

For the ingestion of soil pathway and the inhalation of dust pathway, the differences between the dose concentrations is relatively small and are attributable to differences in exposure factors. The results of dermal contact pathway are more diverse but are explained by differences in the chemical databases as well as differences in exposure factors.

The differences in vegetable ingestion dose concentrations are relatively greater, however they are mainly attributable to different exposure factors used in the assessment of the pathway.

8.4. Test Site 4

Site Description	**Active Agrochemicals Manufacturing Plant**	
Characteristics	Geology	Approximately 9.0m of sand, underlain by a 1.0m layer of loam, underlain by an unspecified thickness of gravel.
	Groundwater	Approximately 9.0m bgl.
Conceptual Site Model		
Sources	Contaminants of Concern	Tetrachloroethene (PCE)
		Trichloroethene (TCE)
		Lindane
	Impacted Medium	Deep and shallow impacted soils
Pathways	Volatilisation of deep soil to indoor air	
	Inhalation of indoor air	
	Incidental ingestion of shallow soils	
	Incidental dermal contact with shallow soils	
Receptors	On-site Commercial Worker	
Models	JAGG (indoor air concentrations only)	
	RBCA	
	RISC	
	Risc-Human	
	SFT99:06	
	UMS	
	Vlier-Humaan	
Model Input Data	Building Properties	Estimates
	Porosity, F_{oc}, bulk density, pH	Literature based, from site data
	Permeability properties	Literature based, from site data
	Depth to deep soil source	1.5m bgl (site data)
	Chemical Properties	Default databases
	Toxicological Properties	Default databases
	Exposure Factors	Default databases
Model Output Data	Indoor Air Receptor Point Concentrations	
	Indoor Air Dose Concentrations	
	Soil ingestion dose concentrations	
	Dermal contact dose concentrations	

8.4.1. Summary of Results

The predicted indoor air concentrations show a similar trend to that encountered during the Phase III GTS testing with UMS predicting the highest concentrations because of the 1% transfer factor and RBCA producing lower concentrations for volatile compounds because of the different VF_{sesp} algorithm used. RBCA, RISC and Risc-Human predict results that are more similar for Lindane, than for TCE and PCE. This finding is explained by similarities and differences in the chemical properties of Lindane, TCE and PCE between models. Model defaults were generally retained for chemical properties, however, as a less common contaminant Lindane was not present in all of the databases. Vlier-Humaan predicts lower concentrations than Risc-Human, explained by the results of the GTS and difference in the definition of hardwired building parameters in Vlier-Humaan.

Dose concentrations for indoor air mirror the receptor point concentrations, whereas for the ingestion and dermal contact pathways differences are attributable to default exposure and chemical databases.

8.5. Test Site 5

Site Description	**Former Petrol Filling Station**	
Characteristics	Site Status	Active machine workshop
	Geology	Clays and silts (up to 1.0m thick) underlain by lacustrine sand and gravel down to 6.0m bgl underlain by London Clay.
	Groundwater	Approximately 0.75m bgl
Conceptual Site Model		
Sources	Contaminants of Concern	Benzene
		Toluene
		MTBE
	Impacted Medium	Groundwater
Pathways	Volatilisation to Indoor Air	
	Inhalation of Indoor Air	
Receptors	Industrial operatives of the site	
Models	RBCA	
	RISC	
	Risc-Human	
	Vlier-Humaan	
Model Input Data	Building Properties	Site data
	Permeability parameters	Literature based, from site data
	Chemical Properties	Default databases
	Toxicological Properties	Default databases
	Exposure Factors	Default databases
Model Output Data	Indoor Air Receptor Point Concentrations	
	- Comparison of predicted concentrations with measured concentrations	
	Indoor Air Dose Concentrations	

8.5.1. Summary of Results

As expected from the GTS testing, RBCA and RISC produce similar results and Risc-Human and Vlier-Humaan produce similar results. However, RISC and RBCA produce receptor point concentrations at levels lower than Risc-Human and Vlier-Humaan, which is not in agreement with the GTS results. Based on the GTS results RBCA would predict lower concentrations than RISC, Risc-Human and Vlier-Humaan, This is because of the different volatilisation factor used for volatile compounds. RISC would be expected to produce higher concentrations than Risc-Human and Vlier-Humaan, however for a groundwater source the RISC model does not include a pressure difference between the building and the soil gas, hence the predicted concentrations from RISC are also lower than Risc-Human and Vlier-Humaan and comparable to those from RBCA.

Comparison of the predicted indoor air concentrations with the available measured indoor air concentrations indicated that each system over-estimated the concentrations, however each system also predicts concentrations within an order of magnitude of the measured concentrations.

The differences between the predicted dose concentrations are dominated by the results of the receptor point concentrations to the point that any differences potentially attributable to differing exposure or chemical factors are masked.

9. CONCLUSIONS

The comparison study has evaluated the risk assessment systems widely used across European countries, culminating in the testing of individual models with defined datasets. In order to maximise the understanding of the models, the examination focused on the use of default parameters, the role of individual algorithms to simulate environmental fate and transport, the methodology of calculating doses and the calculations of risk. Comparisons of output were made for Receptor Point Concentrations, Dose Concentrations and Quantified Risk Levels.

Outlined below are the conclusions of the testing carried out for Phase III – Generic Test Site and Phase IV – Case Study Test Sites.

Generic Test Site – General Conclusions

- When input data were standardised, the models give generally similar Receptor Point Concentrations and Dose Concentrations.
- The methods for assessment of risk for non-threshold (*e.g.* carcinogenic) contaminants are different between the models.
- The models do not produce Quantified Risk Level output in a comparable format.

Generic Test Site – Pathway Specific Conclusions

- Soil ingestion algorithms are all similar, in many cases identical. The predicted soil ingestion doses are correspondingly similar.
- Vegetable ingestion doses are relatively uniform, with results generally within one order of magnitude.
- Dermal contact doses are more variable, being distributed over two orders of magnitude.
- Indoor air models produce the greatest variation, with predicted doses varying over 3 orders of magnitude.
- Groundwater migration models produced generally similar results

Generic Test Site – Sensitivity Analysis Conclusions

The overall conclusion of this process is that the default datasets vary significantly and consequently the results of the modelling processes varied significantly. It should be noted that the default values specified in some of the risk assessment systems are national standards or guidelines and therefore would not be changed when undertaking risk assessment in that country. Care should always be taken in using defaults.

Test Sites

- Use of model default exposure parameters leads to large differences in doses even for those pathways, such as soil ingestion, that produced similar results in the GTS. This demonstrates that the reliance on default data where parameters are unknown can produce a varied response, thereby potentially producing highly variable conclusions in a site's risk

management.

- At Test Site 1, down gradient groundwater concentrations had been monitored and were compared to predicted groundwater concentrations. It was concluded that in this single trial, the groundwater fate and transport predictions produced similar concentrations between the models, and were in reasonable agreement with available site data.

- At Test Site 5, indoor ambient air monitoring had been carried out as part of the original site assessment. Comparison was made between the predicted indoor air concentrations and the measured indoor air concentrations. The models overestimated the measured concentrations but were in reasonable agreement with available site data.

10. REFERENCES

American Society for Testing and Materials (ASTM), 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM E 1739-95).

Environment Agency, 1999. Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources. (Marsland, P.A., and Carey, M.A.) Environment Agency R&D Publication P20.

Environment Agency, (in press). Methodology for Comparison of CLEA with other human health risk assessment packages. Environment Agency NGWCLC Report NC/06/07. LQM Press.

Evans, D., Hers, I., Wolters, R.M., Boddington, R.T.B., Hall, D.H., 2002. Vapour Transport of Soil Contaminants. Environment Agency and Institute of Petroleum Research and Development Technical Report P5-018/TR.

Ferguson, C., Darmendrail, D., Freier, K., Jensein, B.K., Jensen, J., Kasamas, H., Urzelai, A., and Vegter, J. (editors), 1998. Risk Assessment for Contaminated Sites in Europe. Volume 1: Scientific Basis. LQM Press, Nottingham.

Ferguson, C.C., and Kasamas, H. (editors), 1999. Risk Assessment for Contaminated Sites in Europe. Volume 2: Policy Frameworks. LQM Press, Nottingham.

Howard, P.H., Boethling, R.S., Jarvis, W.F. Meylan, W.M., Michalenko, E.M., 1991. Handbook of Environmental Degradation Rates, Lewis Publishers Inc. Chelsea. MI.

Marsland, P.A., Carey, M.A., 1999. Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources. Environment Agency R&D Publication P20.

Spence L & BP Oil, 2001. Risk-Integrated Software for Clean-ups, RISC User's Manual - Version 4.0.

Swartjes, F.A., 2002. Human exposure model comparison study: State of play. Presentation Paper

VROM, 2000. Circular on Target Values and Intervention Values for Soil Remediation. (Dutch) Ministry for Housing, Spatial Planning and Environment.

Whittaker, J.J., Buss, S.R., Herbert, A.W. & Fermor, M., 2001. Benchmarking and Guidance on the Comparison of Selected Groundwater Risk Assessment Models. Environment Agency NGWCLC Report NC/00/14.

Zalaski, R., Gephart, L., 1999. NICOLE Exposure Factors Sourcebook for European Populations, with focus on UK Data.

Rikken, M.G.J., Lijzen, J.P.A., Cornelese, A.A., 2001. Evaluation of Model Concepts on Human Exposure. (Netherlands) National Institute of Public Health and the Environment (RIVM-Report 711701 022).