



ROME REASONABLE MAXIMUM EXPOSURE

Version 2.1

OPERATING MANUAL

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The ROME V. 2.1 software was designed by Environ Italy srl on appointment by ANPA. The project was headed by Dr. Fabio Colombo for Environ Italy srl and by Dr. Francesca Quercia for ANPA.

1. INTRODUCTION

1.1 Software Application Area

Rome V. 2.1, with the aid of this manual, is a software tool for analyzing risk and for assessing cleanup targets at contaminated sites. The software also provides options for risk management and suggests possible cleanup solutions.

The system employed to implement this software is compliant with current Italian regulations (D.M. 471/99), and applies internationally accepted principles and methods, in particular the Risk Based Corrective Action (RBCA) Procedure that was set as a standard by ASTM in 1995 and in 1998. The same principles and methods are also set out in the Unichim Manual published in the year 2002.

The first step in this system involves a table-based comparison between the contaminant concentrations observed on the site and the Limit Concentrations (LC) provided in Annex 1 of the D.M. 471/99. In addition, a further table-based comparison is also possible using generic risk-based screening values for soils that were derived within an ANPA project that utilises a Level 1 ASTM RBCA Procedure. The comparative analysis with LCs has legal merit in Italy, see Annex 1 of the D.M. 471/99, whereas the comparison with the generic risk-based screening values has no legal standing, but is similar to other approaches for risk assessment of contaminated sites currently adopted at international level.

The second step involves the assessment of site-specific risks and cleanup targets, in terms of acceptable residual contamination, applying Level 2 of the Procedure, in compliance with Level 1.

The risk analysis system thereby assesses risks to human health and to water-resources resulting from contamination conditions on the site. Risks to water-resources, for regulated substances, are assessed in terms of compliance with currently applied quality standards.

The main text of this manual describes the operating procedures that must be followed to use the software. Annexes and Appendixes to this Manual provide system references and the detail of calculation procedures. It is also suggested that the User reads the above-mentioned Unichim Manual.

1.2 Decision Making Process

The decision making process for the assessment of contaminated sites, as set out by ANPA, and of which ROME is the computerized version, complies to the D.M. 471/99 and comprises two parts:

- A table-based comparison with published values - Level 1 risk analysis;
- "Site-specific" risk assessment - Level 2 risk analysis.

A description of the two parts of the decision making process is provided below.

1.2.1 Table-Based Comparison

The first part of the assessment procedure for a contaminated site involves comparing the concentrations sampled at a site with the Limit Concentrations (LCs) listed in the D.M. 471/99.

For soil quality only, ROME also allows the user to compare measured concentrations with General Acceptable Limits (GALs). GALs are acceptable limits derived by applying a Level 1 risk analysis that is not site-specific. This involves the creation of a General Conceptual Model (GCM) that considers very strict exposure scenarios to determine a "Reasonable Worst Risk Case". Thus formulated, GALs are similar to "Risk-Based Screening Levels" (RBSLs) employed by the ASTM RBCA system, or to "Soil Screening Levels" (SSLs) used by USEPA.

The GCM and the calculation equations for GALs are provided in [Annex 1](#) and in [Appendix 1](#), respectively. (Note that, conforming with other international procedures, the calculation equations used to determine GALs are not modified in the "site-specific" Level 2 risk analysis). Upon completion of the Level 1 comparison, should the site concentrations be less than the LCs, both for soil and for groundwater, according to D.M. 471/99, the site is classified as "non contaminated", and no further investigation is required. On the other hand, should the site provide one or more contaminants with concentrations exceeding the LCs, there are two possible options available:

- Cleanup the site to re-establish it within the LCs levels;
- Perform a Level 2 risk analysis.

International systems allow users to choose between these two solutions at their discretion, on a case-by-case base, according to considerations based on costs and benefits. However, in Italy, in accordance with the requirements of the D.M. 471/99, the second option is possible only when remediation is incapable of restoring site concentrations to within the LCs *"notwithstanding the application, according to the principles of*

EC regulations, of the best available technologies at sustainable costs". Furthermore, a cleanup performed according to the latter must also include security measures.

1.2.2 Risk Analysis (Level 2)

Level 2 risk analysis is performed with the aim of estimating site-specific risks associated with the observed contamination status of the site, and/or estimating the concentration of "residual" contaminants that can persist on the site as an acceptable alternative to LCs. According to the terminology used in this document, these residual concentrations are defined as site Specific Acceptable Limits (SALs), and correspond to the "Site Specific Target Levels (SSTLs) employed in the ASTM-RBCA Procedure. The ROME risk analysis system complies with international procedures for risk analysis of contaminated sites that are set out in the following documents:

- "Risk Based Corrective Action Applied at Petroleum Release Sites", American Society for Testing and Materials, E1739-95, 1995;
- "Soil Screening Guidance: Technical Background Document", U.S. Environmental Protection Agency, 1996;
- "European Oil Industry Guideline for Risk-Based Assessment of Contaminated Sites", CONCAWE, 1997;
- "Standard Provisional Guide for Risk-Based Corrective Action", American Society for Testing and Materials, PS104-98, 1998.
- CARACAS, "Risk Assessment for Contaminated Sites in Europe, Scientific Basis", Vol. 1, LQM Press, 1999.

A risk analysis procedure is based on four main operations:

- Construction of a Specific Conceptual Model (SCM) for the site;
- Definition of benchmarks for the SCM;
- Evaluation/characterization of the risk, and calculation of SALs;
- Selection of corrective actions based on identified risks.

These procedures are detailed in [Annex 2](#). The formulas for modeling Level 2 specific exposures are provided in [Appendix 2](#).

1.3 ROME Software Main Features

Based on the approach described above, the main features provided by ROME can be summarized as follows:

- ROME is a decision analysis and support tool for contaminated sites, that is compliant with current Italian regulations;
- The procedures comprise two parts: a table-based comparison and a site-specific risk analysis;
- The table-based comparison is performed between the observed site concentrations and the LCs of the D.M. 471/99. Furthermore, it is also possible to perform comparisons using GALs, generic risk-based screening values derived using general, conservative default assumptions. This comparison is described as a Level 1 risk analysis;
- A Level 2 risk analysis is performed with site-specific data: the result is an assessment, in quantitative and qualitative terms, of the risks associated with the contamination status of the site. For Level 2, ROME derives SALs, site-specific cleanup targets, which considers elements such as site features, receptors, and analyzed substances. ROME employs default assumptions when no site-specific data is available;
- In the definition of cleanup targets, the software permits the use of additive effects for human receptors, both for carcinogenic and non-carcinogenic substances present in soil and groundwater. The estimation of such additive effects is performed with a procedure adopted at international level (F.D.E.P., 1999).

1.4 Updates to Version 2.1

Updates to the ROME software were designed to provide a wider range of complete assessments for risks associated with contaminated sites, and for the identification of cleanup targets. The update also enables consideration of surface water resources as a potential contamination receptor.

ROME V. 2.1 contains substantial updates with respect to V. 1.0., published in 1999. The updates, described in the following pages and summarized in the table below, reflect a greater consistency with current regulatory requirements, and incorporate consideration of requests and remarks made to ANPA by different users of the software.

- Comparison with table-based limits. Users can compare observed concentrations using either LCs in the D.M. 471/99, that were not available in the previous version, or GALs. In either case, the software highlights any concentration value which exceeds the limit.
- Level 2 risk analysis. ROME V. 2.1 performs a Level 2 risk analysis on all input substances identified on the site, which is independent of the results obtained with the table-based comparison.
- Surface water resources. ROME V. 2.1 assesses risks due to infiltration of rain water through contaminated soils to groundwater and of migration of groundwater contaminants to surface water bodies.
- Additive effects of substances. With ROME V 2.1, the user can calculate cleanup targets (SALs) taking into account the additive effects of carcinogenic and of non-carcinogenic substances. Up to 16 target organs can be considered for non-carcinogenic effects.
- On-line Help. Users, while using ROME V. 2.1, are also supported by “on-line” comments: brief, written comments with additional information (tool-tips) can be displayed by moving and placing the mouse over the various icons.
- Graphics and Features enhancement. The software was thoroughly revised with the aim of making it more user-friendly and comprehensive.
- English version. An English version of ROME V. 2.1. makes this software available for countries other than Italy, thereby enhancing comparibility with similar tools available worldwide.

	Version 2.1	Version 1.0
Interface	<p>Main menu screen with instrument bar and cascade commands.</p> <p>The conceptual site model is a block diagram built by the User by connecting contamination sources to receptors, along potentially active exposure pathways.</p> <p>By selecting any active exposure path, the User directly accesses the needed formula, and can modify input parameters.</p> <p>Interactive summary tables for input parameters employed in the risk analysis.</p>	<p>Main menu screen displaying all commands.</p> <p>The conceptual site model is an active screen from which the User can select possible paths.</p> <p>The User must open all selected paths in a predefined sequence to visualize the formula and the model for each path.</p> <p>Non-interactive summary tables for input parameters employed in the risk analysis.</p>
Data Assessment	<p>The first phase of the assessment can be performed by comparing concentrations with table-based limit values in the D.M. 471/99, and with GALs, obtained from a Level 1 risk analysis.</p> <p>Soil contaminant concentrations, calculated by the software – both for GALs and for SALs – always refer to ‘dry soil’.</p> <p>The software highlights any substance with concentrations exceeding the limit values (D.M. 471/99 or GALs) selected by the User, but the Level 2 risk analysis can be performed for all substances. .</p> <p>Level-2 risk analysis considers the following receptors: humans (workers and/or residents, children and adults), underground and surface water resources.</p> <p>SALs, with respect to additive effects, are reviewed with regard to 16 target organs (in addition to carcinogenic effect), using an internationally approved procedure.</p>	<p>The first phase of the assessment can be performed through a Level 1 risk analysis, with comparison between concentrations and GALs.</p> <p>Soil contaminant concentrations, calculated by the software are considered for ‘unit weight’ (i.e. for water content as measured).</p> <p>Level-2 risk analysis can be performed only for those substances exceeding GAL values.</p> <p>Level-2 risk analysis considers the following receptors: humans (workers and residents, children and adults), and underground water resources.</p> <p>SALs, with respect to additive effects, are reviewed with regard to 7 target organs (in addition to carcinogenic effect).</p>
Graphics	<p>The graphic representation of the relative significance of the exposure paths to the overall risk can be performed both for soil (surface and underground) and for groundwaters sources.</p>	<p>The graphic representations of the relative significance of the exposure paths to the overall risk can be performed for soil sources.</p>

2. ROME V. 2.1 USER'S MANUAL

2.1 Program Installation and execution

ROME V.2.1. can be installed on any PC equipped with the following minimum requirements:

- 486 processor, or higher;
- 8 MB RAM;
- 20 MB hard disk available space;
- Microsoft® Windows 3x, NT, 2000;
- CD reader or Internet connection (to install the program).

Installation procedure:

- Close any application in use;
- Insert the installation CD, or, download all installation files from ANPA's Internet site, and copy them in a single directory;
- Run the "Setup.exe" program;
- Follow, step by step, the instructions displayed on the screen.

Once the installation procedure has been completed, the chosen directory should contain the executable "Rome.exe" file, and the "Database" folder with the following two files:

- "Rome.mdb": Microsoft® ACCESS file with all default parameters, and the complete chemical substances database;
- "Language.mdb": Microsoft® ACCESS file with words and text in English and in Italian.

These files are vital for the correct execution of ROME, and cannot, therefore, be either modified or deleted. To start the program, select the icon named ROME that, by default, can also be found in the "Programs" folder, subfolder "Rome".

All files containing ROME projects can be opened directly from ACCESS environment (".mdb" file). This provides the additional advantage that the files can be managed and/or edited using any ACCESS specific functions, as well as allowing information to be exported to other programs within the Microsoft Office® family or others.

2.2 Main Menu

Once ROME has been started, after the program's logo is displayed, the ROME display appears on screen (**Figure 1**). This screen should show two separate horizontal bars: the first of which contains text that activates pop-up menus, and the second of which contains text with associated icons. The first bar lists the following options: "Project", "Functions", and "?": These are pop-up menus containing, under the appropriate heading, all the icons which appear in the second bar.

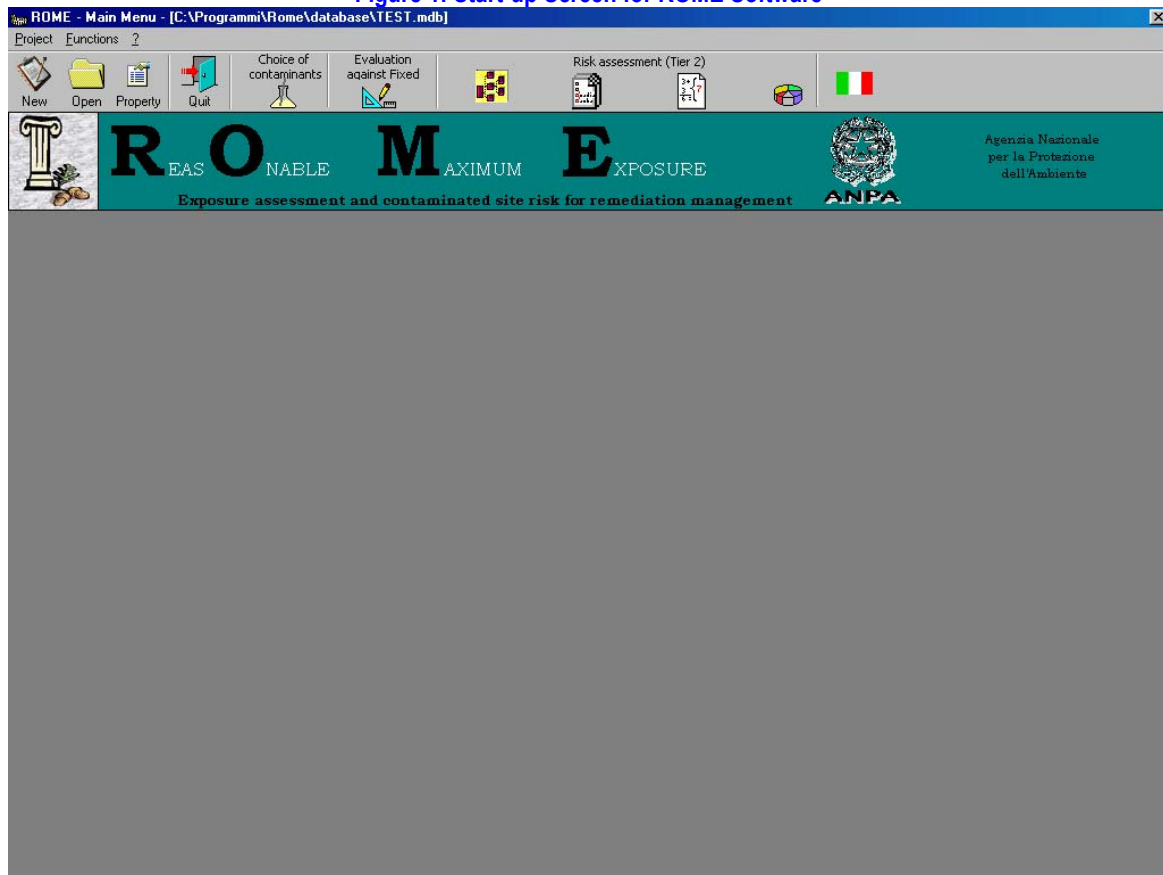
When the software is opened, the second bar ("main bar") should display only three functions relative to the option "Project", specifically: "New", "Open", and "Exit". The fourth icon, "Properties", is not active at this stage, and will be displayed subsequently, together with the other icons that relate to the "Functions" option. Furthermore, the Italian flag should appear on the right side of this bar, i.e. in a different language from the one in use, which can be modified at any time using the mouse.

Once the program has been started, the user must open a project (".mdb" file). This file/project can be:

- An existing project activated by selecting the "Open" icon, (the same operation can be performed by selecting "Project" in the first bar, and then the option "Open" in the subsequent pop-up menu);
- A new project activated by selecting the "New" icon, (the same operation can be performed by selecting "Project" in the first bar, and then the option "New" in the pop-up menu).

For better readability, from here on it is assumed that Users are using the icons in the main bar when using ROME. It must, nevertheless, be emphasised that the same operations can be performed with the pop-up menus, which can be activated from the first bar in the main screen.

Figure 1: Start-up Screen for ROME Software



Before describing subsequent program screens, it should be noted that Users can decide, at any moment, to close the program from the “Main Menu” by selecting the “Exit” icon available in the main bar.

When a new project is opened, the following window “ROME – Create new project” becomes active. Users should specify the name of the file to be saved as a “.mdb” file in the pre-selected folder, or in the default “Database” subfolder. A second window, titled “Project Properties”, will be displayed after this first window has been completed. Users should fill it in with the project’s specifications, specifically (Figure 2):

Figure 2: Project Properties

- Name of the site;
- Site location;
- Operator’s name;
- Date on which the site analysis was performed.

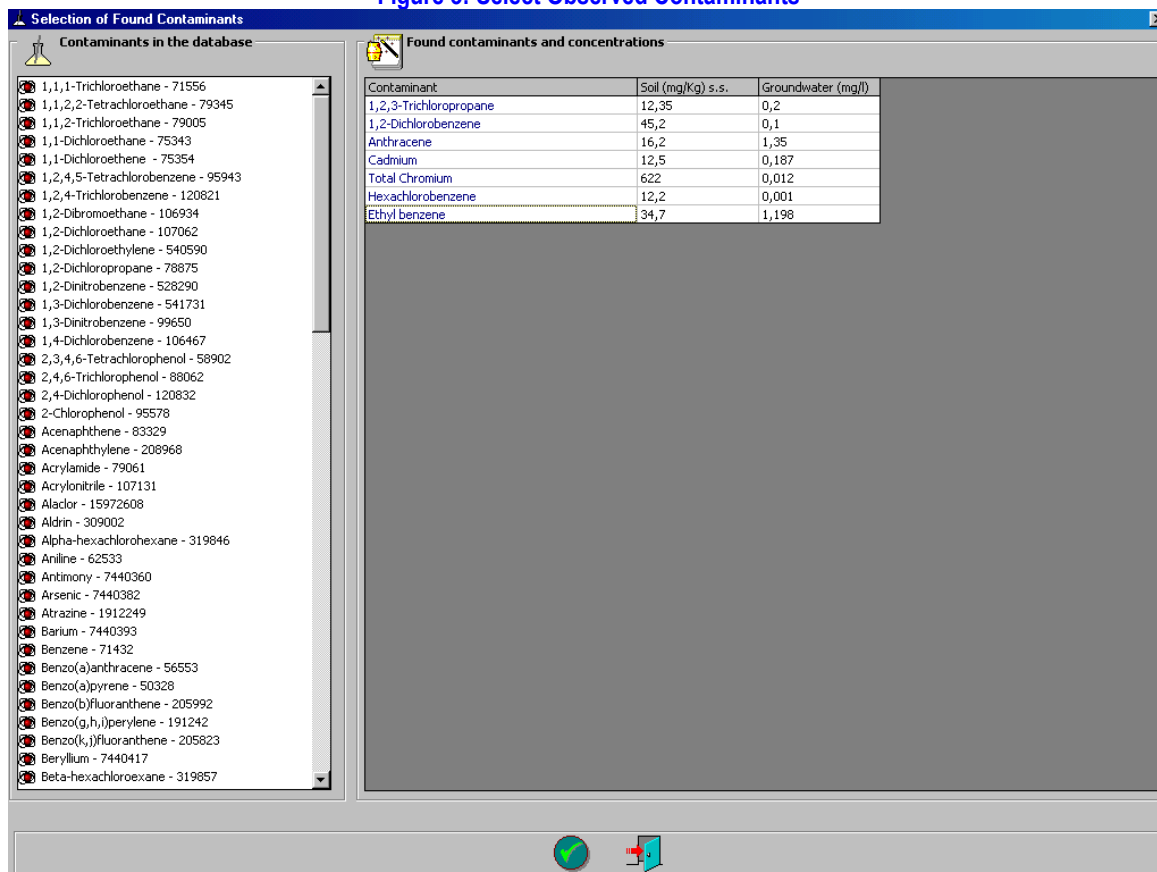
The last line indicates the name of the file and the folder containing the project.

Once these details have been specified, the user can exit this screen either saving (🟢) or not saving (🔴) the information. The above icons, which have the same meaning, respectively, as “Save modifications and exit” and “Exit without saving modifications”, will be used in all the subsequent software displays.

2.3 Insert Contaminants

Upon leaving the “Project Properties” display, the icon “Insert Contaminants” should appear in the Menu main bar. This icon allows you to access the “Select Observed Contaminants” screen ([Figure 3](#)).

Figure 3: Select Observed Contaminants



Using this screen, Users can specify concentrations of chemicals found in the soil (mg/kg) and in groundwater (mg/l) on the site: A number of contaminants (118¹), listed in alphabetical order, which are included on the ROME databases, are provided within the table.

Selecting any contaminant in the list with the right mouse button automatically moves it to the “Observed Contaminants and Concentrations” window located on the right side of the display. To remove a selected contaminant, and place it again on the left side of the display, the user may double-click on the contaminant in the “Observed Contaminants and Concentrations” window.

The “Observed Contaminants and Concentrations” window contains, in addition to the first column listing the selected contaminants, two further columns for data input:

- The observed concentration (mg/kg) for “dry substance” (d.s.) for each contaminant found in the soil can be input in the first column;

¹ The contaminants in the database correspond to those listed in the D.M. 471/99 for which it is possible to perform a risk analysis using the necessary chemico-physical and toxicological parameters and the contaminants available in ROME V.1.0. Microsoft Access can be used to open the “Rome.mdb” file, in order to add further contaminants to the database. For this purpose, the necessary chemico-physical and toxicological parameters needed to complete a risk assessment and characterization for that chemical must also be provided by the User.

- The observed concentration (mg/l) for each contaminant found in groundwater can be input in the second column.

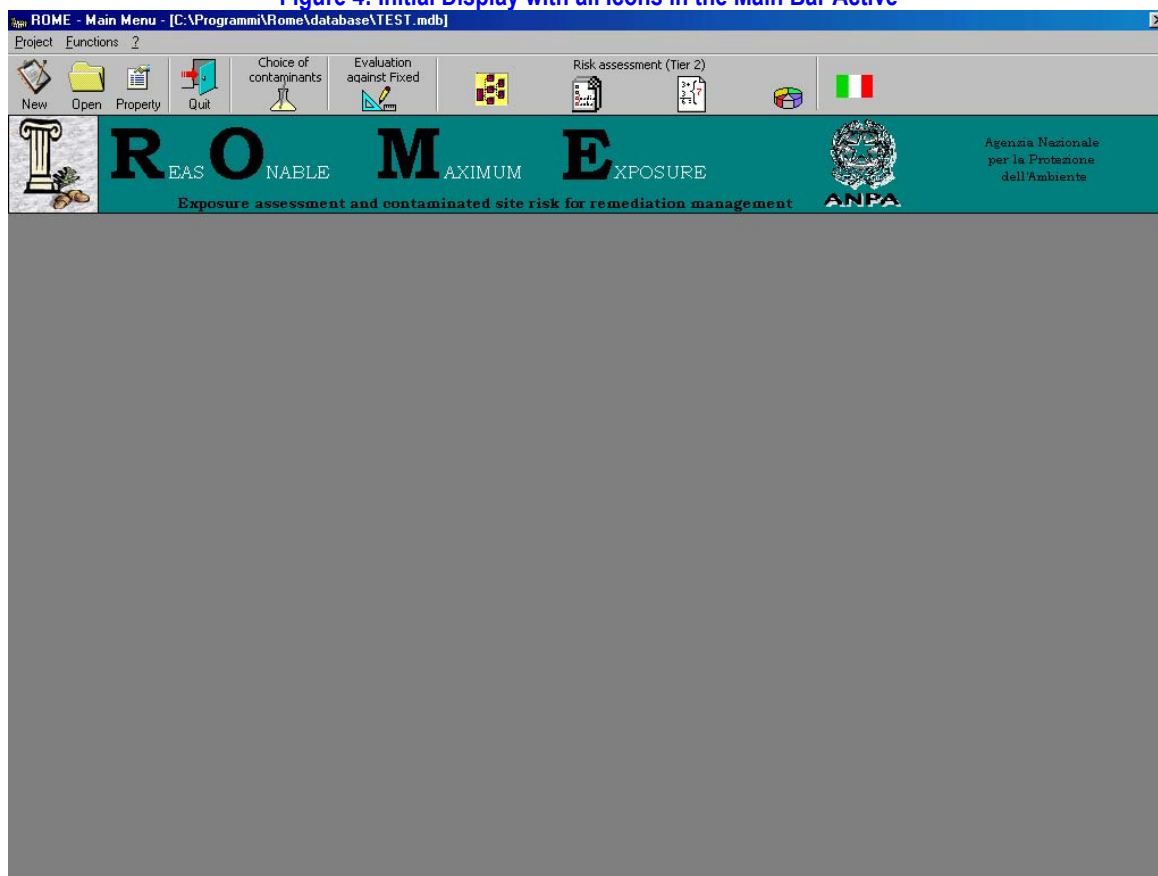
Figure 3 shows an example for a site at which 7 contaminants were found: 1,2,3-Trichloropropane, 1,2-Dichlorobenzene, Anthracene, Cadmium, total Chromium, Hexachlorobenzene, and Ethyl benzene.

Please remember that you can exit this display using the two icons at the base of the screen: use the left one to exit saving the data, or use the right one to exit without first saving modifications.

Once the contaminants have been selected, new icons (**Figure 4**) will become active in the main bar of the Menu. These will let you access the following “Functions”:

- Comparison with table-based limit values;
- Risk analysis (Level 2):
 - Conceptual model;
 - Input parameters;
 - Results and SALs;
 - Graphics for exposure paths.

Figure 4: Initial Display with all Icons in the Main Bar Active



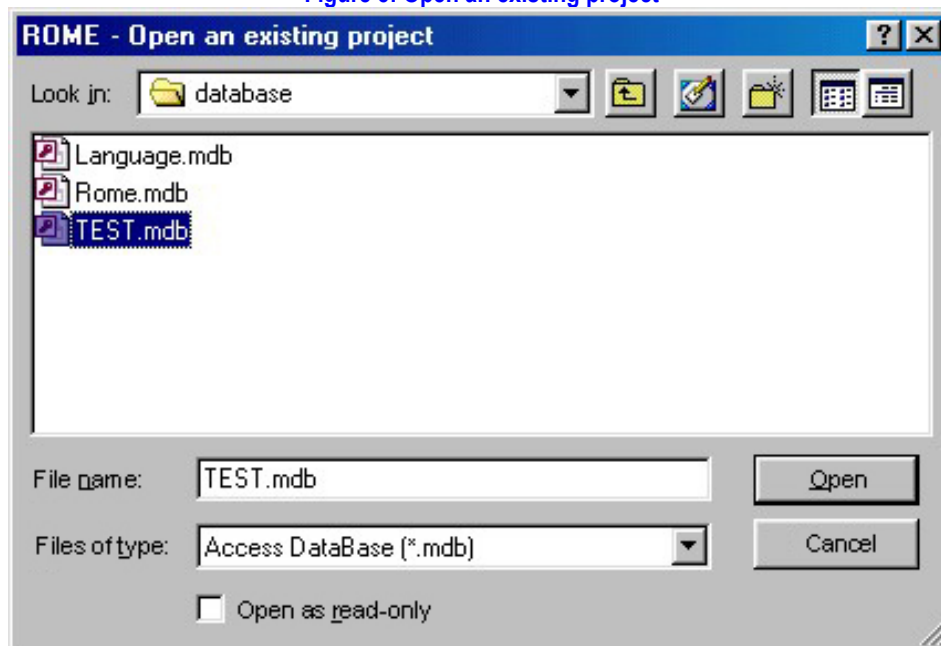
If you open a previously created file by clicking on the “Open” icon at the beginning of the program and selecting an existing file from the screen (as in **Figure 5**), you will see that all the Menu options are already active, as shown in **Figure 4**. In this case you can directly access any part of the Menu, displaying/editing parts of interest.

Activating all icons on the main bar permits Users to perform a complete assessment for a contaminated site, specifically:

- A table-based comparison between the concentrations found in the site and those listed in the D. M. 471/99, in addition to the possibility of displaying GALs defined for the “soil” environmental matrix;
- A Level 2 risk analysis, calculating the risk resulting from the observed contaminations and site-specific acceptability limits for residual contaminations (SALs).

Please see the technical annexes for further information about the decision making process, GALs, and on how to perform the risk analysis.

Figure 5: Open an existing project



It is probably useful to remind Users that the table-based comparison and the risk analysis are independent of each other with ROME V. 2.1. This means, for example, that you can perform risk analysis on substances observed in concentrations less than those listed in the D.M. 471/99, or that you can choose to directly access the risk analysis feature without having previously performed the table-based comparison.

The following sections illustrate the various operations needed to perform a complete assessment of a contaminated site.

2.4 Table-based Comparison

In general, when the table-based comparison is performed based on limited amounts of field data, the maximum concentration found on the site for each contaminant should be used. However, other choices are possible, for example, the 95% Upper Confidence Level (UCL) of the mean value for soil concentrations. Please also see the Unichim Manual 196/1 for further information on the assessment of significant concentrations.

Select "Comparison with Table-based Limits", to choose between two different table-based comparisons:

- A comparison between the detected concentrations and the LCs listed in the D.M. 471/99;
- A comparison between the detected concentrations and GALs, "risk-based" general acceptability limits.

2.4.1 Comparison with D.M. 471/99 Limits

The first option provided by the "Table-based Comparison" icon allows the user to perform a comparison with values listed in the D.M. 471/99. When this option is selected, the software activates the screen shown in [Figure 6](#), with the following six columns:

- Description (contaminant's name);
- Concentration detected in the soil (mg/kg on dry substance), as previously input in the "Insert Contaminants" display;
- Limit concentration (LC) in the D.M. 471/99 for residential/recreative soil (mg/kg of dry substance);
- LC in the D.M. 471/99 for industrial/business soil (mg/kg of dry substance);
- Concentration detected in groundwater (mg/l), as previously specified in the "Insert Contaminants" display;
- LC in the D.M. 471/99 for groundwater (mg/l).

No comparison is performed in this screen for chemicals that are listed in the ROME database, but not included in the D.M. 471/99 (the cells relative to LCs remain blank). The legend in the lower left side of the display provides an interpretation key for the colors used to highlight observed concentrations in the table that exceed the LCs. For example, the color orange indicates that the LC for residential soil is exceeded.

Figure 6: Screen for Comparison with D.M. 471/99 Limits

Comparison with fixed limits					
Description	Soil media			Groundwater media	
	Found (mg/kg) d.w.	DM 471 (RES) (mg/kg) d.w.	DM 471 (IND) (mg/kg) d.w.	Found (mg/l)	DM 471 (Groundwater) (mg/l)
1,2,3-Trichloropropane	12,35	0,1	1	0,2	0,00001
1,2-Dichlorobenzene	45,2	1	50	0,1	0,27
Anthracene	16,2			1,35	
Cadmium	12,5	2	15	0,187	0,005
Total Chromium	622	150	800	0,012	0,05
Hexachlorobenzene	12,2	0,05	5	0,001	0,00001
Ethyl benzene	34,7	0,5	50	1,198	0,05

Exceeding of Tier 1 RES limit

Exceeding of Tier 1 IND limit

Exceeding of Tier 1 RES and IND limits

Exceeding of DM471 limit for Groundwater

Soil limit:
RES : include the residential and recreational land use
IND : include the industrial and commercial land use

Once the table-based comparison is concluded, according to the D.M. 471/99, the site contamination assessment may be concluded if no contaminant exceeds the respective LC for the appropriate land use (i.e., no color in the “Found” columns, both for soil and for groundwater).

2.4.2 Comparison with GALs

The second option provided by the “Table-based Comparison” icon allows the use of GALs within the comparison. This type of comparison corresponds to a Level 1 risk analysis. The selection of this option activates a sub-menu from which the user can choose whether to perform the comparison using human protection GALs, or both human and groundwater resources protection GALs (see [Table 5](#) for a list of the numerical values for GALs, and [Annex 1](#) for a description on how to calculate them).

The screen for human protection GALs ([Figure 7](#)) includes the following four columns:

- Description (contaminant's name);
- Concentration observed in the soil (mg/kg of dry substance), as previously input in the “Insert Contaminants” display;
- General acceptability limit for residential/recreative soil - GAL (RES) (mg/kg of dry substance);
- General acceptability limit for industrial/business soil - GAL (IND) (mg/kg of dry substance).

A legend provides an interpretation key to the colors used to highlight observed concentrations in the table that exceed the GALs. For example, the color red indicates that the observed concentration exceeds the GAL for industrial soil.

The screen for human and undergroundwater resources protection GAL includes the following six columns ([Figure 8](#)):

- Description (contaminants name);
- Concentration found in the soil (mg/kg of dry substance), as previously input in the “Insert Contaminants” screen;
- General acceptability limit for residential/recreative soil - GAL (RES) (mg/kg of dry substance);
- General acceptability limit for industrial/business soil - GAL (IND) (mg/kg of dry substance);
- Concentration found in groundwater (mg/l), as previously input in the “Insert Contaminants” screen;
- General acceptability limit for groundwater – GAL (groundwater) (mg/l).

Figure 7: Comparison with human protection GALs

Soil media			
Description	Found (mg/kg) d.w.	LAG (RES) (mg/kg) d.w.	LAG (IND) (mg/kg) d.w.
1,2,3-Trichloropropane	12,35	0,008	0,07
1,2-Dichlorobenzene	45,2	46	569
Anthracene	16,2	10	10
Cadmium	12,5	75	757
Total Chromium	622	113000	2070000
Hexachlorobenzene	12,2	1,2	4,8
Ethyl benzene	34,7	42,5	365

= Exceeding of Tier 1 RES limit
 = Exceeding of Tier 1 IND limit
 = Exceeding of Tier 1 RES and IND limits

Soil limit:
LAG : generic acceptable limits, equivalent to screening values
RES : include the residential and recreational land use
IND : include the industrial and commercial land use

Figure 8: Comparison for both Human and Undergroundwater Resources Protection GALs

Soil media				Groundwater media	
Description	Found (mg/kg) d.w.	LAG (RES) (mg/kg) d.w.	LAG (IND) (mg/kg) d.w.	Found (mg/l)	LAG (Groundwater) (mg/l)
1,2,3-Trichloropropane	12,35	0,000014	0,000014	0,2	0,000001
1,2-Dichlorobenzene	45,2	14	14	0,1	0,27
Anthracene	16,2	10	10	1,35	
Cadmium	12,5	5,1	5,1	0,187	0,005
Total Chromium	622	814	814	0,012	0,05
Hexachlorobenzene	12,2	0,1	0,1	0,001	0,00001
Ethyl benzene	34,7	1,5	1,5	1,198	0,05

= Exceeding of Tier 1 RES limit
 = Exceeding of Tier 1 IND limit
 = Exceeding of Tier 1 RES and IND limits
 = Exceeding of LAG for Groundwater

Soil limit:
LAG : generic acceptable limits, equivalent to screening values
RES : include the residential and recreational land use
IND : include the industrial and commercial land use

Annex 1 illustrates in detail the following principle: for each contaminant the software displays, as shown in **Figure 8**, the minimum value between soil GAL for human protection and soil GAL for undergroundwater resources protection. By definition, thus, soil GALs for both human and groundwater protection cannot be higher than those for human protection.

Groundwater GALs correspond to groundwater LCs in D.M. 471/99: it was decided not to formulate risk-based GALs since the D.M. 471/99 does not indicate that the LCs for groundwater were derived with regard to a particular groundwater use or exposure scenario.

Only soil GALs for human protection have been derived with regard to strict criteria for Level 1 health risk analysis. Therefore, in terms of usability, only soil GALs for human protection can be strictly defined as risk-based screening values. Conversely, soil GALs for groundwater protection and GALs for groundwater enable compliance with regulatory standards for undergroundwater resources.

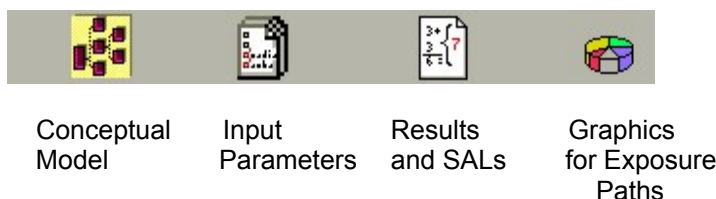
The legend provides an interpretative key for the colors used in the table to highlight detected concentrations that exceed GAL values. For example, light blue indicates that the observed concentration exceeds the GAL value for groundwater.

Please note that ROME V. 2.1. considers all compounds selected by the User in the screen “Insert Contaminants” within the Level 2 risk analysis.

2.5 Level 2 Risk Analysis

A site-specific risk analysis can be performed using either of two approaches: the direct method calculates the risks associated with measured site contamination; the inverse method calculates cleanup targets or acceptable residual concentrations that can remain on-site without presenting an unacceptable risk to receptors. The steps involved within the ROME model, as well as the input data needed are identical for both approaches, since the models employed for each are essentially the same: the equations for assessing exposure and risk (using the direct method) are simply inverted when calculating SALs (using the inverse method) ([Annex 2](#)).

For a Level 2 risk analysis, the program displays the following four icons:



2.5.1 Conceptual Model of the Site

Selecting the “Conceptual Model” icon, the User can display the screen shown in [Figure 9](#), which is divided into three separate columns:

- Sources to be assessed;
- Exposure paths;
- Receptors.

In the first column, “Sources to be assessed”, the User can select the relevant environmental media in which the source of contamination has been identified from those available (i.e. surface soil, underground soil, groundwater (dissolved or aqueous phase) and free or floating product). It is possible to select between one to four of the media for any site. For example, in [Figure 9](#), all four sources were selected.

In this first column there is also a yellow box named “Concentration Details for Environmental Media”. Selecting this box, the User activates a window similar to the one shown in [Figure 10](#), which details the contamination found in the site, subsequently subject to risk analysis.

This box contains a table with up to five columns:

- The first column sets out a list of contaminants at the site. These were previously selected by the User at the “Insert Contaminants” screen;
- The second column lists, for each contaminant, the concentrations detected in surface soils (0.0 to 1.0 m below ground level (bgl)). Relevant data may be input at this stage. Otherwise, by default, these values will be the same as those input in the “Observed Contaminants and Concentrations” window during the selection of contaminants;
- The third column lists, for each contaminant, the concentrations detected in deeper soils (> 1.0 m bgl). Relevant data may be input at this stage. Otherwise, by default, these values will be the same as those input in the “Observed Contaminants and Concentrations” window during the selection of contaminants;
- The fourth column can be used to input leachate test results, if available;
- The fifth column can be used to input information relative to the free product, if present. That is, data relative to the existence, above groundwater, of a separate phase lighter than water (“LNAPL – Light

Non-Aqueous Phase Liquid"). (The information is input through "Yes" or "No" answers, and can be selected using the right and left arrows on the keyboard, as shown in the legend.)

FIGURE 9: Conceptual Site Model

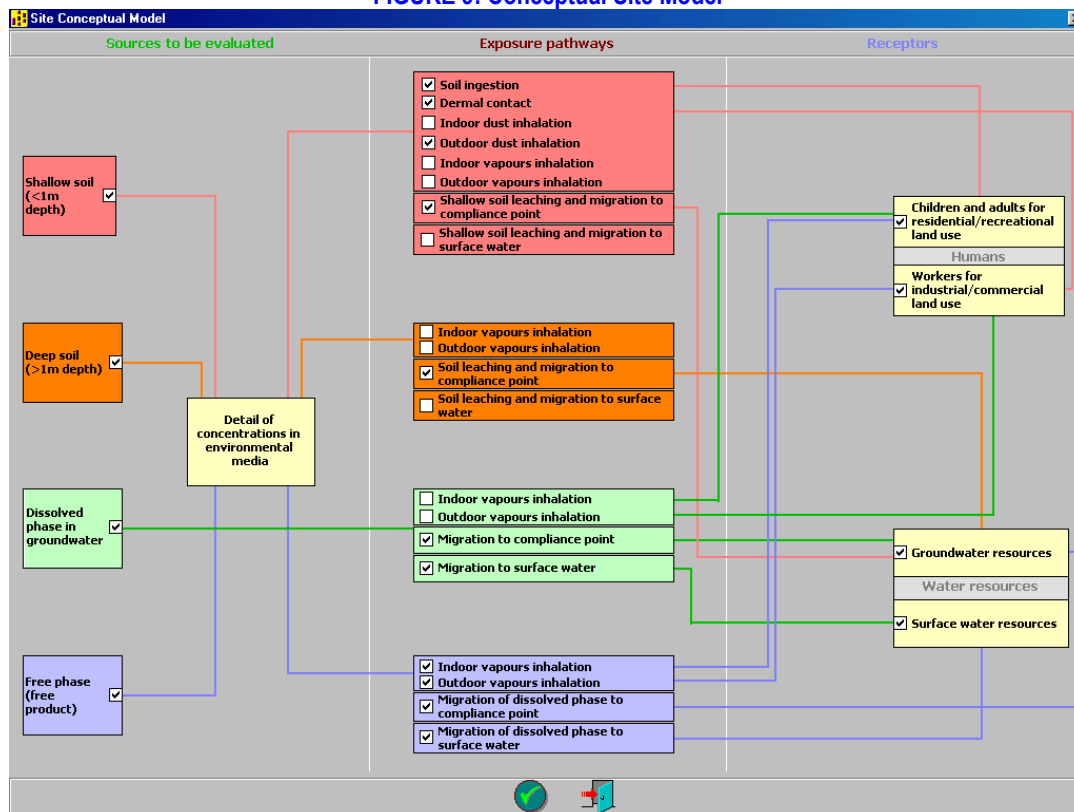


FIGURE 10: Concentration Details for Environmental Matrixes

Detailed concentrations in environmental media				
Contaminant description	Shallow Soil conc. (mg/kg) d.w.	Deep Soil conc. (mg/kg) d.w.	Leachate (mg/l)	LNAPL
1,2,3-Trichloropropane	12,35	12,35	0	-
1,2-Dichlorobenzene	45,2	45,2	0	-
Anthracene	16,2	16,2	0	-
Cadmium	12,5	12,5	0	-
Total Chromium	622	622	0	-
Hexachlorobenzene	12,2	12,2	0	-
Ethyl benzene	34,7	34,7	0	Yes

Free product on groundwater. To calculate the risk from free product, select the appropriate box of contaminant of concern using the right and the left arrow for YES or NO.

Print

Shallow soil : < 1m from ground level
Deep soil : > 1m from ground level

LNAPL :

In the risk analysis, as shown by the second and third columns, contamination found in surface soils is considered separately from contamination in deeper soils.

ROME assumes by default that both the concentrations for surface soil and for deep soil are the same as the values input during the selection of contaminants (see section 2.3). The maximum value between these two matrixes must correspond to the value input in the “Observed Contaminants and Concentrations” window in the Main Menu. It is up to Users to modify this default assumption, adapting it to the site’s real conditions, considering the following:

- At least one of the two concentrations in these columns must correspond to the value specified in the “Insert Contaminants” window”;
- The other concentration cannot exceed this value.

The program automatically displays a warning message if the specified values are not compatible with this scheme.

The fourth column should be used to specify the values, if available, for the leachate concentrations resulting from leachate tests.

The software, when using data from leachate tests, is designed to use this concentration to calculate risks from the overlying soil contamination to groundwater resources.

In the absence of such data, the software employs an equation describing the partitioning of the contaminant, at equilibrium, between the different phases, thereby obtaining a theoretical value for the concentration of the contaminant in the soil pore water.

Given that the calculation of a theoretical soil pore water concentration provides, in general, conservative results and, in some instances, very conservative results, it is strongly recommended that a leachate test be performed and that this experimental data be used to repeat the risk analysis. This approach is considered more appropriate for describing the actual real transport of the contaminants detected on the site. This may be an important consideration when facing an unacceptable risk to groundwater resources due to contaminated soil.

For those substances whose limit concentrations (LCs) for groundwaters are not specified in the D.M. 471, ROME uses an acceptable “substitute” concentration. This concentration is the result of a risk-based assessment, and it corresponds to a contaminant concentration that would be acceptable assuming an adult resident at the site consumes 2 litres of contaminated water per day. The software uses this “substitute” concentration in the same way as it uses the LCs specified in the D.M. 471. In the results, an asterisk highlights the use of “substitute” concentrations

The fifth column of the “Concentrations Details for Environmental Matrixes” window is used to specify detected free product floating on groundwater (LNAPL). This option is only possible for certain substances. Chemical substances in the ROME database, classified as LNAPL, include:

- Benzene
- Ethyl benzene
- Toluene
- Total Xylenes
- Styrene
- TPH (range of Gas oils)
- TPH (range of gasolines)

To specify a free product, use the keyboard arrows to modify the “No” setting, which is set by default for LNAPL substances, to “Yes”. Other substances, not compatible with the presence of a free product, are indicated with a “-” sign.

It is useful to remember that this fifth column will not be highlighted if, in the “Conceptual Model” window, no selection was made for groundwater amongst the sources detected on the site, or if no selection was made for the source “Separate Phase (free product)” in the “Concentrations Details for Environmental Media” box.

In the second column of the conceptual model, “Exposure paths”, Users can select those exposure pathways considered as potentially active for the site under examination.

In the third column, “Receptors”, Users can select those receptors exposed to contamination. The software considers the following: “Man” (children and adults or workers, according to the assigned use) and “Water Resources” (groundwater and surface water).

It is emphasised that a risk analysis can be performed only for complete exposure paths, i.e. those characterized by a contamination source, a receptor, and a path connecting them.

If no pathway characterized by the sequence “source-pathway-receptor” is completed, the software will not perform any calculation either for the risk or for SALs. The conceptual model scheme was designed to highlight, with the aid of different colors, all complete exposure pathways present on the site.

By using the right mouse button on each selected exposure pathway, the User can open a dedicated screen with the following information:



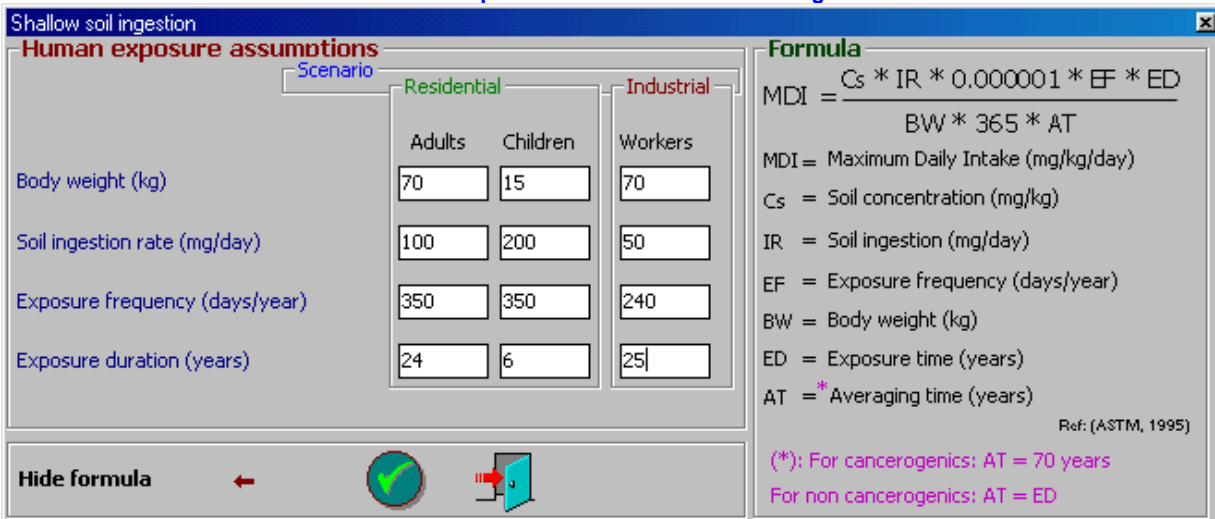
- All parameters relative to human exposure and to the site that are of interest for the exposure pathway under examination;
- The formula needed to calculate the “Maximum Daily Intake, MDI”: select the  icon, located on the lower left side of the screen to display it;
- The formula needed to calculate the concentration at the exposure point: select the  icon, located on the lower right side of the screen to access this formula, if present;
- Bibliographic references for the displayed formulas.

Figure 11 shows, for illustration purposes, the screen corresponding to the exposure path “Surface Soil Ingestion”.

FIGURE 11: Exposure Path for “Surface Soil Ingestion”



Shallow soil ingestion

Human exposure assumptions

Scenario: Residential (Adults, Children) and Industrial (Workers)

Parameter	Adults	Children	Workers
Body weight (kg)	70	15	70
Soil ingestion rate (mg/day)	100	200	50
Exposure frequency (days/year)	350	350	240
Exposure duration (years)	24	6	25

Formula

$$MDI = \frac{C_s * IR * 0.000001 * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)

C_s = Soil concentration (mg/kg)

IR = Soil ingestion (mg/day)

EF = Exposure frequency (days/year)

BW = Body weight (kg)

ED = Exposure time (years)

AT = * Averaging time (years)

Ref: (ASTM, 1995)

(*): For cancerogenics: AT = 70 years
For non cancerogenics: AT = ED

Buttons: Hide formula, Display formula, Concentration formula

For a newly created file (“Create New Project” icon, in the main bar of the Menu), the software uses default numerical values for parameters related to human exposure and to the site that are displayed on the screen. It is important to underline, that these default values are the same as the values used to determine GALs with the General Conceptual Model (see [Annex 1](#) and [Tables 1 to 4](#)). Therefore, Users can perform a risk analysis without modifying the default values, provided all exposure paths are active, which will result in surface soil SAL values for human protection that correspond with the GAL values listed in [Table 5](#) (or with very small differences due to rounding off).

All screens in which parameters are displayed are interactive, and the default values (or User specified values for an existing project), can thus be overwritten with values more consistent with actual site conditions and exposure scenarios (“site-specific” parameters). Whenever high quality, site specific data is not available, it is strongly recommended that great care be exercised when overwriting default values, and to do so only if unavoidable.

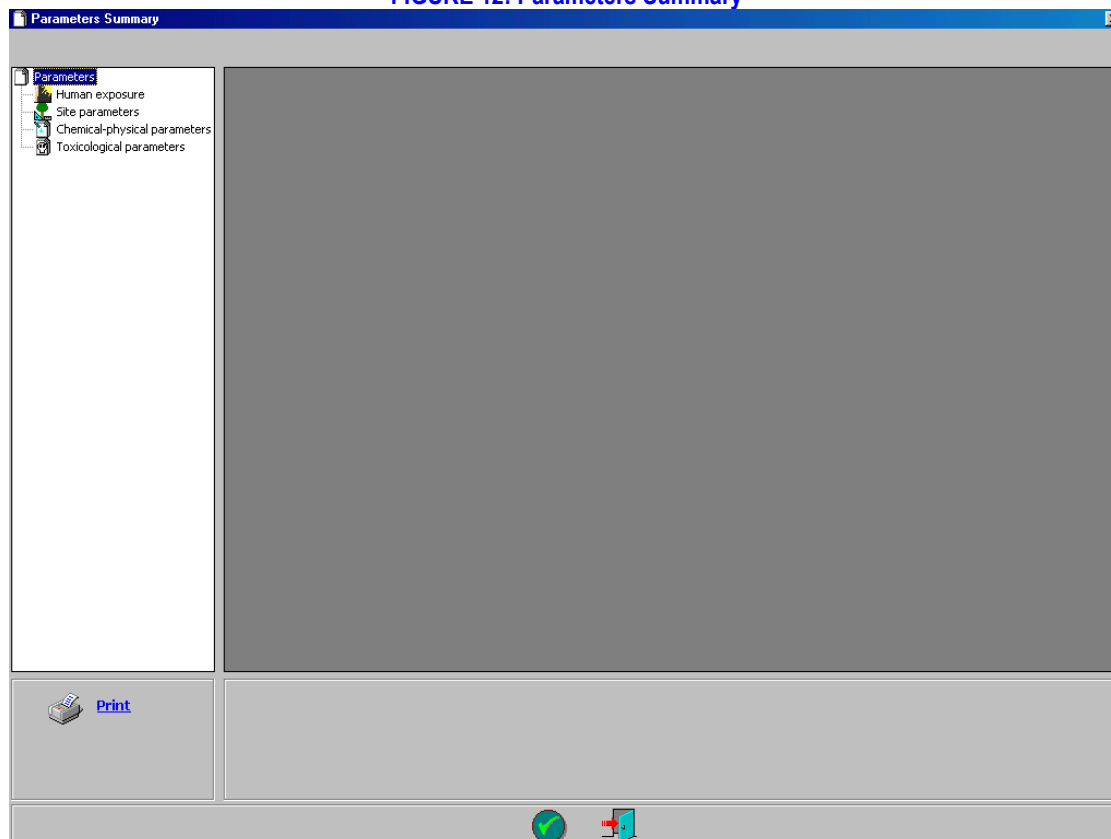
2.5.2 Input Parameters (Parameters Summary)

Selecting the “Input Parameters” icon from the main bar in the Menu, will display the screen shown in [Figure 12](#), from which the User can access all parameters for the conceptual model, that is:

- Human exposure parameters;
- Characteristics of the site;
- Chemico-physical parameters (limited to the contaminants of interest for the risk analysis);
- Toxicological parameters (limited to the contaminants of interest for the risk analysis).

To access these tables, select the appropriate icon located on the left side of the screen ([Figure 12](#)). The values listed in these tables correspond to the default values, unless these were previously overwritten in the conceptual model screen or in a preceding project revision.

FIGURE 12: Parameters Summary



The “Human Exposure” table (Figure 13) lists all data relative to the “Man” receptor, classified by residents (adults and children) and workers. All parameters can be modified and adapted to more accurately represent specific characteristics of the receptors present on the site.

FIGURE 13: Human Exposure Parameters

The screenshot shows the same 'Parameters Summary' window, but now the 'Human exposure' table is populated with data. The table has columns for 'Scenario' (Residential / Recreational, Industrial / Commercial, Workers) and rows for various human exposure parameters. The 'Human exposure' folder in the tree view is still selected.

Human exposure parameter	Scenario		
	Residential / Recreational	Industrial / Commercial	Workers
Body weight (kg)	70	15	70
Exposure duration (years)	24	6	25
Exposure frequency (days/year)	350	350	240
Life duration (days)	25550	25550	25550
Soil ingestion rate (mg/day)	100	200	50
Skin surface (cm ² /day)	17938	6381	17938
Fraction of exposed skin (unit less)	0,2	0,5	0,2
Adherence factor (mg/cm ²)	1	1	1
Indoor inhalation rate (m ³ /day)	15	6	8
Outdoor inhalation rate (m ³ /day)	5	3	2
Time fraction spent on site	1	1	1

The “Site Characteristics” table (**Figure 14**) lists general parameters for the site, including unsaturated and saturated zones beneath the site and those relative to surface water resources. All parameters can be modified and adapted to more accurately represent the site’s real and specific characteristics. A useful aid is provided by **Table 6**, which lists all reasonable ranges of values for the parameters, as well as the sensitivity of the results to changes in this parameter.

FIGURE 14: Site Characteristics

Parameters	Symbol	Default value
GENERAL		
Wind speed (cm/s)	Uair	225
Mixing zone height (cm)	Dair	200
Residential building height (cm)	LB(R)	200
Industrial building height (cm)	LB(I)	300
Air exchange rate (1/h) res. land use	ER(R)	0,504
Air exchange rate (1/h) ind. land use	ER(I)	0,828
Thickness of building foundation/wall (cm)	Lcrack	15
Foundation/wall crack fraction (cm ² /cm ²)	n	0,01
Air content in cracks (unit less)	Oacrack	0,26
Water content in cracks (unit less)	Owcrack	0,12
OF VADOSE ZONE		
Bulk density (g/cm ³)	Ps	1,7
Fraction of organic Carbon in vadose zone (g-C/g-soil)	Foc	0,01
Contamination depth in shallow soil (cm)	Ls(S)	50
Contamination depth in deep soil (cm)	Ls(P)	100
Thickness of capillary fringe (cm)	hcap	5
Vadose zone thickness (cm)	h _v	295
Air content in soil (unit less)	Oas	0,26
Water content in soil (unit less)	Ows	0,12
Total soil porosity (unit less)	Qt	0,38
Air content in capillary fringe (unit less)	Oacap	0,038
Water content in capillary fringe (unit less)	Owcap	0,342
Soil particles in dust (unit less)	Fsd	1
Outdoor dust concentration (mg/m ³)	PMo	0,07
Indoor dust fraction (unit less)	Fi	1
Indoor dust concentration (mg/m ³)	PMi	0,07
Source length parallel to wind direction (m)	Lw	15
Source width perpendicular to wind direction (cm)	W	15
Source length parallel to groundwater flow direction (m)	L	15
Source width perpendicular to groundwater flow direction (m)	Swp	15
OF SATURATED ZONE		
Bulk density (g/cm ³)	Ps(sat)	1,7
Fraction of organic Carbon in saturated zone (g-C/g-soil)	Foc(sat)	0,001

Site parameters
NB: bold values are fixed

After considering all uncertainties associated with the characterization data, the choice of value for input parameters should, generally, be directed towards those values that are representative in a precautionary or conservative way.

The tables “Chemico-Physical Parameters” and “Toxicological Parameters” (**Table 3** and **Table 4**, respectively) list such parameters for contaminants of interest for risk analysis.

Since all the numerical values listed for these parameters have been obtained from international databases, and are generally considered to be reliable, the default value will only be modified occasionally, when updated values are published from these sources or from similarly authoritative data sources.

2.5.3 Results: Risk and SALs Assessment

Once the site-specific conceptual model has been completed, and the input data revised, as required, select the “Results and SAL” icon from the main bar of the Menu. This allows the User to access a pop-up menu from which you can choose whether to display “Results” in terms of “Risks for Man” or “Risks for Water Resources” (groundwater and surface water), or “Cleanup Targets” (SALs).

These options are described separately below.

2.5.3.1 Risks for Man

“Risks for Man”, that is health risks, can refer to:

- Carcinogenic substances;
- Non-carcinogenic substances.

The screen that appears when “Risks for Man” is selected allows Users to choose between these two options by selecting the appropriate icon amongst the two panels located on the left screen side.

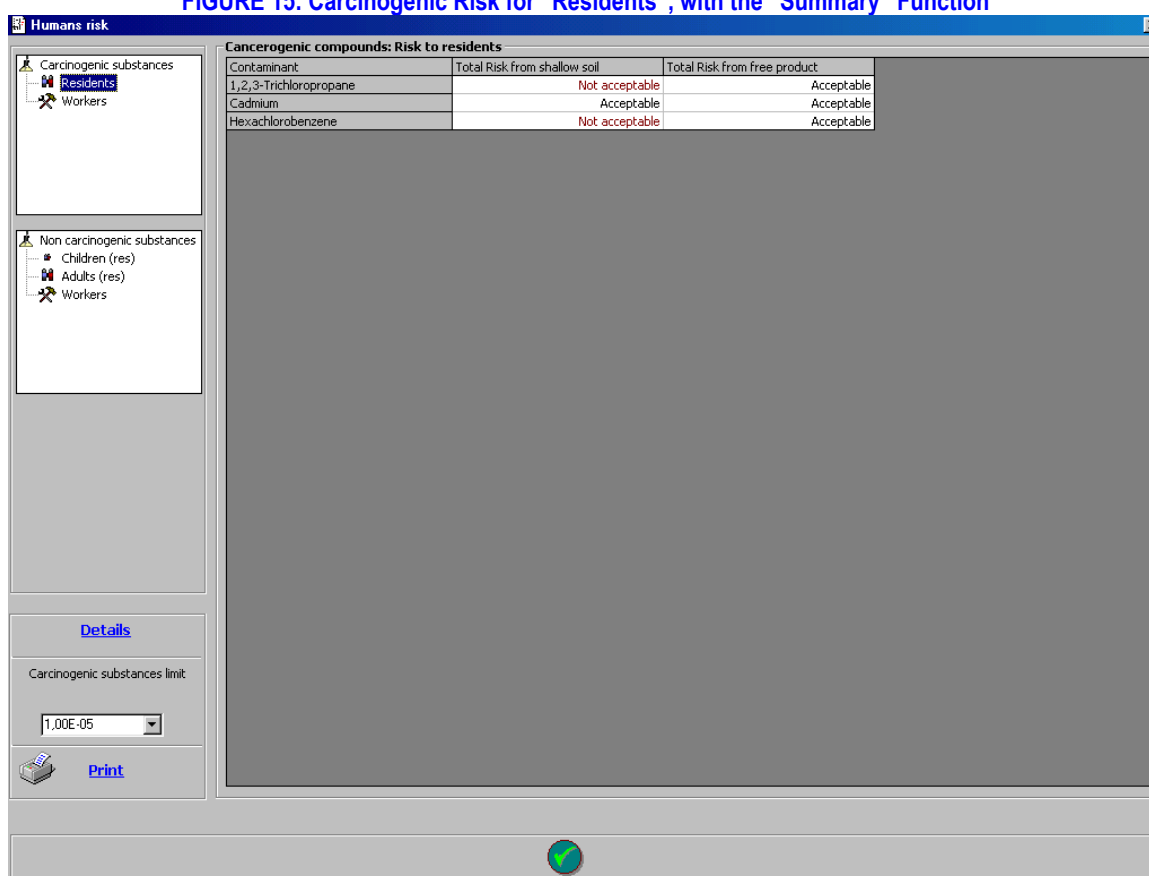
2.5.3.1.1 Carcinogenic Substances

To access the results of the risk analysis for carcinogenic substances, select the desired receptor from those available, i.e. “Residents” and “Workers”. As far as residents are concerned, please remember that when assessing carcinogenic risk, as illustrated in [Appendix 1](#), no difference is made between children and adults, since the risk calculation is performed over the entire life period. The calculation thus assumes that the initial part of the lifetime exposure will be lived as children while the remaining part will be lived as adults. For this purpose, please consult [Appendix 1](#) and the “AT = average time” parameter.

The results of the risk estimation can be displayed in two possible ways:

- In terms of “Acceptable” or “Non Acceptable”: select the text “Summary” in the left column ([Figure 15](#));
- In numerical terms: select the text “Details” in the left column.

FIGURE 15: Carcinogenic Risk for “Residents”, with the “Summary” Function



The threshold for risk acceptability in terms of incremental cancer risk over a lifetime due to exposure to carcinogenic substances present in soil and groundwater at the site (Risk) can be set by Users by selecting from the following values: 1×10^{-4} (i.e., an excess cancer risk probability of one in 10,000 risk over a lifetime), 1×10^{-5} (this is the default value used to calculate GALs, and is used extensively as an acceptable risk level for contaminated sites in Europe), and 1×10^{-6} . To select a value, go to the desired screen and click with the mouse on the button with the downward arrow, located in the left side column (see [Figure 15](#)).

The “Summary” option allows you to display a table for the selected receptors, such as the one that appears in [Figure 15](#), with the following information:

- First column: a list of carcinogenic contaminants from those of interest for the risk analysis;
- Second column: risk acceptability or non acceptability for carcinogenic substances present in surface soil;
- Third column: risk acceptability or non-acceptability for carcinogenic substances present in deep soil;

- Fourth column: risk acceptability or non-acceptability for carcinogenic substances present in groundwater;
- Fifth column: risk acceptability or non-acceptability for carcinogenic substances present in free product.

The second to fifth columns are displayed only when contaminants were detected in the corresponding environmental media or in free product floating on groundwater.

For example, the fourth and fifth column will not be displayed in the absence of groundwater, and the fifth column will not appear where groundwater is present, but in the absence of floating product.

The “Details” option allows you to display a table with the following information:

- First column: a list of carcinogenic contaminants from those of interest for the risk analysis;
- From the second to the fifth column: overall risk for human receptors due to the four single environmental media: surface soil, deep soil, undergroundwater and free product (should all be present);
- Remaining columns: the risk associated with each active exposure path, which is consistent with the selections made in the earlier screen regarding the conceptual model.

The two available options, (“Summary” and Details”), highlight non-acceptable risks, i.e., those exceeding the specified risk acceptability criteria, in red. It is important to emphasise that during this phase the risk is individually considered for each single contaminant. The option to assess additivity of effects among several contaminants is available in a submenu relating to cleanup targets for SALs.

2.5.3.1.2 Non-Carcinogenic Substances

To access the results of risk analysis for non-carcinogenic substances, select the desired receptor from those available i.e. “Resident Children”, “Resident Adults”, and “Workers”.

The results of the risk assessment can be displayed in two possible ways:

- In terms of “Acceptable” or “Non-acceptable”: by selecting the text “Summary” in the left column;
- In numerical terms: select the text “Details” in the left column.

The threshold for risk acceptability for non-carcinogenic substances (“HI” or “Hazard Index”) is set equal to 1, and cannot be modified by Users.

Selecting the “Summary” option, for the specified receptors, allows you to display a table with the following information:

- First column: list of non-carcinogenic contaminants from those of interest for the risk analysis;
- Second column: risk acceptability or non-acceptability for non-carcinogenic substances present in surface soil;
- Third column: risk acceptability or non-acceptability for non-carcinogenic substances present in deep soil;
- Fourth column: risk acceptability or non-acceptability for non carcinogenic substances present in groundwater;
- Fifth column: risk acceptability or non-acceptability for non-carcinogenic substances present in free product.

The second to fifth columns are displayed only when contaminants were detected in the corresponding environmental media, or in free product floating on groundwater.

Select the “Details” option to display a table with the following information:

- First column: list of non-carcinogenic contaminants from those of interest for the risk analysis;
- Second to fifth columns : overall HI for human receptors relating to the four individual environmental media: surface soil, deep soil, undergroundwaters, and free product (should all be present);
- Remaining columns: HI associated with each single active exposure path, which is consistent with the selections made in the earlier screen regarding the conceptual model.

For both options (“Summary” and “Details”), non-acceptable HI values, i.e. higher than 1, are highlighted in red. It must be stressed that in this phase HI refers to each contaminant, considered individually; the option to assess additive effects amongst several contaminants is available in the SALs cleanup targets sub-menu.

2.5.3.2 Risks for Water Resources

“Risks for Water Resources” can refer to:

- Groundwater resource;
- Surface water resource.

2.5.3.2.1 Groundwater Resources

To access the results of risk analysis for groundwater resources, select the “Groundwater Resources” receptor in the pop-up menu displayed when the option “Risks for Water Resources” is selected.

The results of the risk assessment can be displayed in two possible ways:

- In terms of “Acceptable” or “Non-acceptable”: by selecting the text “Summary” in the left column;
- In numeric terms: by selecting the text “Details” in the left column.

Risk assessment for groundwater resources is performed by comparing, for each desired contaminant, the concentration calculated at the so called “compliance point” with the LC value reported in the D.M. 471/99. Should the latter not be available, a “substitute D.M. 471” concentration can be used to perform the comparison (please consult Paragraph 2.1 in [Appendix 2](#) for a precise description on how to calculate this concentration). The ratio between the two concentrations provides a numerical definition of risk for groundwater resources.

The threshold for risk acceptability for groundwater resources is set equal to 1, and cannot be modified.

In terms of significance and evaluation criteria, risk assessment for groundwater resources thus differs from risk assessment for man: it does not represent (except for “substitute” substances) a risk to health, but an estimation of whether contaminant concentrations will exceed the relevant LC at the compliance point.

FIGURE 16: Risk for Undergroundwater Resource with the “Details” Function



Contaminant	Risk from soil	Risk from groundwater	Risk from groundwater
1,2,3-Trichloropropane	9,76E+05	2,00E+05	
1,2-Dichlorobenzene	3,57E+00	3,70E-01	
Anthracene	5,20E-04	1,23E-01 *	
Cadmium	2,75E+00	3,74E+01	
Total Chromium	8,56E-01	2,40E-01	
Hexachlorobenzene	1,26E+02	1,00E+02	
Ethyl benzene	2,65E+01	2,40E+01	3,29E+03

* DM471 Surrogate

Select the “Summary” option for the specified receptors to display a table with the following information:

- First column: a list of contaminants included within the risk analysis;
- Second column: risk acceptability or non-acceptability for groundwater due to contaminants present in the soil (surface and deep);
- Third column: risk acceptability or non-acceptability for groundwater due to contaminants present in the soil. The contaminants are assessed on the base of the leachate test results;
- Fourth column: risk acceptability or non-acceptability for groundwater due to contaminants present in groundwater (migration of the contamination found in groundwater towards the compliance point);

- Fifth column: risk acceptability or non-acceptability for groundwater due to contaminants present as floating free product.

The second to fifth columns will be displayed only if contaminants were found in the corresponding environmental media, or in free product floating on groundwater.

Selecting the “Details” option enables the User to visualize a table displaying the same columns described for the “Summary” option, with the difference that these report the results of the risk assessment numerically (instead of in terms of acceptability or non-acceptability) ([Figure 16](#)).

Both options (“Summary” and “Details”) highlight in red risks higher than 1, that is, non-acceptable risks.

Please consult [Annex 2](#) for a detailed description of risk analysis for groundwater receptors, as well as of the exposure paths directly involved in the risk assessment itself.

2.5.3.2.2 Surface Water Resource

To access the results of risk assessment for surface water resources, select the “Surface Water Resource” receptor in the pop-up menu that is displayed when the option “Risks for Water Resources” is selected.

The results of the risk assessment can be displayed in two possible ways:

- In terms of “Acceptable” or “Non-acceptable”: by selecting the text “Summary” in the left column;
- In numeric terms: by selecting the text “Details” in the left column.

The risk assessment for surface water resources is performed by comparing, for each contaminant of interest, the concentration calculated in surface waters with the corresponding acceptable concentration established in the D.Lgs. 152/99, reported in [Table 8](#). The ratio between these two provides a numerical definition of the risk for surface water resources.

The threshold for risk acceptability for surface water resources is set equal to 1, and cannot be modified.

Select the “Summary” option for the desired receptors to visualize a table with the following information:

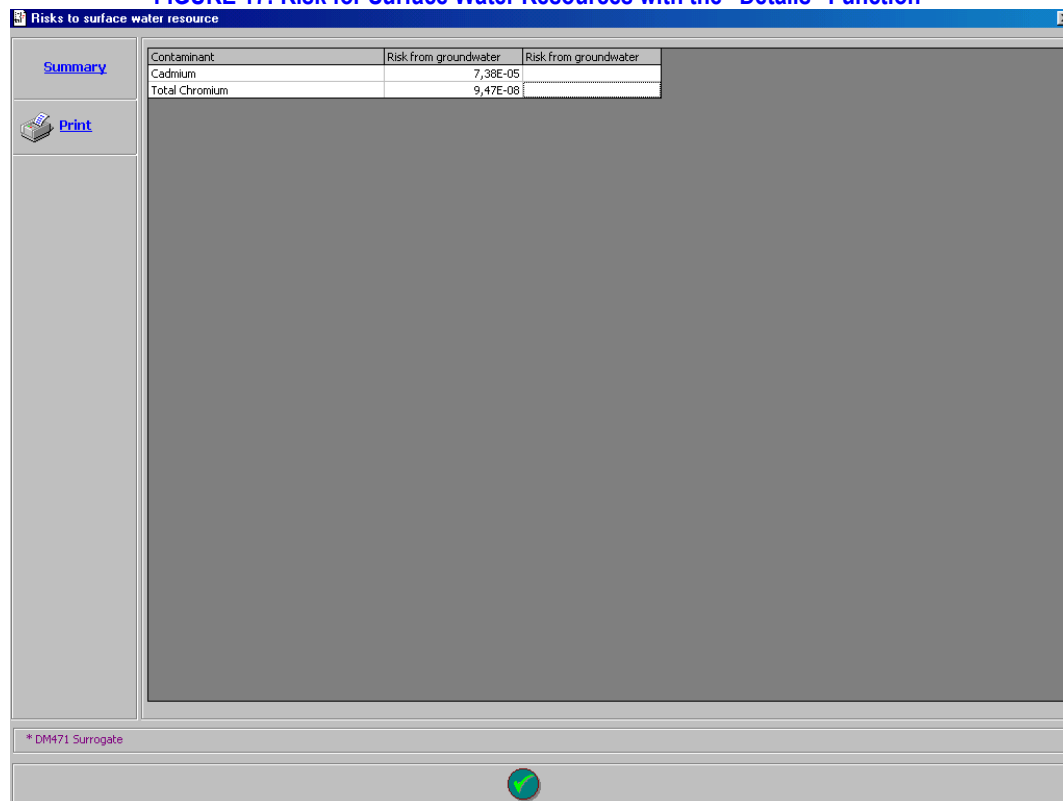
- First column: a list of contaminants of interest for the risk analysis;
- Second column: risk acceptability or non-acceptability for the resource due to contaminants present in the soil (surface and deep);
- Third column: risk acceptability or non-acceptability for the resource due to contaminants present in the soil. The contaminants are assessed on the base of leachate tests results;
- Fourth column: risk acceptability or non-acceptability for the resource due to contaminants present in groundwater (migration of the contamination found in groundwater and its dilution in the surface water resources);
- Fifth column: risk acceptability or non-acceptability for the resource due to contaminants present as floating free product.

The second to fifth columns are displayed only if contaminants were found in the corresponding environmental media, or in free product floating on groundwater.

Selecting the “Details” option allows you to visualize a table with the same columns described for the “Summary” option, with the difference that these report the results of the risk assessment numerically (instead of in terms of acceptability or non-acceptability) ([Figure 17](#)).

Both options (“Summary” and “Details”) highlight in red all risks with values higher than 1, that is, non-acceptable risks.

FIGURE 17: Risk for Surface Water Resources with the “Details” Function



2.5.3.3 Cleanup Targets (SALs)

SALs, or site-specific acceptability levels, derived by the risk analysis can be calculated in two different ways:

- For individual, single substances, without taking into account possible additive effects of other contaminant substances present simultaneously on the site: this is the default calculation mode. This method of calculation can also be activated by deselecting the text "Consider Substance Additivity", located in the lower left part of the screen;
- For similar substances, by considering an additivity of effects factor for the human receptor: this calculation mode can be activated by selecting the text "Consider Substance Additivity".

Independent of the chosen measurement mode, SALs for a contaminant are, by definition, calculated only when a non-acceptable risk exists in relation to a specific environmental matrix and for a given receptor. In any other circumstance, a SAL is not calculated and the box within the SALs results table remains blank. Please see [Annex 2](#) for a detailed description on how SALs are measured.

2.5.3.3.1 SALs Calculation for Single Substances

The table with SALs calculated for individual, single substances contains the following information ([Figure 18](#)):

- First column: a list of contaminants of interest for the risk analysis;
- Second to seventh columns: SALs for protection of human health:
 - The first three columns are for residential/recreational land use;
 - The following three columns are for industrial/business land use;
- Columns eight to thirteen: SALs for protection of water resources:
 - The first three columns are for protection of groundwater resources;
 - The following three columns are for protection of surface water resources.

These columns are completed only if contaminants were found in the corresponding environmental media, and if these involve a non-acceptable risk for the receptors present on the site.

FIGURE 18: Cleanup Target without Selection of the Additivity Function

Cleanup values									
Contaminant	HUMAN HEALTH PROTECTION (additivity not considered)						WATER RESOURCES PROTECTION		
	Residential / Recreational			Industrial / Commercial			Groundwater		
	Shallow soil	Deep soil	Groundwater	Shallow soil	Deep soil	Groundwater	Soil	Soil (leachate)	Groundwater
1,2,3-Trichloropropane	3,20E-01			1,17E+00			1,42E-05		1,00E-01
1,2-Dichlorobenzene							1,42E+01		
Cadmium							5,09E+00		5,00E-01
Hexachlorobenzene	1,40E+00			5,10E+00			1,09E-01		1,00E-01
Ethyl benzene							1,46E+00		5,00E-01

☐ Consider the additivity of compounds

LAS are shown only if risks exceed the maximum acceptable level.

Shallow soil = LAS for shallow soil (mg/kg) d.w. Soil = LAS for soil (mg/kg) d.w. Soil (leachate) = LAS for leachate (mg/l)

Deep soil = LAS for deep soil (mg/kg) d.w. Groundwater = LAS for groundwater (mg/l) * DM471 Surrogate

The three columns relating to the protection of human health for residential/recreational land use contain the following information:

- First column: SALs for surface soil (mg/kg d.s. – dry substance);
- Second column: SALs for deep soil (mg/kg d.s.);
- Third column: SALs for groundwater (mg/l).

The following three columns, relating to protection of human health for industrial/business land use, are set in the same way.

The three columns relating to protection of groundwater resources contain the following information:

- First column: SALs for both surface and deep soil (mg/kg d.s.);
- Second column: SALs for soil leachate (mg/l);
- Third column: SALs for groundwater (mg/l).

The following three columns, relating to the protection of surface water resources are set in the same way.

When assessing soil SALs for groundwater protection, it is advisable to use, if available, leachate SALs (Soil (leachate)), as these are more representative of site conditions.

This means that, provided leachate tests have been performed and the risks to water resources associated with the leachate are acceptable, the site does not require soil cleanup actions for the protection of water resources (soil SALs for the protection of this receptor can therefore be ignored).

SALs for free product floating on groundwater cannot be meaningfully evaluated: should the assessment of the free product determine non-acceptable risks, it will be necessary to consider procedures to remove the free product from the site.

2.5.3.3.2 SALs Assessment Considering Additivity

As for non-additive SALs, additive SALs are derived only for those substances calculated to represent a non-acceptable risk. Nonetheless, it should be remembered that, considering the additivity of effects, some substances which present an acceptable risk when considered individually, could result in a non-acceptable risk due to additive effects when several similar substances are considered, thereby producing an additive SAL.

The table for SALs calculated considering additivity (**Figure 19**) contains the same information as that for substances considered individually (**Figure 18**): the columns relating to protection of man report additive SALs, whereas those relative to protection of water resources remain unchanged.

Select the “Display Additivity Details” button, located in the lower left portion of the screen shown in **Figure 19**, to visualize for which substances it is possible to calculate additive SALs, and on which organs non-carcinogenic substances act. Table A-7 provides a complete list of all substances considered by ROME V. 2.1., and of all organs on which each substance acts.

Please see **Annex 2** and **Appendix 2** for a detailed description of the general procedure used to calculate additive SALs.

FIGURE 19: Cleanup Target Selecting the Additivity Function

Contaminant	HUMAN HEALTH PROTECTION (additivity considered)						WATER RESOURCES PROTECTION		
	Residential / Recreational			Industrial / Commercial			Groundwater		
	Shallow soil	Deep soil	Groundwater	Shallow soil	Deep soil	Groundwater	Soil	Soil (leachate)	Groundwater
1,2,3-Trichloropropane	1,07E-01			3,89E-01			1,42E-05		1,00E-01
1,2-Dichlorobenzene							1,42E+01		
Cadmium							5,09E+00		5,00E+00
Hexachlorobenzene	4,67E-01			1,70E+00			1,09E-01		1,00E-01
Ethyl benzene							1,46E+00		5,00E-01

☒ Consider the additivity of compounds

LAS are shown only if risks exceed the maximum acceptable level.

Shallow soil = LAS for shallow soil (mg/kg) d.w. Soil = LAS for soil (mg/kg) d.w. Soil (leachate) = LAS for leachate (mg/l)

Deep soil = LAS for deep soil (mg/kg) d.w. Groundwater = LAS for groundwater (mg/l) * DM471 Surrogate

[Show additivity details](#)

2.5.3.3.3 Recommendations for SALs Use

The following approach is recommended when evaluating tables containing SALs:

- Establish the relevant land use/identify receptors for the cleanup targets under consideration;
- Residual concentrations for soil (surface and deep) and groundwater at the site must be equal to or less than the minimum SAL value calculated for the protection of human health and the SAL for protection of water resources (ground and surface);
- For the protection of water resources, SALs calculated for soil leachate (mg/l) are preferable to those for dry substance (mg/kg d.s.), as these are more representative of the real site conditions;
- Non-acceptable risks due to floating free product require the product's removal (SALs for free product cannot be calculated).

Intake assumptions and models specific to Level 2 risk analysis, produce conservative SALs. It is thus assumed that, in most cases, SALs assessed for individual substances are sufficiently precautionary for public health.

The use of additive SALs should be evaluated on a case-by-case base, in order to avoid excessive over-rating of risks, that are not truly representative of the risk effectively associated with the site.

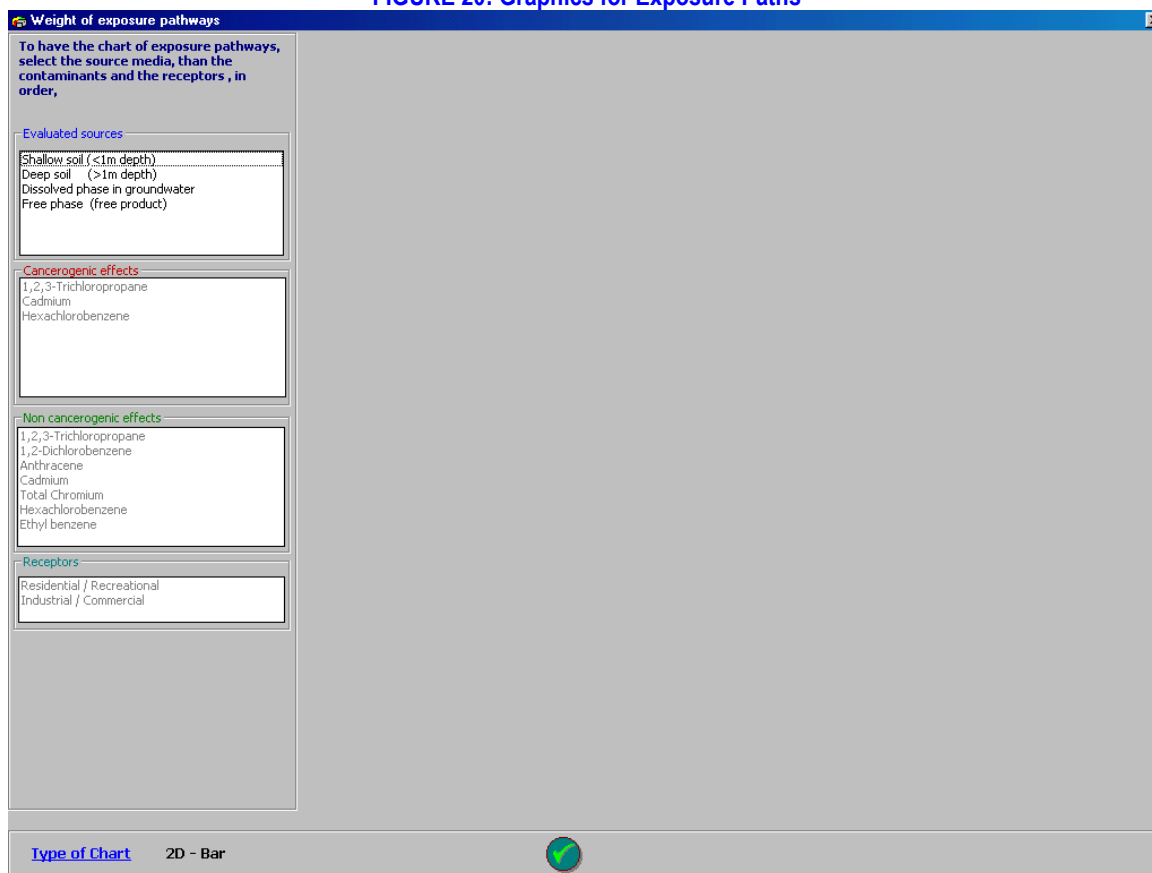
It is important to emphasise that SALs are designed to be protective of human health and water resources, and that the identification of appropriate residual concentrations for a site should also include consideration of other factors that are not strictly related to health, specifically:

- A comparison with the natural local background levels;
- Eco-toxicological criteria, which are not considered in ROME V. 2.1;
- Other relevant criteria (aesthetic criteria, odors, taste, and color), which in some cases can be important in defining an acceptable residual contamination: for some substances present in waters such as, for example, Phenols, Creosols, Chlorobenzene, and Dichlorobenzenes, the evaluation of an acceptable residual contamination also considers factors such as the odor and the taste acquired by the waters (Paragraph 3.1 in [Annex 1](#)).

2.5.4 Graphics for Exposure Paths

Select the “Graphics for Exposure Paths” icon from the main bar in the Menu, to access a graphic representation of the significance of each single exposure path with respect to the total risk for human health ([Figure 20](#)).

FIGURE 20: Graphics for Exposure Paths



Using the right mouse button within the tabulated boxes, located to the left of the screen, to select specific information, you can use to create the desired graph. These include:

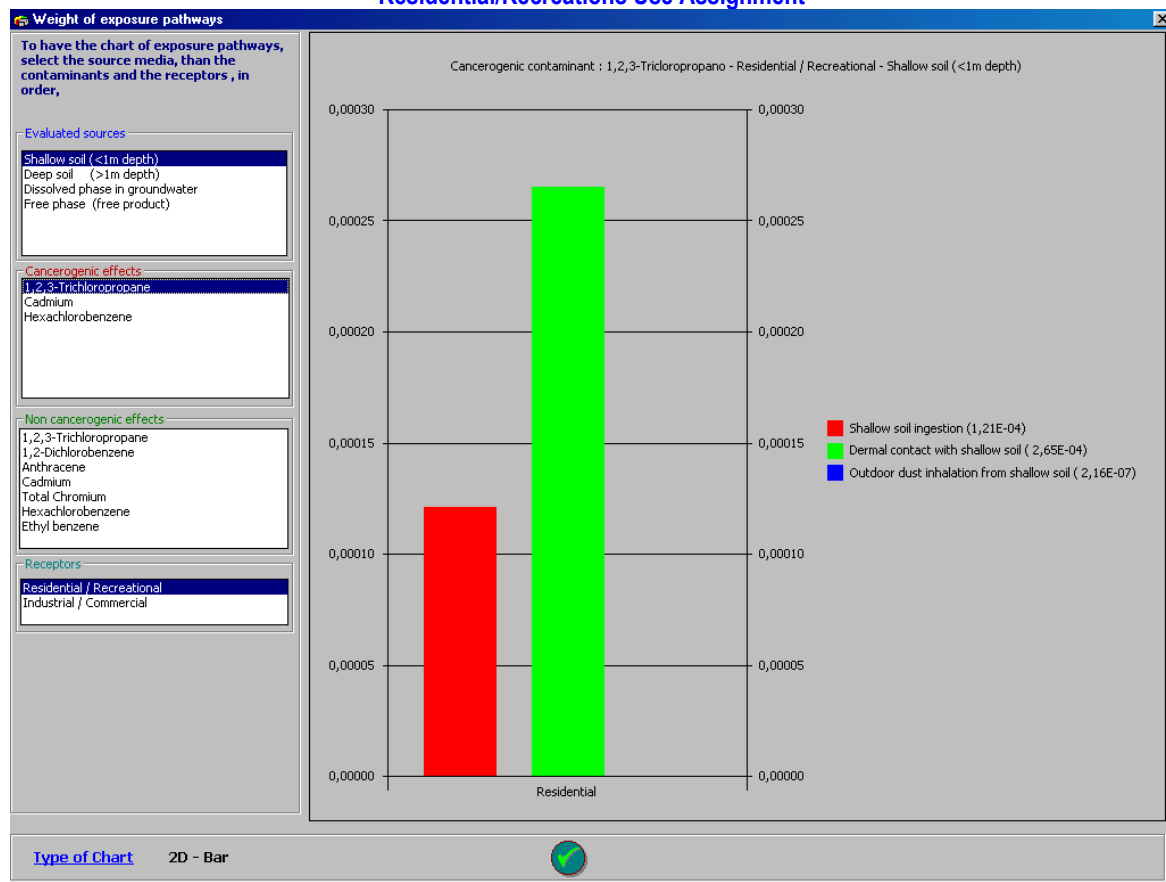
- First box: the source (contaminated environmental media): surface soil, deep soil, and dissolved phase in groundwater;
- Second and third box: the contaminant, from those of interest for the risk analysis, classified as having “carcinogenic effects, and “non-carcinogenic effects” respectively;
- Fourth box: human receptors, including residents (Residential/Recreational use assignment), and workers (Industrial/business use assignment).

In the bottom section of the column, the User can also select a “graph type”, which offers the following choices: 2D bar graph, 2D pie chart, and 3D bar graph.

For each graph type, the figure presents the selected features, and a key illustrates all active paths for these features, as well as the numerical value for the calculated risk ([Figure 21](#)).

Please note that paths with little or no significance with respect to the total risk do not appear in the graph, and are reported only by the key.

FIGURE 21: Graph of Exposure Paths Significance over Total Risk for 1,2,3-Trichloropropane in Surface Soil for Residential/Recreations Use Assignment



2.6 Printing Data

ROME V. 2.1 offers a print option that can be used to print the main data types and the results of the risk analysis. An icon labeled "Print" is available in the following screens:

- Human Exposure Parameters;
- Site Characteristics;
- Chemical-physical Parameters;
- Toxicological Parameters;
- Risk Analysis for Man (carcinogenic and non-carcinogenic risks);
- Risk Analysis for Ground Water Resources;
- Risk Analysis for Surface Water Resources.

To start printing, select the label "Print" and follow the instructions.

Furthermore, each screen displayed by ROME can be saved as an image by pressing in sequence the keys "Alt" + "Print", and subsequently pasting the output in the relevant program, such as Microsoft Word and Power Point.

2.7 Exit

To exit ROME, return to the Main screen, select the "Exit" icon, and answer affirmatively to the request to confirm your choice.

2.8 Tables

Table 1: Site Characteristics

General Parameters	Value	Symbol	Ref.
Wind average speed at soil surface (cm/s)	225	U_{air}	1
Open air mixing zone height (cm)	200	δ_{air}	1
Height for residential buildings (cm)	200	LB (R)	1
Height for industrial buildings (cm)	300	LB (I)	1
Air exchange rate for residential buildings (1/h)	0.504	ER (R)	1
Air exchange rate for industrial buildings (1/h)	0.828	ER (I)	1
Thickness foundations/walls for buildings (cm)	15	L_{crack}	1
Fraction of fractures per area (in foundations/walls) (-)	0.01	n	1
Air content in fractures (-)	0.26	ϕ_{acrack}	1
Water content in fractures (-)	0.12	ϕ_{wcrack}	1
Non-saturated zone parameters			
Dry density (g/cm ³)	1.7	ρ_s	1
Organic carbon fraction in non sature zone (g-C/g-soil)	0.01	F_{oc}	1
Contamination depth in surface soil (cm)	50	Ls(s)	2
Contamination depth in deep soil (cm)	100	Ls(p)	2
Capillarity fringe thickness (cm)	5	h_{cap}	1
Non-sature zone thickness (cm)	295	h_v	= $L_{GW} - h_{cap}$
Air content in soil (-)	0.26	ϕ_{as}	1
Water content in soil (-)	0.12	ϕ_{ws}	1
Soil total porosity (-)	0.38	ϕ_T	= $\phi_{as} + \phi_{ws}$
Air content in capillary fringe (-)	0.038	ϕ_{acap}	1
Water content in capillary fringe (-)	0.342	ϕ_{wcap}	1
Fraction of soil particles in dust (-)	1	F_{sd}	2
Concentration of outdoor dust (mg/m ³)	0.07	PMo	4
Fraction of indoor dust (-)	1	Fi	2
Concentration of indoor dust (mg/m ³)	0.07	PMi	PMox Fi
Source width perpendicular to wind direction (m)	15	W	2
Source length parallel to wind direction (m)	15	LW	2
Source width perpendicular to groundwater flow direction (m)	15	Swp	3
Source length parallel to groundwater flow direction (m)	15	L	1
Saturated zone parameters			
Aquifer dry density (g/cm ³)	1.7	ρ_s (sat)	3
Fraction of organic carbon in saturated zone (g-C/g-soil)	0.001	$F_{oc}(sat)$	3
Groundwater subgency (cm)	300	Lgw	1
Aquifer saturated thickness (m)	10	esat	2
Thickness of aquifer contaminated by dissolved phase (m)	20.5	Sd	2
Depth of free product (LNAPL) (cm)	400	Ls	1
Width of zone contaminated with product (m)	10	Wp	3
Length of zone contaminated with product (m)	10	Lp	3
Thickness of aquifer contaminated by LNAPL (m)	1	Sp	2
Effective infiltration (m/year)	0.3	I	1
Aquifer hydraulic conductivity (m/day)	13.7	K	3
Hydraulic gradient (-)	0.005	i	1
Effective aquifer porosity (-)	0.15	n_e	3
Longitudinal dispersiveness (cm)	10	a_l	3
Transversal dispersiveness (cm)	3.3	a_t	3
Vertical dispersiveness (cm)	1	a_z	3
Compliance point distance from source (m)	0.1	dist	2
Surface water resources parameters			
Distance from surface water resource (m)	100	dist (ris)	2
Surface water resource concentration uphill from site (mg/l)	0	Cu	2
Surface water resource discharge uphill from site (m ³ /s)	1	Qu	2
Discharge of groundwater drained by surface water resource (m ³ /s)	0,1	Qa	2

NB: values shown in bold cannot be modified.

References: 1) "RBCA" (ASTM, 1995); 2) Conservative type assumption; 3) Average value in an Italian site; 4) "RIVM Report" (value used to calculate "Intervention Values" for Dutch Tables)

Table 2: Human Exposure Parameters

Human Exposure Parameter	Adults	Ref.	Children	Ref.	Workers	Ref.
Body weight (kg)	70	1.2	15	1	70	1.2
Exposure time (years)	24	1	6	1	25	1.2
Exposure frequency (days/year)	350	1.2	350	1	240	7
Life time (days)	25550	3	25550	3	25550	3
Soil intake rate (mg/day)	100	1.2	200	1	50	1.2
Skin surface (cm ²)	17938	4	6381	4	17938	4
Fraction of exposed skin (-)	0.2	3a	0.5	3	0.2	3
Adhesion factor (mg/cm ² - day)	1	3b	1	3b	1	3b
Indoor intake rate (m ³ /day)	15	1	6	3.6	8	3.6
Outdoor intake rate (m ³ /day)	5	1	3	3.6	2	3.6
Fraction of time spent on the site (-)	1	5	1	5	1	5

Bibliographic references:

- 1 "Supplementary Risk Assessment Guidance for Superfund" (USEPA, 1989)
- 2 "Risk-Based Corrective Action Applied at Petroleum Release Sites" (ASTM, 1995)
- 3 "Exposure Factors Handbook" (USEPA, 1996)
 - 3a: same as industrial use
 - 3b: mean value between the range supplied by USEPA
- 4 Calculated from body weight (ICRP, 1975)
- 5 Conservative type assumption
- 6 "RIVM Report" (value used to calculate "Intervention Values" in Dutch Tables)
- 7 "Air Quality Guidelines for Europe" (Organizzazione Mondiale della Sanità, 1987)

Table 3: Chemical-physical Parameters

Substances	CAS	MW (g/mole)	Ref.	H (-)	Ref.	Koc (*) (ml/g)	Ref.	Sol (mg/l)	Ref.	Dair (cm ² /s)	Ref.	Dwat (cm ² /s)	Ref.
1,1,1-Trichloroethane	71556	133.4	7	0.705	1	135	1g	1330	1	0.078	1	0.0000088	1
1,1,2,2-Tetrachloroethane	79345	167.9	7	0.0182	7	74.1	7	2960	7	0.071	10	0.0000079	10
1,1,2-Trichloroethane	79005	133.4	7	0.0374	1	75	1g	4420	1	0.078	1	0.0000088	1
1,1-Dichloroethane	75343	99	7	0.23	1	53	1g	5060	1	0.0742	1	0.0000105	1
1,1-Dichloroethene	75354	96.9	7	1.07	1	65	1g	2250	1	0.09	1	0.0000104	1
1,2,3-Trichloropropane	96184	14.4	7	0.0155	7	97.2	13	1900	7	0.0701	9	0.0000079	9
1,2,4,5-Tetrachlorobenzene	95943	215.9	7	0.0494	7	1780	7	1.27	7	0.0521	14	0.00000622	15
1,2,4-Trichlorobenzene	120821	181.5	7	0.0582	1	1660	1g	300	1	0.03	1	0.00000823	1
1,2-Ethylene dibromide	106934	187.9	7	0.0266	7	44	7	4150	7	0.0762	14	0.00000871	15
1,2-Dichlorobenzene	95501	147	8	0.0779	1	379	1g	156	1	0.069	1	0.0000079	1
1,2-Ethylene chloride	107062	99	7	0.0401	1	38	1g	8520	1	0.104	1	0.0000099	1
1,2-Dichloroethylene	540590	96.9	7	0.186	7	49	7	3500	7	0.0736	10	0.0000113	10
1,2-Dichloropropane	78875	113	7	0.115	10	47	10	2800	10	0.0782	10	0.00000873	10
1,2-Dinitrobenzene	528290	168.11	16	0.000902	9	94.3	7	1070	9	0.279	9	0.00000764	9
1,3-Dichlorobenzene	541731	147	8	0.151	2	1700	2c	123	1	0.069	s	0.0000079	s
1,3-Dinitrobenzene	99650	168.11	16	0.000902	9	94.3	7	1070	9	0.279	9	0.00000764	9
1,4-Dichlorobenzene	106467	147	8	0.0996	1	616	1g	73.8	1	0.069	1	0.0000079	1
2,3,4,6-Tetrachlorophenol	58902	213.9	7	0.000105	5	1580	5	1000	2	0.1	s	0.00001	s
2,4,6-Trichlorophenol	88062	197.5	7	0.000319	1	2000	2	800	1	0.0318	1	0.00000625	1
2,4-Dichlorophenol	120832	162.9	7	0.00013	1	380	2	4500	1	0.0346	1	0.00000877	1
2-Chlorophenol	95578	128.6	8	0.016	1	363	c	22000	1	0.0501	1	0.00000946	1
Acenaphthene	83329	154.2	7	0.00636	1	4900	1g	4.24	1	0.0421	1	0.00000769	1
Acenaphthylene	208968	150.2	7	0.0622	2	2500	2	3.93	2	0.1	d	0.00001	d
Phthalic acid	88993	166.1	20	0.541	9	66.7	18	2000	9	0.064	9	0.0000068	9
Acrylamide	79061	71.1	7	5.83E-08	7	0.107	7	2050000	7	0.0817	14	0.00000996	15
Acrylonitrile	107131	5.1	7	0.00371	2c	0.85	2	79000	2	0.1	d	0.00001	d
Aldrin	309002	364.9	7	0.00697	1	48700	1g	0.18	1	0.0132	1	0.00000486	1
Alpha-hexachlorohexane	319846	290.9		0.000352		6920		1	7	0.0446	9	0.0000052	9
Aniline	62533	93.1	7	0.0000449	9	350	7	34000	9	0.0761	9	0.0000083	11
Antimony	7440360					45	1	6000	9				
Anthracene	120127	178.2	7	0.00267	1	23500	1g	0.0434	1	0.0324	1	0.00000774	1
Silver	7440224					8.3	1						
Arsenic	7440382					29	1	1000					
Atrazine	1912249	215.7	7	0.000000109	c	746	1	70	c	0.1	d	0.00001	d
Barium	7440393					41	1						
Benzene	71432	78.1	7	0.228	1	62	1g	1750	1	0.088	1	0.0000098	1
Benzo(a)anthracene	56553	228.3	7	0.000137	1	358000	1g	0.0094	1	0.051	1	0.000009	1
Benzo(a)pyrene	50328	252.3	7	0.0000463	1	969000	1g	0.00162	1	0.043	1	0.000009	1

Substances	CAS	MW (g/mole)	Ref.	H (-)	Ref.	Koc (*) (ml/g)	Ref.	Sol (mg/l)	Ref.	Dair (cm ² /s)	Ref.	Dwat (cm ² /s)	Ref.
Benzo(b)fluoranthene	205992	252.3	7	0.00455	1	1230000	1c	0.0015	1	0.0226	1	0.00000556	1
Benzo(g,h,i)perylene	191242	268.4	7	0.00000224	2c	1600000	2	0.0007	2	0.1	d	0.00001	d
Benzo(k,j)fluoranthene	205823	252.3	7	0.00000647	7	550000	7	0.0008	7	0.0226	10	0.00000556	10
Beryllium	7440417					790	1	1700	9				
Beta-hexachloroexane	319857	290.9	7	0.0000469	7	2290	7	0.1	7	0.0446	9	0.0000052	9
Bis(2-etilexil)phtalate	137893	390.5	8	0.00000418	1	111000	1g	0.34	1	0.0351	1	0.00000366	1
Bromodichloromethane	75274	163.8	13	0.0982	7	61	7	1500	7	0.0298	9	0.0000106	9
Cadmium	7440439					75	1	1700	9				
Free Cyanides	57125	27	9	0.00000111	9	99	10	0.076	9	0.521	9	0.0000228	9
Chlordane	57749	409.8	7	0.00199	1	51300	1g	0.056	1	0.0118	1	0.00000437	1
Chloromethane	74873	50.5	7	0.395	7	4.29	7	5240	7	0.104	14	0.0000131	15
Chloronitrobenzenes	100005	157.6	8	0.000647	8	160	8	200	8	0.0315	9	0.00000937	9
Vinyl chloride	75014	62.5	7	1.11	7	18.6	10	2760	7	0.106	10	0.00000123	10
Cobalt	7440484					60	5						
Chrysene	218019	228.3	7	0.00388	1	398000	1c	0.0016	1	0.0248	1	0.00000621	1
Chromium (VI)	18540299					19	1						
Total Chromium	7440473					1200		0.005	19				
DDD	72548	320	7	0.000164	1	458000	1g	0.09	1	0.0169	1	0.00000476	1
DDE	72559	319	7	0.000861	1	86400	1g	0.12	1	0.0144	1	0.00000587	1
DDT	50293	354.5	7	0.000332	1	678000	1g	0.025	1	0.0137	1	0.00000495	1
Dibenzo(a,h)anthracene	53703	278.4	7	0.000000603	1	1790000	1g	0.00249	1	0.0202	1	0.00000518	1
Dibenzo(a)pyrene		278.4	7	0.00000308	7	1660000	7	0.00249	7	0.0202	10	0.00000518	10
Dibenzofuran	132649	168.2	7	0.000031	9	9120	9	10	9	0.0578	9	0.000006	9
Dibromochloromethane	124481	208.3	9	0.00233	9	34.5	13	17300	9	0.025	9	0.00000757	9
Dichloromethane	75092	84.9		0.0898	1	10	1	13000	1	0.101	1	0.0000117	1
Dieldrin	60571	380.9	7	0.000619	1	25500	1g	0.195	1	0.0125	1	0.00000474	1
Diphenylamine		169.2	7	0.0000142	7	365	7	300	7	0.0503	1	0.00000906	1
Endrin	72208	380.9	7	0.000308	1	10800	1g	0.25	1	0.0125	1	0.00000474	1
Eptachlor	76448	373.3	7	0.0344	1	9530	1g	0.18	1	0.0112	1	0.00000569	1
Hexachlorobenzene	118741	284.8	7	0.0541	1	80000	1g	6.2	1	0.0542	1	0.00000591	9
Hesachlorobutadiene	87683	260.76		0.334	1	295	t	3.23	1	0.0561	10	0.0000061	1
Ethyl benzene	100414	106.2	7	0.323	1	204	1g	169	1	0.075	1	0.0000078	9
Phenanthrene	85018	178.2	7	0.00668	2c	14000	2	1	2	0.1	d	0.00001	
Phenol	108952	94.1	7	0.0000163	1	28.8	2c	82800	1	0.082	1	0.0000091	9
Iron	7439896					165	5						
Fluoranthene	206440	202.3	7	0.00066	1	49100	1g	0.206	1	0.0302	1	0.00000635	1
Fluorene	86737	166.2	7	0.00261	1	7710	1g	1.98	1	0.0363	1	0.00000788	1
Indeno(1,2,3-c,d)pyrene	193395	276.3	9	0.0000656	1	3470000	1c	0.000022	1	0.019	1	0.00000566	1
Cumene	98828	120.2	7	0.211	3	2820	3	50	7	0.065	1	0.0000073	1

Substances	CAS	MW (g/mole)	Ref.	H (-)	Ref.	Koc (*) (ml/g)	Ref.	Sol (mg/l)	Ref.	Dair (cm ² /s)	Ref.	Dwat (cm ² /s)	Ref.
Lindane	58899	290.9	7	0.000574	1	1350	1g	6.8	1	0.0142	1	0.00000734	1
m,p-Anisidine	536903	123.2	16	0.00000175	9	6.3	18	130000	9	0.0565	9	0.00000893	9
Manganese	7439965					50	5						
Mercury	7439976			0.47	1	5200	1	600	9	0.13	1	0.00000724	9
m-Methylphenol	108394	108.15	8	0.0000369	7	34.7	7	22000	7	0.0613	14	0.00000717	15
Molybdenum	7439987					10	5						
Monochlorobenzene	108907	112.6	7	0.152	1	224	1g	472	1	0.073	1	0.0000087	1
Naphthalene	91203	128.2	7	0.0198	1	1190	1g	31	1	0.059	1	0.0000075	1
Nickel	7440020					65	1						
Nitrobenzene	98953	123.1	8	0.000524	7	50.1	7	1900	7	0.076	10	0.0000086	10
o-Anisidine	90040	123.2	16	0.00000175	9	6.7	18	130000	9	0.0565	9	0.00000893	9
o-Methylphenol	95487	108.15	8	0.0000631	7	21.9	7	26000	7	0.074	10	0.0000083	10
PCB	1336363	274	7	0.0445	1	530000	1	0.59	1	0.043	1	0.00000422	1
Pentachlorobenzene	608935	250.34		0.0316	t	31600	t	0.65	t	0.067	10	0.000009	10
Pentachlorophenol	87865	266.3	2	0.000001	1	53000	2	1950	1	0.056	1	0.0000061	1
Lead	7439921					55	5	12000					
Pyrene	129000	202.3	7	0.000451	1	68000	1g	0.135	1	0.0272	1	0.00000724	1
p-Chloroaniline	106478	127.6	7	0.0000136	1	66.1	1	5300	1	0.0483	1	0.0000101	1
p-Methylphenol	106445	108.15	8	0.0000264	7	49	7	20000	7	0.0644	14	0.0000768	15
p-Toluidina	106490	107.16	t	0.00328	t	25.1	t	7200	t	0.08	t	0.0000099	t
Copper	7440508					35	6						
Selenium	7782492					5	1						
Sum. PCDD, PCDF(conv. T.E.)		322	7	0.0135	7	1100000	7	0.000019	7	0.1	d	0.00001	d
Tin	7440315					50	17						
Styrene	100425	104.1	7	0.13	1	912	1g	310	1	0.071	1	0.000008	1
Thallium	7440280					59900	7						
Tetrachloroethylene	127184	165.8	7	0.754	1	265	1g	200	1	0.072	1	0.0000082	1
Carbon tetrachloride	56235	153.8	7	1.25	1	152	1g	793	1	0.078	1	0.0000088	1
Toluene	108883	92.1	7	0.272	1	140	1g	526	1	0.087	1	0.0000086	1
Bromoform	75252	252.8	7	0.0239	7	126	10	3100	7	0.0149	10	0.0000103	10
Trichloroethylene	79016	131.4	7	0.422	1	94	1g	1100	1	0.079	1	0.0000091	1
Chloroform	67663	119.4	7	0.15	1	53	1g	7920	1	0.104	1	0.00001	1
Vanadium	7440622					1000	1						
Xylene (m)	108323	106.2	7	0.301	10	196	1c	161	7	0.07	10	0.0000078	10
Xylene (p)	106423	106.2	7	0.314	10	311	1c	185	7	0.0769	10	0.00000844	10
Xylene (o)	95476	106.2	7	0.213	10	241	1c	178	7	0.087	10	0.00001	10
Xylenes	1330207	106.2	7	0.314	c	196	c	161	7	0.087	c	0.00001	c
Zinc	7440666					62	1						
Hydrocarbons C<12 (Gasolines range)		78.1	21	0.228	21	62	21	1750	21	0.088	21	0.0000098	5

Substances	CAS	MW (g/mole)	Ref.	H (-)	Ref.	Koc (*) (ml/g)	Ref.	Sol (mg/l)	Ref.	Dair (cm ² /s)	Ref.	Dwat (cm ² /s)	Ref.
Hydrocarbons C>12 (Gas oils range)		202.3	22	0.000451	22	68000	22	0.135	22	0.0272	22	0.00000724	22

(*) Kd for metals

Bibliographic reference:

- 1 "Soil Screening Guidance: Technical Background Document" (USEPA, 1996)
- 1c "Soil Screening Guidance: Technical Background Document" (USEPA, 1996) - (calculated)
- 1g "Soil Screening Guidance: Technical Background Document" (USEPA, 1996) - (geometrical average)
- 2 "Superfund Public Health Evaluation Manual" (USEPA, 1986)
- 2c "Superfund Public Health Evaluation Manual" (USEPA, 1986) - (calculated)
- 3 "Groundwater Chemicals Desk Reference" (Montgomery, 1996)
- 4 "Selection of Representative TPH Fractions Based on Fate and Transport Considerations" (TPH Criteria working Group, Vol. III, 1997)
- 5 "Default Soil, Soil/Liquid Partition, Coefficients, Kds, for Major Soil Types: A Compendium" (Sheppard and Thibault, 1990)
- 6 "A Review and Analysis of Parameters for Assessing Transport of Environmental Released Radionuclides through Agriculture (Baes et Al., 1984)
- 7 Mackay, D., Wan-Ying, S., Kuo-Ching, M. 1997. "Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals". CRP Press LLC
- 8 Croner's Substances Hazardous to the Environment. Croner Publications Ltd
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- 10 US EPA. 1996. "Technical Background Document for Soil Screening Guidance – Review Draft".
- 11 Calculated with Le Bas molar volume, after Hayduk, W, e Laudie, H. 1974. Prediction of diffusion coefficients for non-electrolysis in dilute aqueous solutions. AIChE J 20,611-15
- c Calculated with other parameters
- d Default value (assuming the worst case)
- s Value of a substitute with similar characteristics
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- 13 Calculated from solubility and molar weight, after Chiou, CT, Peters, LJ. and Freed, VH. 1979. "A physical concept of soil-water equilibria for non-ionic organic compounds." Science 206, 831-832
- 14 Calculated from Le Bas molar volume and from molecular weight after Fuller, EN, Schettler, PD, and Giddings, JC. 1966. "A new method for the prediction of binary gas-phase diffusion coefficients." Ind. En. Chem. 58, 19-27.
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- 16 Budavari, S. (Ed). 1989. "The Merck Index Eleventh Edition." Merck and Co., Inc., Rahway NJ, USA.
- 17 Spitz, K, and Moreno, o, J. 1996. A Practical Guide to Groundwater and Solute Transport Modelling. John Wiley and Sons, Inc., New York.
- 18 Calculated from solubility, after Kenaga, EE and Goring, CAI. 1980. "Relationship between water solubility, soil sorption, octanol-water partitioning, and bioconcentration of chemicals in biota." Special Technical Publication 707. ASTM, Philadelphia, PA.
- 19 Hern, J.D. 1989. "Study and Interpretation of the Chemical Characteristics of Natural Water." USGS Water Supply Paper 2254. US Government Printing Office, Washington DC.
- 20 Sax, NI, and Irving R.J.L. 1989. Dangerous Properties of Industrial Materials, Seventh Edition. Van Nostrold Reinhold, New York
- t TAC 350.53 - Chemical/Physical Parameter Values (State of Texas).
- 21 Benzene parameters
- 22 Pyrene parameters

Table 4: Toxicological parameters

Substances	CAS	TDI ing. (*)	Ref.	TDI inal. (*)	Ref.	SF ing. (-)	Ref.	SF inal. (-)	Ref.
1,1,1-Trichloorethane	71556	0.6	W	0.6	r				
1,1,2,2-Tetrachloroethane	79345	0.06	l	0.06	r	0.2	l	0.2	l
1,1,2-Trichloroethane	79005	0.004	l	0.004	r	0.06	l	0.06	l
1,1-Ethylene chloride	75343	0.1	H	0.14	H				
1,1-Dichloroethylene	75354	0.009	l	0.009	r	0.6	l	0.2	l
1,2,3-Trichloropropane	96184	0.006	l	0.006	r	7	H	7	R
1,2,4,5-Tetraclorobenzene	95943	0.0003	l	0.0003	r				
1,2,4-Triclorobenzene	120821	0.01	l	0.01	r				
1,2-Ethylene dibromide	106934					85	l	0.77	l
1,2-Dichlorobenzene	95501	0.09	l	0.04	H				
1,2-Ethylene chloride	107062					0.09	l	0.09	l
1,2-Dichloroethylene	540590	0.009	H	0.009	r				
1,2-Dichloropropane	78875	0.00114	r	0.00114	l	0.068	H	0.068	r
1,2-Dinitrobenzene	528290	0.0004	l	0.0004	r				
1,3-Dichlorobenzene	541731	0.03	l	0.03	r				
1,3-Dinitrobenzene	99650	0.0001	l	0.001	r				
1,4-Dichlorobenzene	106467	0.23	r	0.23	l				
2,3,4,6-Tetrachlorophenol	58902	0.03	l	0.03	r				
2,4,6-Trichlorophenol	88062					0.01	l	0.01	l
2,4-Dichlorophenol	120832	0.003	l	0.003	r				
2-Chlorophenol	95578	0.005	l	0.005	r				
Acenaphthene	83329	0.06	l	0.06	r				
Acenaphthylene	208968	0.06	l	0.06	r				
Phthalic acid	88993	1	H	1	r				
Acrylamide	79061	0.0002	l	0.0002	r	4.5	l	4.5	l
Acrylonitrile	107131	0.0006	l	0.0006	r	0.54	l	0.24	l
Alaclor	15972608	0.01	l	0.01	r	0.08	H	0.08	r
Aldrin	309002	0.00003	l	0.00003	r	17	l	17.15	l
Alpha-hexachlorohexane	319846					6.3	l	6.3	r
Aniline	62533	0.0003	r	0.0003	l	0.0057	l	0.0057	r
Antimony	7440360	0.0004	l	0.0004	r				
Anthracene	120127	0.3	l	0.3	r				
Silver	7440224	0.005	l	0.005	r				
Arsenic	7440382	0.0003	l	0.0003	r	1.5	l	15	l
Atrazine	1912249	0.035	l	0.035	r	0.22	H	0.22	r
Barium	7440393	0.07	l	0.07	r				
Benzene	71432			0.0017	E	0.029	l	0.029	l
Benzo(a)anthracene	56553					0.7	E	0.6	E
Benzo(a)pyrene	50328					7.3	l	6.1	E
Benzo(b)fluoranthene	205992					0.7	E	0.6	E
Benzo(g,h,i)perylene	191242	0.03	b	0.03	b				
Benzo(k,j)fluoranthene	205823					0.073	l	0.031	l
Beryllium	7440417	0.002	l	0.000006	r	4.3	l	8.4	l
Beta-hexachloroexane	319857					1.8	l	1.8	r
Bis(2-etilexil)phtalate	137893	0.02	l	0.02	r	0.014	l	0.014	r
Bromodichloromethane	75274	0.02	l	0.02	r	0.062	l	0.062	r
Cadmium	7440439	0.001	l	0.001	r			6.3	l
Free Cyanides	57125	0.02	l	0.02	r				
Chlordane	57749	0.0005	l	0.0025	r	0.35	l	0.35	l
Chloromethane	74873			0.086	l	0.013	l	0.0035	l
Chloronitrobenzenes	100005					0.025	H	0.025	r
Vinyl chloride	75014					1.9	H	0.3	H
Cobalt	7440484	0.06	E	0.00029	E				

Substances	CAS	TDI ing. (*)	Ref.	TDI inal. (*)	Ref.	SF ing. (-)	Ref.	SF inal. (-)	Ref.
Chrysene	218019	0.03	b	0.03	r	0.007	E	0.006	E
Chromium (VI)	18540299	0.003	l	0.00003	l			41	H
Total Chromium	7440473	1.5	l	1.5	r				
DDD	72548	0.0005	l	0.0005	r	0.24	l	0.24	l
DDE	72559	0.0005	l	0.0005	r	0.34	l	0.34	l
DDT	50293	0.0005	l	0.0005	r	0.34	l	0.34	l
Dibenzo(a,h)anthracene	53703					7.3	E	6.1	E
Dibenzo(a)pyrene	189640					120	O	39	O
Dibenzofuran	132649	0.004	E	0.004	r				
Dibromochloromethane	124481	0.02	l	0.02	r	0.084	l	0.084	r
Dichloromethane	75092	0.06	l	0.06	r	0.008	l	0.002	l
Dieldrin	60571	0.00005	l	0.00005	r	16	l	16	l
Diphenylamine	122394	0.025	l	0.025	r				
Endrin	72208	0.0003	l	0.0003	r				
Eptachlor	76448	0.0005	l	0.0005	r	4.5	l	4.6	l
Hexachlorobenzene	118741	0.0008	l	0.0008	r	1.6	l	1.6	l
Hexachlorobutadiene	87683	0.0002	H	0.0002	r	0.078	l	0.078	l
Etyl benzene	100414	0.1	l	0.3	l				
Phenanthrene	85018	0.03	b	0.03	b				
Phenol	108952	0.6	r	0.6	l				
Iron	7439896	0.8	W	0.8	r				
Fluoranthene	206440	0.04	l	0.04	r				
Fluorene	86737	0.04	l	0.04	r				
Indeno(1,2,3-c,d)pyrene	193395	0.03	b	0.03	r	0.7	E	0.6	E
Isopropylbenzene (Cumene)	98828	0.1	l	0.11	l				
Lindane	58899	0.0003	l	0.0003	r				
m,p-Anisidine	536903	0.007	ASL	0.007	r				
Manganese	7439965	0.14	l	0.000014	l				
Mercury	7439976	0.0003	H	0.00009	l				
m-Metylphenol	108394	0.05	l	0.05	r				
Molybdenum	7439987	0.005	l	0.005	r				
Monochlorobenzene	108907	0.02	l	0.006	H				
Naphthalene	91203	0.04	T	0.05	T				
Nickel	7440020	0.02	l	0.02	r				
Nitrobenzene	98953	0.0005	l	0.0006	A				
o-Anisidine	90040	0.004	TRI	0.00006	TRI	0.14	CRI	0.14	CRI
o-Metylphenol	95487	0.05	l	0.05	r				
PCB	1336363					7.7	l	7.7	r
Pentachlorobenzene	608935	0.0008	l	0.0008	r				
Pentachlorophenol	87865	0.03	l	0.03	r	0.12	l	0.12	r
Lead	7439921	0.0035	W	0.0035	r				
Pyrene	129000	0.03	l	0.03	r				
p-Chloroaniline	106478	0.004	l	0.004	r				
p-Metylphenol	106445	0.005	H	0.005	r				
p-Toluidina	106490					0.19	H	0.19	r
Copper	7440508	0.04	H	0.5	r				
Selenium	7782492	0.005	l	0.005	r				
Sum. PCDD, PCDF(conv. T.E.)	1746016					150000	l	0.12	l
Tin	7440315	0.6	H	0.6	r				
Styrene	100425	0.2	l	0.29	l				
Thallium	7440280	0.00008	l	0.00008	r				
Tetrachloroethylene	127184	0.01	l	0.01	r	0.05	l	0.002	l
Carbon tetrachloride	56235	0.0007	l	0.0007	r	0.13	l	0.05	l
Toluene	108883	0.2	l	0.1	l				

Substances	CAS	TDI ing. (*)	Ref.	TDI inal. (*)	Ref.	SF ing. (-)	Ref.	SF inal. (-)	Ref.
Tribromomethane (Bromoform)	75252	0.02	I	0.02	r	0.0079	I	0.0039	I
Trichloroethylene	79016	0.006	E	0.006	r	0.01	I	0.002	E
Trichloromethane (Chloroform)	67663	0.01	I	0.01	r	0.006	I	0.08	I
Vanadium	7440622	0.007	H	0.007	r				
Xylene (m)	108323	0.2	W	0.2	r				
Xylene (p)	106423	0.2	W	0.2	r				
Xylene (o)	95476	0.2	W	0.2	r				
Xylenes	1330207	2	I	2	r				
Zinc	7440666	0.3	I	0.3	r				
Hydrocarbons C<12 (Gasolines range)		0.2	T	0.114	T				
Hydrocarbons C>12 (Gasolins range)		0.04	T	0.06	T				

(*) = mg/kg-day ; (-) = kg-day/mg

Bibliographic reference:

- H "Health Effects Assessment Summary Table" (HEAST)
- I "IRIS Database" (USEPA, 1996)
- E USEPA other data
- T "TPH Criteria Working Group" (1997)
- W "Drinking Water Guidelines" (WHO, 1993)
- b Based on Pyrene value
- r Extrapolation on the base of ingestion or inhalation value
- A "Agency for Toxic Substances and Disease Registry" (ATSDR, 1999).
- HC "Health Canada".
- ASL "A.S.L. Città di Milano" – Ex A.S.L. n. 38 – Presidio Multizonale di Igiene e Prevenzione – Chemical Operations.
- TRI "US EPA 1997". TRI (Toxics Release Inventory).
- CRI "Californian EPA Office of Environmental Health Hazard Assessment. Criteria for Carcinogens 11", 1994.
- O "Technical Support Document for Describing Available Cancer Potency Factors" (OEHHA, 1999)

Table 5: General Acceptability Limits (GAL)

Substances	RES GAL (mg/kg d.s.)	IND GAL (mg/kg d.s.)	GAL with g.w. protect. (mg/kg d.s.)
1,1,1-Trichloroethane	27	336	454
1,1,2,2-Tetrachloroethane	0.2	1.7	0.00055
1,1,2-Trichloroethane	0.3	2.6	0.002
1,1-Dichloroethane	8.4	105	7
1,1-Dichloroethene	0.003	0.06	0.0006
1,2,3-Trichloropropane	0.008	0.07	0.000014
1,2,4,5-Tetrachlorobenzene	2.5	23	0.44
1,2,4-Trichlorobenzene	106	1160	43
1,2-Dibromoethane	0.01	0.06	0.000007
1,2-Dichlorobenzene	46	569	14
1,2-Dichloroethane	0.07	0.7	0.018
1,2-Dichloroethylene	0.6	7.8	0.5
1,2-Dichloropropane	0.05	0.5	0.001
1,2-Dinitrobenzene	2.2	25.4	0.2
1,3-Dichlorobenzene	73	892	254
1,3-Dinitrobenzene	5.4	63.5	0.05
1,4-Dichlorobenzene	93	340	0.04
2,3,4,6-Tetrachlorophenol	997	8650	236
2,4,6-Trichlorophenol	219	809	1.4
2,4-Dichlorophenol	98	857	5.8
2-Chlorophenol	30	353	9
Acenaphthene	208	208	208
Acenaphthylene	99	99	99
Phthalic acid	38	478	412
Acrylamide	0.36	1.6	0.0001
Acrylonitrile	0.05	0.5	0.002
Alaclor	28	102	0.002
Aldrin	0.13	0.5	0.2
Alpha-hexachlorohexane	0.35	1.3	0.094
Aniline	9.9	86	0.5
Antimony	30	551	3
Anthracene	10	10	10
Silver	377	6890	1.1
Arsenic	3.7	24	4
Atrazine	10	37	0.03
Barium	5270	96400	1420
Benzene	0.07	0.7	0.01
Benzo(a)anthracene	3.2	12	4.9
Benzo(a)pyrene	0.3	1.1	1.3
Benzo(b)fluoranthene	3.2	11.6	16.7
Benzo(g,h,i)perylene	11	11	2.2
Benzo(k,j)fluoranthene	4.4	4.4	3.7
Beryllium	1.35	9	43
Beta-hexachloroexane	1.2	2.3	0.03
Bis(2-ethylhexyl)phthalate	160	377	377
Bromodichloromethane	0.23	2.1	0.0016
Cadmium	75	757	5.1
Free Cyanides	0.08	0.08	0.08
Chlordane	6.4	23.3	0.7
Chloromethane	0.07	0.7	0.0035
Chloronitrobenzenes	60	276	0.01
Vinyl chloride	0.0007	0.007	0.003
Cobalt	2900	31000	40
Chrysene	6.4	6.4	6.4
Chromium (VI)	27	116	1.3
Total Chromium	113000	2070000	814
DDD	9.3	34	6.2
DDE	6.6	24	1.2
DDT	6.6	24	9.2

Substances	RES GAL (mg/kg d.s.)	IND GAL (mg/kg d.s.)	GAL with g.w. protect. (mg/kg d.s.)
Dibenzo(a,h)anthracene	0.3	1.1	2.4
Dibenzo(a)pyrene	0.02	0.07	1.6
Dibenzofuran	135	913	181
Dibromochloromethane	4.2	32	0.0007
Dichloromethane	0.6	5.7	0.27
Dieldrin	0.14	0.5	0.1
Diphenylamine	830	1120	46
Endrin	10	27	0.15
Eptachlor	0.4	1.7	0.25
Hexachlorobenzene	1.2	4.8	0.1
Hexachlorobutadiene	0.05	0.6	0.006
Ethyl benzene	42.5	365	1.5
Phenanthrene	140	140	140
Phenol	18100	29700	106
Iron	60300	110000	448
Fluoranthene	101	101	101
Fluorene	153	153	153
Indeno(1,2,3-c,d)pyrene	0.8	0.8	0.8
Isopropylbenzene (Cumene)	329	1420	1400
Lindane	9.9	87	0.02
m,p-Anisidine	210	1880	0.5
Manganese	376	2360	34
Mercury	0.12	1.5	0.7
m-Methylphenol	1480	9190	10
Molybdenum	377	6890	25
Monochlorobenzene	2	25	1.3
Naphthalene	371	371	237
Nickel	1510	27500	17.6
Nitrobenzene	7.5	79	0.03
o-Anisidine	13	54	0.01
o-Methylphenol	1220	7530	7.2
PCB	0.3	1	0.7
Pentachlorobenzene	24	206	21.4
Pentachlorophenol	18.5	68	3.6
Lead	264	4820	7.5
Pyrene	92	92	92
p-Chloroaniline	130	1130	1.45
p-Methylphenol	131	1220	1.4
p-Toluidina	2.8	19.4	0.0015
Copper	3020	55550	476
Selenium	377	6890	0.7
Sum. PCDD, PCDF(conv. T.E.)	0.000015	0.00005	0.0006
Tin	45200	826000	14900
Styrene	496	2850	3.1
Thallium	6	110	1620
Tetrachloroethylene	0.84	10	0.04
Carbon tetrachloride	0.02	0.2	0.16
Toluene	10.3	129	0.3
Tribromomethane (Bromoform)	48	355	0.0054
Trichloroethylene	0.3	4	0.022
Trichloromethane (Cloroform)	0.02	0.13	0.0013
Vanadium	527	9640	3470
Xylene (m)	31.6	334	206
Xylene (p)	43	535	0.4
Xylene (o)	43.4	447	249
Xylenes	244	335	335
Zinc	22600	413000	2530
Hydrocarbons C<12 (Gasolines range)	0.16	2	229
Hydrocarbons C>12 (Gasolins range)	89	89	89

TABLE 6: Acceptable Ranges for the Parameter's Values and their Influence on SALs Calculation

Symbol	Parameters	Interested Paths	Fields of Action	Influence on SALs
α_1	Longitudinal dispersivity	Migration of contamination to groundwater	1 – 100 m	Avg/high
α_1/α_t	Ratio between longitudinal and transversal dispersivity	Migration of contamination to groundwater	3 – 10	Avg/high
α_1/α_z	Ratio between longitudinal and vertical dispersivity	Migration of contamination to groundwater	10 – 100	Avg/high
δ_{air}	Height of air exchange area in buildings	Outdoor inhalation of vapours from groundwater Outdoor inhalation of vapours from soil	100 – 250 cm	Low
η	Fraction of fractures per area	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil	0.001 – 0.1 cm ² -fractures / cm ² -total area	Low
θ_{acap}	Air content in capillary fringe	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater	0.05 – 0.40 cm ³ -air/cm ³ -soil	Average
θ_{acrack}	Air content in foundations/walls	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil	0.05 – 0.40 cm ³ -air/cm ³ -total volume	Low
θ_{as}	Air content in unsaturated area	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil Outdoor inhalation of vapours from soil Infiltration of contaminated waters from soil to groundwater	0.05 – 0.40 cm ³ -air / cm ³ -soil	High
θ_{ws}	Hydric content in unsaturated area	Internal vapours inhalation from groundwater External vapours inhalation from groundwater Internal vapours inhalation from soil External vapours inhalation from ground Infiltration of contaminated waters from soil to groundwater	0.05 – 0.40 cm ³ -H ₂ O / cm ³ -soil	High
θ_T	Soil total porosity	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil Outdoor inhalation of vapours from soil	0.25 – 0.70 cm ³ /cm ³ -soil	Low
θ_{wcap}	Water content in capillary fringe	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater	0.05 – 0.40 cm ³ -H ₂ O/cm ³ -soil	Average
θ_{wcrack}	Water content in foundations/walls	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil	0.05 – 0.40 cm ³ -H ₂ O/cm ³ -total volume	Low
ρ_s	Dry densisty of non-saturated soils	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil Outdoor inhalation of vapours from soil Infiltration of contaminated waters from soil to groundwater	1.0 – 3.0 g/cm ³	Low
$\rho_{s(sat)}$	Dry density of saturated soils	Migration of contamination to groundwater	1.0 – 3.0 g/cm ³	Low
A	Area of source	Outdoor inhalation of vapours from soil	> 1 m ²	High
da	Depth of contamination source in groundwater	Infiltration of contaminated waters from soil to groundwater	> 1 m	Average
esat	Aquifer saturated thickness	Infiltration of contaminated waters from soil to groundwater Migration of contamination to groundwater	> 1 m	High
dist	Distance of compliance point from source	Migration of contamination to groundwater	1 – 1000 m	High
ER	Air exchange in buildings	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil	0.25 – 60/hr	High
F _{oc}	Fraction of organic carbon in unsaturated area	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater	0.0001 – 0.03 g-C/g-soil	High

Symbol	Parameters	Interested Paths	Fields of Action	Influence on SALs
		Indoor inhalation of vapours from soil Outdoor inhalation of vapours from soil Infiltration of contaminated waters from soil to groundwater		
Foc(sat)	Fraction of organic carbon in saturated area	Migration of contamination to groundwater	0.0001 – 0.03 g-C/g-soil	High
h_{cap}	Capillary fringe thickness	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater	0 – 2 m	High
H_v	Un-saturated area thickness	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater	> 1 m	Average
i	Hydraulic gradient	Infiltration of contaminated waters from soil to groundwater Migration of contamination to groundwater	0.001 – 0.02	High
I	Effective infiltration	Infiltration of contaminated waters from soil to groundwater	10 – 1000 mm/year	High
K	Hydraulic conductivity	Infiltration of waters from soil to groundwater Migration of contamination to groundwater	0.00001 – 0.001 m/s	High
L_a	Length of source parallel to groundwater flow	Infiltration of contaminated waters from soil to groundwater	> 1 m	High
L_B	Building height	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil	100 – 300 cm	Average
L_b	Ratio between infiltration volume/area in buildings	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil		
L_{crack}	Thickness of foundations or walls in buildings	Indoor inhalation of vapours from groundwater Indoor inhalation of vapours from soil	10 – 30 cm	Low
L_{gw}	Groundwater subjacency	Indoor inhalation of vapours from groundwater Outdoor inhalation of vapours from groundwater	> 1 m	Average
L_p	Depth of contamination in deep soil	Indoor inhalation of vapours from soil Outdoor inhalation of vapours from soil	> 1 m	Average
L_s	Depth of contamination in surface soil	Indoor inhalation of vapours from soil Outdoor inhalation of vapours from soil Soil ingestion Dermal contact with soil Inhalation of dusts	0 – 1 m	Average
n_e	Aquifer effective porosity	Migration of contamination to groundwater	0.001 – 0.3	High
U_{air}	Wind average speed at soil surface	Outdoor inhalation of vapours from groundwater Outdoor inhalation of vapours from soil	0 – 20 m/s	Average
W	Source width parallel to wind direction	Outdoor inhalation of vapours from groundwater Outdoor inhalation of vapours from soil	>1 m	Average
w	Source width parallel to groundwater flow	Migration of contamination to groundwater	> 1 m	Average

Table 7: Target Organs on which Substances Act

Substances	Effect / Target organs
1,1,1-Trichloroethane	nn
1,1,1,2-Tetrachloroethane	Carcinogenic
1,1,2-Trichloroethane	Carcinogenic, Liver
1,1-Dichloroethane	Kidneys
1,1-Dichloroethylene	Carcinogenic, Liver
1,2,3-Trichloropropane	Carcinogenic, Liver, Mortality, Body weight, Kidneys
1,2,4,5-Tetrachlorobenzene	Kidneys
1,2,4-Trichlorobenzene	Adrenal glands, Body weight
1,2-Dibromoethane	Carcinogenic
1,2-Dichlorobenzene	Body weight
1,2-Dichloroethane	Carcinogenic
1,2-Dichloroethylene	Liver, Blood
1,2-Dichloropropane	Carcinogenic, Nasal cavities
1,2-Dinitrobenzene	Spleen
1,3-Dichlorobenzene	Nn
1,3-Dinitrobenzene	Spleen
1,4-Dichlorobenzene	Liver
2,3,4,6-Tetrachlorophenol	Liver
2,4,6-Trichlorophenol	Carcinogenic
2,4-Dichlorophenol	Immune system
2-Chlorophenol	Reproduction
Acenaphthene	Liver
Acenaphthylene	Liver, Body weight
Phthalic acid	Nn
Acrylamide	Carcinogenic, Neurologic system
Acrylonitrile	Carcinogenic, Nasal cavities, Reproduction
Alaclor	Carcinogenic, Blood
Aldrin	Carcinogenic, Liver
Alpha-hexachlorohexane	Carcinogenic
Aniline	Carcinogenic, Blood
Antimony	Mortality, Blood
Anthracene	nn
Silver	Skin
Arsenic	Carcinogenic, Cardiovascular system, Skin
Atrazine	Carcinogenic, Body weight
Barium	Cardiovascular system
Benzene	Carcinogenic
Benzo(a)anthracene	Carcinogenic
Benzo(a)pyrene	Carcinogenic
Benzo(b)fluoranthene	Carcinogenic
Benzo(g,h,i)perylene	Neurologic system
Benzo(k,j)fluoranthene	Carcinogenic
Beryllium	Carcinogenic, Gastroenteric system, Respiratory system
Beta-hexachloroexane	Carcinogenic
Bis(2-ethylhexyl)phthalate	Carcinogenic, Liver
Bromodichloromethane	Carcinogenic, Kidneys
Cadmium	Carcinogenic, Kidneys
Free Cyanides	nn
Chlordane	Carcinogenic, Liver
Chloromethane	Carcinogenic
Chloronitrobenzenes	Carcinogenic
Vinyl chloride	Canrcinogenic
Cobalt	Cardiovascular system, Immune system, Neurologic system, Reproduction.
Chrysene	Carcinogenic
Chromium (VI)	Carcinogenic, Respiratory system
Total Chromium	nn
DDD	Carcinogenic
DDE	Carcinogenic
DDT	Carcinogenic, Liver

Substances	Effect / Target organs
Dibenzo(a,h)anthracene	Carcinogenic
Dibenzo(a)pyrene	Carcinogenic
Dibenzofuran	Nn
Dibromochloromethane	Carcinogenic, Liver
Dichloromethane	Carcinogenic, Liver
Dieldrin	Carcinogenic, Liver
Diphenylamine	Nn
Endrin	Liver
Eptachlor	Carcinogenic, Liver
Hexachlorobenzene	Carcinogenic, Liver
Hexachlorobutadiene	Carcinogenic
Ethyl benzene	Liver, Kidneys, Development
Phenanthrene	Kidneys
Phenol	Development
Iron	Gastroenteric system, Blood
Fluoranthene	Liver, Kidneys, Blood
Fluorene	Blood
Indeno(1,2,3-c,d)pyrene	Carcinogenic
Isolpropylbenzene (Cumene)	Adrenal glands, Kidneys
Lindane	Liver, Kidneys
m,p-Anisidine	Nn
Manganese	Neurologic system
Mercury	Neurologic system
m-Methylphenol	Neurologic system, Body weight
Molybdenum	Nn
Monochlorobenzene	Liver
Naphthalene	Nasal cavities
Nickel	Body weight
Nitrobenzene	Liver, Adrenal glands, Kidneys, Blood
o-Anisidine	Carcinogenic
o-Metylphenol	Neurologic system, Body weight
PCB	Carcinogenic
Pentachlorobenzene	Liver, Kidneys
Pentachlorophenol	Carcinogenic, Liver, Kidneys
Lead	Neurologic system
Pyrene	Kidneys
p-Chloroaniline	Nn
p-Metylphenol	Neurologic system, respiratory system
p-Toluidina	Carcinogenic
Copper	Carcinogenic
Selenium	Gastroenteric system
Sum. PCDD, PCDF(conv. T.E.)	Neurologic system, Skin
Tin	Carcinogenic
Styrene	Liver, Kidneys
Thallium	Liver, Neurologic system, Blood
Tetrachloroethylene	Nn
Carbon tetrachloride	Carcinogenic, Liver, Skin
Toluene	Carcinogenic, Liver
Tribromomethane (Bromoform)	Liver, Neurologic system, Kidneys
Trichloroethylene	Carcinogenic, Liver
Trichloromethane (Cloroform)	Canrcinogenic
Vanadium	Carcinogenic, Liver
Xylene (m)	Nn
Xylene (p)	Nn
Xylene (o)	Nn
Xylenes	Nn
Zinc	Mortality, Neurologic system, Body weight
Hydrocarbons C<12 (Gasolines range)	Nn
Hydrocarbons C>12 (Gasoils range)	Nn

Table 8: Acceptable Concentrations established in D.Lgs 152/99 for Surface Waters

Substances	Concentrations (mg/l) A1 category	Notes
Arsenic	0.01	1
Barium	0.1	2
Cadmium	0.001	1
Free Cyanides	0.05	2
Total Chromium	0.05	2
Phenol	0.001	2
Iron	0.1	1
Manganese	0.05	1
Mercury	0.0005	1
Lead	0.05	2
Copper	0.02	1
Selenium	0.01	2
Zinc	0.5	1

Legend

1 = Guidance Value;

2 = Maximum Allowable Concentration.

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ANNEX 1: METHOD FOR DEFINING GALs

AL1.1 Introduction

This chapter provides a detailed description of the method and the assumptions employed to define GALs – General Acceptability Limits for soil contamination. Soil GALs (from now on “GALs”) were set so as to enable their use for any site. The conceptual model and the parameters used to define it were chosen so as to represent the worst possible reasonable risk case (excluding the presence of a protected and sensitive ecosystem). Consequently, the conceptual model was named “General Conceptual Model or GCM”. Providing a definition for “GALs” has involved various preliminary activities, including identification of the following:

1. Definition of the “GCM”:
 - Area use designation;
 - Potentially exposed receptors for every migration path;
 - Potentially exposed paths for each use assignment;
2. The model’s parametrization:
 - Assumptions relative to site parameters, both for saturated and for the un-saturated area;
 - Assumptions relative to human exposure;
 - Chemical-physical parameters for the chemical substances of interest;
 - Toxicological parameters for the chemical substances of interest.

GALs are calculated through the identification of the following: exposure paths, potentially exposed receptors, and possible future use of the site.

A strictly conservative or precautionary model was assumed specifically for the human receptor, based on the assumption that all main exposure paths are active concurrently.

For the water resources receptor, that is, for a definition of soil quality aimed at safeguarding groundwater quality, LCs for groundwaters immediately below the contamination source must meet the values specified in the D.M. 471/99.

It is important to underline that GALs for undergroundwater resources are not derived from a risk-based approach (toxicological), but from a comparison for each contaminant between the concentration dissolved in groundwater and the quality standard for the corresponding substance (LC).

AL1.2 Definition of the General Conceptual Method (GCM)

The GCM covers the following use assignments:

- Residential/recreational;
- Industrial/business.

The following have been considered as potentially exposed receptors within the site:

- Humans: adults and children, according to the land use assignment;
- Groundwater resources (for all soil use assignments).

The following exposure paths have been considered for human receptors:

- Surface soil ingestion;
- Dermal contact with surface soil;
- Inhalation in confined environments (indoor) of dusts from surface soil;
- Inhalation in open environments (outdoor) of dusts from surface soil;
- Indoor inhalation of vapours from surface soil;
- Outdoor inhalation of vapours from surface soil;
- Indoor inhalation of vapours from deep soil;
- Outdoor inhalation of vapours from deep soil.

For water resource receptors, washing of contaminated ground by infiltrating rain waters was considered as a migration and exposure pathway.

AL1.3 Model Parametrization

This paragraph provides a definition of the parameters employed in the GCM for calculating the equations of GALs. These specific parameters refer to the physical features of the site, human exposure, and chemical-physical and toxicological characteristics of potential contaminants.

AL1.3.1 Assumptions for the Site

To calculate GALs, a hypothetical site was considered and characterized so as to determine the worst possible reasonable exposure case. **Table 1**, in this document, lists parameters and the respective numeric values assumed for the GCM. In general, these values originate from generic assumptions, mostly taken from literature. In some cases though, completely new values were assigned to some parameters on the base of conservative assumptions, specifically:

- Contamination depth in surface and deep soil: which are required to calculate the migration of vapours, have been assumed, respectively, to be equal to 50cm and 100cm., (i.e. close to the surface);
- Mixing zone in groundwater: calculated from the saturated layer; the mixing zone height, which corresponds to the part of the mixing layer in which mixing of infiltration waters from the non-saturated zone and groundwater takes place, was calculated using the equation reported in UKDoE, 1994.

AL1.3.2 Assumptions Relative to Human Exposure

The list of parameters relative to human exposure and their corresponding numeric values is provided in **Table 2** of this document (the list is also comprehensive for Level 2 risk analysis). Here too the necessary information was taken from available literature on this subject, with the following order of preference in the choice of sources to be used:

- WHO (World Health Organization) and USEPA data;
- Data reported in "RBCA" (ASTM, 1995);
- Data reported in other methods for the evaluation of contaminated sites;
- Conservative and commonly used assumptions.

AL1.3.3 Chemical-physical Parameters for Chemical Substances

The chemical-physical characteristics for the chemical substances are listed in **Table 3** in this document. The majority of these parameters were taken from the data published by USEPA.

For the purpose of defining GALs, for the "Total Petroleum Hydrocarbon (TPH)" parameter, two main fractions were considered:

- A light fraction (C<12) ascribable to Gasolines (Gasolines range);
- A heavier fraction (C>12) ascribable to Gasoils (Gasoils range).

In compliance with the documents published by the "Total Petroleum Hydrocarbon Criteria Working Group" in 1997, n-Hexane was used as substitute in the Gasolines range, whereas Pyrene was used for the Gasoils range. The toxicological characteristics and the chemical-physical parameters listed in the tables refer to these substitutes.

AL1.3.4 Toxicological Parameters for Chemical Substances

Table 4 in this document lists the toxicological parameters for each chemical substance, both for inhalation and by ingestion. The toxicity criteria adopted for non-carcinogenic substances corresponds to "Tolerable Daily Intakes" (TDI) in units of mg/kg/day; a Slope Factor (SF) was used for carcinogenic effects. The SF is the angular coefficient of the starting point of the curve dose-intake resulting from toxicological tests.

AL1.4 GALs Calculation

The calculation of GALs was performed starting from the relationship between tolerable intakes and effective intakes. **Appendix 1** provides a detailed description of the equations used for all exposure pathways considered.

For the purpose of defining soil GALs for the protection of human receptors, it was assumed that all exposure paths, both for surface and deep soil, be concurrently active. This is a conservative assumption

that permits GALs to be defined with reference to the site use (CONCAWE, 1997), rather than with respect to each exposure path (ASTM RBCA, 1995).

For the purpose of defining soil GALs for the protection of groundwater resources, the adopted criteria was washing of contaminated soil by infiltrating rain waters, and dilution of the contaminated flow arriving from the non-saturated zone by groundwater flow.

Soil GALs for the protection of groundwater were derived using theoretical partitioning equations to calculate the concentration of the contaminant in various phases ([Appendix 1](#)). This approach allows the calculation of a water concentration comparable to that obtained with experimental leachate tests. This permits savings in terms of time and resources, but results in a far more conservative concentration value than the experimental test.

This method is often very conservative and it is necessary to carry out a Level 2 analysis to obtain a more detailed assessment of real risks.

Soil GALs for residential/recreational use and industrial/business use assignments are listed in [Table 5](#) in this document.

ANNEX 2: METHOD FOR DEFINING SALs

This Annex provides a practical description of the procedure and the assumptions needed to assess risk and to define SALs – specific acceptability limits for soil and groundwater contamination through a Level 2 risk analysis.

Level-2 risk analysis comprises four main operations:

- Construction of a site Specific Conceptual Model - SCM;
- Identification of the parameters for the conceptual model;
- Assessment and characterization of risk and SALs calculation;
- Selection of corrective actions for the identified risks.

AL2.1 Construction of a Site Specific Conceptual Model

For the purpose of a Level 2 risk analysis, the conceptual model is site-specific. The construction of such model must therefore involve both the acquisition of information and the characterization of all the elements that build-up the site. Thus:

- Contamination sources. That is, the areas within which contaminants were found in concentrations higher than those specified by the LCs in the D.M. 471/99, as well as the environmental media of interest;
- Potential contamination migration routes and exposure paths for any source or media identified by the preceding point: such exposure paths can include, for example, exposure routes involving direct contact with contaminated soil; inhalation of vapours originating from soil and undergroundwaters; discharge of contaminated groundwaters into surface waters located close to the site;
- Receptors potentially exposed to contamination: these can include humans, ground and surface waters, as well as any ecological end-point (the latter are not included in ROME V. 2.1.).

On the basis of the specific characteristics and the completeness of information collected for the site, further data acquisition may be required before performing any risk characterization or SALs calculation.

The construction of a site-specific conceptual model is a fundamental step for a Level 2 analysis, and requires two complementary steps:

- A detailed study of all documentation concerning the site;
- A site survey.

These complementary tasks and any other information of interest for the construction of a site-specific conceptual model are described in the following paragraphs; definitions of soil use comply with those specified in D.M. 471/99:

- Residential/recreational use;
- Industrial/business use.

For large sites, a single conceptual model cannot describe the heterogeneity or the complexity of contamination, exposure paths, receptors, or various use assignments. In such cases, in addition to the global SCM, it is suitable to divide the site in discrete areas, and to create detailed conceptual sub-models for each one of these areas. It is also recommended that a flow chart or a block diagram to describe the interactions between the sub-models and the global model be prepared.

AL2.1.1 Assessment of Chemical Substances

The chemical substances that must be assessed for each environmental media are those found in concentrations above LCs specified in D.M. 471/99. However, ROME V. 2.1 allows you to assess both risk and SALs for any other observed substance. The location of the points in which values exceed acceptable limits are used to define the extent of the contamination in all three dimensions, as well as to identify the so-called "source areas" and hot spots.

Risk analysis can also be performed on those substances detected at a site, which could be potentially harmful to human health and to the environment, but that are not included in the D.M. 471/99. This requires that the toxicological, chemical-physical and fate and transport parameters for each such substance in the environment are obtained. The values for these parameters should be supported by scientific literature.

AL2.1.2 Environmental Matrixes

Environmental Media considered for Level 2 include:

- a) Surface soil (between the topographic surface and at 1mt. depth);
- b) Deep soil (over 1m depth);
- c) Ground waters;
- d) Free product ("LNAPL – Light Non-Aqueous Phase Liquid" separate phase).

The analysis is performed on groundwaters in all cases where a groundwater resource has been detected, or whenever it is reasonable to assume that groundwaters are present. Should groundwater quality meet LC values it will, nonetheless, be necessary to evaluate the possibility that soil contamination might have a future impact on the quality of groundwater resources. As a rule and a precautionary assumption, the presence of a groundwater resource must be taken into consideration at all sites, unless specific studies (hydrogeological) demonstrate that the infiltration of rain waters through subsoil is absent, and/or that there is no reasonable doubt that contaminated infiltration waters from the surface will not come into contact with a groundwater resource.

Furthermore, the risk analysis must also take into consideration any pure product detected on the site. Specifically, the tests to be performed cannot be limited to the contaminant phase dissolved in undergroundwaters, but must also consider the vapour phase liberated by product, if any, floating on the surface of the groundwater. ROME V. 2.1. provides an automatic function to assess risks due to petroleum products, which are characterized by a Light Non-Aqueous Phase Liquid ("LNAPL"), and can thus float on groundwater thereby producing so-called floating free product.

AL2.1.3 Contamination Receptors

Receptors potentially exposed to contamination can include:

1. Humans (adults for industrial and business use assignment, adults and children for residential use assignment and in all referable ones);
2. Ground water resources;
3. Surface water resources;
4. Other environmental receptors ("ecological end points").

For humans, it will be necessary to assess their presence on the site, including the frequency and the period of their possible exposure to contaminants.

For groundwater resources, the first step involves verifying whether any drinking water supply works, or abstractions for any other use, are present in the surroundings of the site, with specific reference to areas located down hydraulic gradient.

As a rule, any perennial ground water resource should be considered a resource to be protected. However, for seasonal and/or perched groundwater, considerations on clean-up costs and time, availability of appropriate technologies, use of the site and the resource itself, can lead to different quality targets in the case of active industrial sites..

For ground water, a site-specific risk analysis enables the User to assess whether that resource complies with relevant limits at a compliance point, which can be located at a distance from the contaminant source. Generally, this compliance point is situated between the maximum area of groundwater contamination (source), and the first receptor detected down hydraulic gradient. It is also dependent on the land use planned for the territory.

The location of a compliance point is established on the basis of specific characteristics of the site and the surrounding territory. Please consult the Unichim Manual 196/1 for further information.

For surface water resources, it will be necessary to verify the proximity of such features to the site, as well as their use. For this receptor, a risk analysis must be performed when the potential for migration of contamination from groundwaters present at the site towards the surface water body has been detected, or it is reasonable to assume that this will occur. The risk assessment calculates the dilution ratio due to the difference between the incoming contaminated flow rate and the surface water body flow rate. Quality targets for surface waters coincide with standards specified in current rules.

Lastly, whenever particular land use assignments for the site determine the presence of other ecological end points, or whenever these are present at a distance from the site such that the contamination from the site itself can impact on them, it will be necessary to perform a specific "Ecological Risk Assessment". This capability is not included in ROME V. 2.1 (with the exclusion of surface water resources). This ecological risk assessment involves a process that enables the evaluation of the occurrences of harmful effects for any given receptor and/or the ecosystem. Specifically for soil, this type of risk analysis is aimed at ensuring

support and recovery of ecological functions according to the soil's original use assignment ("fitness for use"). Screening values for different soil use assignments, based on eco-toxicological criteria, as well as guides for performing site-specific toxicity tests can be found in international literature.

It is, nevertheless, reasonable to assume that the conservative approach adopted by ROME V. 2.1 for risk and SALs assessment, provides a protective solution for most contaminants and soil use assignments even though it is limited to assessing health risks and to protecting water resources.

AL2.1.4 Potentially Active Exposure Paths

Potentially active exposure paths associated with each environmental media, including free product (LNAPL), and distinguished for each potentially exposed receptor type include the following:

1. Human Receptor:
 - 1.a: associated with surface soil:
 - Soil ingestion;
 - Dermal contact with soil;
 - Outdoor inhalation of soil dusts;
 - Indoor inhalation of soil dusts;
 - Outdoor inhalation of soil vapours;
 - Indoor inhalation of soil vapours;
 - 1.b: associated with deep soil:
 - Outdoor inhalation of soil vapours;
 - Indoor inhalation of soil vapours;
 - 1.c: associated with groundwaters:
 - Outdoor inhalation of vapours from undergroundwaters;
 - Indoor inhalation of vapours from undergroundwaters;
 - 1.d: associated with free phase product:
 - Outdoor inhalation of vapours from the pure product;
 - Indoor inhalation of vapours from the pure product.
2. Groundwater Resource Receptor:
 - 2.a.b: associated with soil (both surface and deep):
 - Infiltration of rain water (passing through contaminated soil);
 - 2.c: associated with undergroundwaters:
 - Down gradient migration of dissolved phase contaminants in groundwater;
 - 2.d: associated with free phase product:
 - Down gradient creation (by solution) and migration of dissolved phase contaminants in groundwater;
3. Surface Water Resource Receptor:
 - 3.a.b: associated with soil (both surface and deep):
 - Infiltration through soil and to groundwater, and discharge of dissolved phase contaminants in groundwater;
 - 3.c: associated with undergroundwaters:
 - Discharge of dissolved phase contaminants in groundwater;
 - 3.d: associated with free phase product:
 - Creation and discharge of dissolved phase contaminants in groundwater.

During each step of the risk analysis, if no specific or reliable information is available, it is best to ensure the highest degree of caution reasonably possible. On this basis, assumptions based on unreliable data will tend to over-evaluate the calculated risks, rather than under-evaluating effective critical situations.

Since, even when considering similar land uses, each situation can differ from the next, all active exposure paths must be accurately assessed during the site characterization procedure. The risk analysis must consider all exposure paths applicable for the specific site use.

Some of the main site characteristics that provide useful information as to which paths are active or not, comprise:

- For direct soil contact, including dust inhalation, verify that the area within which the contamination was detected is not paved, cemented, or covered by buildings or other structures;

- For indoor inhalation of vapours and dusts, verify that there are closed spaces on the site that are regularly inhabited by humans. It is also important to indicate underground spaces (e.g. basements), that may be potentially closer to the contaminated area;
- For infiltration of contaminated waters towards groundwater, it is necessary that these waters pass through the contaminated area, dissolving contaminants, then reaching groundwaters. As a precautionary measure, soil coverings, unless specifically designed for this purpose, are considered to reduce, in a more or less significant way, the amount of infiltrating water, but do not completely remove this exposure path;
- For vapour inhalation in outdoor spaces, the same holds true as that stated for water infiltration towards groundwater. Coverings, unless specifically designed for this purpose, are not generally considered a sufficient measure to interrupt exposure paths.

The exposure path involving infiltration of contaminated waters towards groundwater is very important for the protection of undergroundwater resources. During Level 2 risk calculations, substituting the theoretically calculated value for the contaminated water used in Level 1 with empirically derived values based on soil leachate tests is a practicable and advisable solution. In fact, as recognized by scientific literature, this theoretical calculation provides exceedingly conservative results, and leads to extremely limited soil cleanup targets for the protection of undergroundwater resources.

Potentially active exposure paths associated with each environmental media as well as free phase product are illustrated in **Figure 1** for human receptors, and in **Figure 2** for groundwater resources receptors.

Throughout the investigation phase it is important to verify which paths are effectively active. Furthermore, all possible risk scenarios must be evaluated whenever use assignments differing from the current ones are foreseen.

FIGURE 1: Potentially Active Exposure Paths Associated to Human Receptors

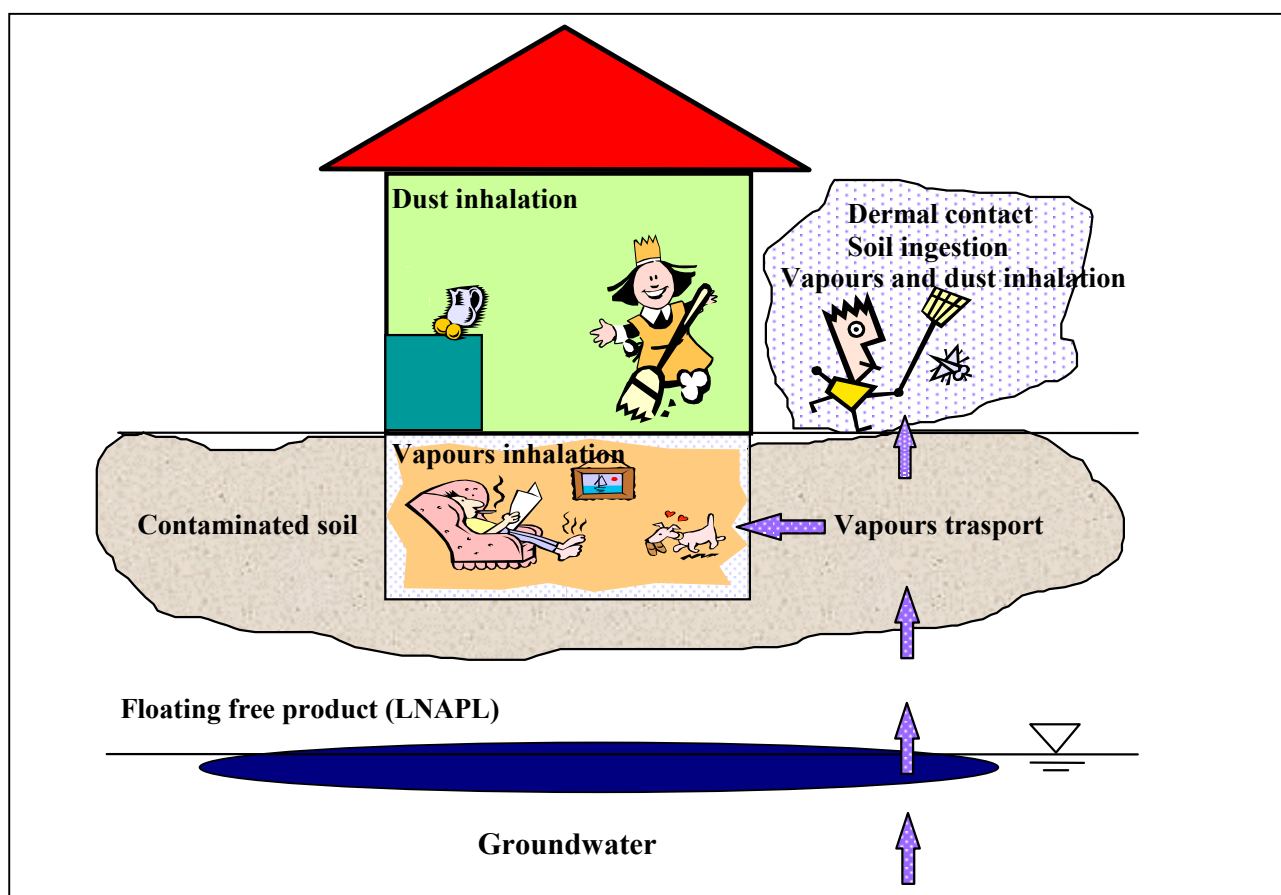
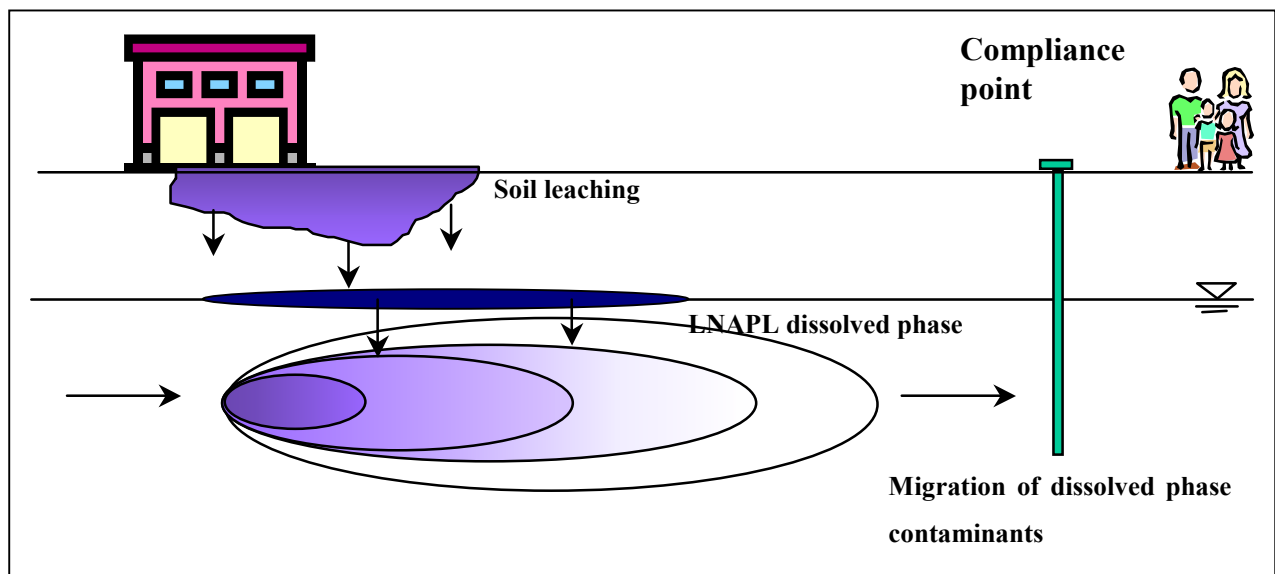


FIGURE 2: Potentially Active Exposure Paths Associated to Water Resources

AL2.2 Identification of Parameters for the Conceptual Model

As far as the selection of site-specific parameters is concerned, Users can choose between the following solutions:

- Perform Level 2 eliminating all non-active exposure paths, and using all default parameters permitted in the General Conceptual Model: in this case no site-specific parameter is used; or
- Perform Level 2 eliminating all non-active exposure paths, and using site-specific values for all parameters that appear in the equations for active exposures: in this case only site-specific parameters are used.

It is clear that, if you select from within ROME all potentially active exposure paths, without varying any default parameter, the SALs calculated by the program will be the same as the GALs derived for Level 1.

Should there be any reasonable doubt as to the numeric or qualitative results of the site characterization investigation, it is suggested that non-site-specific default values be used. These default parameters refer to the worst possible reasonable case, and are thus aimed at protecting human and environmental health.

The choice of the number of site-specific parameters to be acquired will depend on a costs-benefits evaluation. This involves a comparison of the costs necessary to collect the parameters in the field with the likely benefits that can arise in terms of results and implications for site clean up by increasing the parameter's specificity.

This choice can be guided by the following operations:

1. List all parameters relative to the equations for active exposure paths;
2. Verify for which of the above parameters the calculation equations are more sensitive: for this purpose, [Table 6](#) in this document can be a great aid.
3. Assess the possible results of the value defined for each site-specific parameter, and compare it with conservative default values.

The acquisition of site-specific parameters can also be performed on a step-by-step basis, analyzing the obtained results at each single step. This approach, provided that time does not represent a critical factor, offers the advantage that it permits resources required to characterize the site to be optimized.

The acquisition of new data to perform Level 2 covers the following:

- Define the contamination status in the different environmental media;
- Define the parameters used to calculate the exposures present at the site (for example: source area dimensions, site structural and meteorological data, local and regional geology and hydrogeology, saturated and non-saturated zone parameters).

For the purpose of characterizing the contamination status of the environmental media, every possible effort should be made during sampling for Level 2 to collect the samples, not only in the supposedly more contaminated areas, but also relating to exposure or compliance points. These locations represent, in fact, the points in which receptors are potentially exposed.

Please consult the Unichim 196/1 Manual for more information on how significant concentrations for contaminated sources are assessed.

In general, parameters relating to human exposure have a direct proportional influence on the calculation of intakes by human receptors, and thus of risk. Any modification of the default values with site-specific data must be justified in detail.

Numerical values for parameters relating to chemical-physical properties and to toxicity of chemical substances are not, generally, site-specific and should not be modified, except by revisions introduced by Agencies or Departments that manage the corresponding databases (from which the data available in the database of ROME V. 2.1. was taken). The coefficient for the distribution of metals (Kd) is slightly more site-specific, and can represent an exception to this general rule.

Table 6 reports the various ranges for each parameter and the exposure paths, and the exposure pathways most influenced by changing in these values. This table, resulting from a sensitivity analysis, is also a useful tool for the control agency, who can use it to evaluate those parameters requiring major attention.

The equations relative to each exposure path are provided in **Appendix 1**.

AL2.3 Calculation of Risks and SALs

ROME V. 2.1, similarly to other models employed for Level 2 risk analysis, has the following features:

- Algorithms employed for the calculations are relatively simple. In most cases they comprise algebraic or analytical expressions describing the main chemical-physical and exposure processes with respect to contaminants. Conservative assumptions and predictions supply the necessary information whenever other possible processes cannot be considered;
- Required input data is practically limited to that typical of the site, which can be collected through surveys or from literature (for example, soil density and porosity);
- Site-specific validation/calibration tests are not required, provided that the input parameters are based on assumptions for the worst possible reasonable case;
- Source extinction due to physical removal means is not taken into consideration (for example, through leaching);
- Bio-degradation processes of contaminants are not considered.

For human receptors, the approach and the equations for calculating risk and SALs are the same as those used for GALs (**Annex 1**).

For a water resource receptor, risk calculation is performed with respect to a “compliance point”, hydrogeologically downgradient of the site. This implies the need to calculate the attenuation that chemical substances will be subject to during their migration from the source to this specific point. For this purpose, ROME V. 2.1 uses a mathematical model created by Domenico (1987), which resolves the flow and transportation of contaminants in groundwater under steady conditions. Domenico’s model is also used to calculate risks to surface waters.

Risk acceptability levels are the same as those used to define GALs, that is:

1. Human receptor:
 - Carcinogenic substances: suggested acceptable risk = 1×10^{-5} (one in a hundred thousand risk of developing cancer over a lifetime as a result of exposure); in ROME V. 2.1 this value can also be set to 1×10^{-4} or 1×10^{-6} ;
 - Non-carcinogenic substances: “HI – Hazard Index” = 1, where HI is defined as the ratio between the Maximum Daily Intake (“MDI”) and the Tolerable Daily Intake (“TDI”).
2. Ground water receptor:
 - Compliance to LCs for groundwater as specified in D.M. 471/99 for a compliance point;
3. Surface water receptor:
 - Compliance to LCs for surface waters as specified in D.Lgs. 152/99.

When the concentrations found at the site result in a risk above acceptable levels, ROME V. 2.1 indicates that the site contamination is not acceptable and that an action is required to reduce the associated risks. The cleanup action will require the calculation of SALs that is, residual concentrations for environmental media that meet risk acceptability requirements.

SALs cannot be calculated for free product. In this case that free product is present, the solution involves evaluating whether its presence results in acceptable or non-acceptable risks. Dependent on the outcome of this test, it may be necessary to consider its complete removal from the subsoil.

Since risk, and thus SALs, calculation uses analytical mathematical modeling techniques, it ensures a transparent process with reproducible results for control Authorities.

AL2.3.1 Comparison with other Significant Criteria

The assessment of residual acceptable concentrations at a contaminated site can also be performed on the basis of other criteria, called “other significant criteria”. These include: aesthetic criteria, odor, taste, and also color. In some instances, these other significant criteria can suggest a corrective action even if the risks set by the site remain below the specified acceptability levels.

AL2.3 Choice of Corrective Actions for Identified Risks

Whenever the contaminant concentrations measured in environmental media exceed SALs, corrective actions for the risk will be necessary, unless it will be possible to demonstrate that these concentrations are due to natural background levels.

The identification of contamination sources, exposure paths, as well as of the possible critical receptors through the execution a 2-Level analysis, permits a scientific and rational evaluation of the best-suited corrective action. Since only complete exposure paths result in a risk, the corrective action can be targeted at the individual elements that contribute to the creation of a complete exposure path:

- Actions at source level: reduce concentrations found on the site within SALs (traditional cleanup action);
- Actions at path level: interruption of migration and exposure courses (as for example, through capping) (“system security”);
- Actions at receptor level: limitation of the use of land space, for example, by refusing to permit new groundwater abstraction wells for potable or other use, or changing the use assignment (“usage limitation/land space management” action).

In terms of risk analysis, all the above-mentioned action types can be considered equally efficient since they interrupt the connection between source and receptors. This ensures that the risks associated with a site return to or are managed within acceptable limits.

An alternative action involves monitoring the natural bio-degradation of contaminants at a site.

Upon conclusion of a Level 2 analysis, for complex cases, risk analysis can be further examined by passing to a Level 3 analysis, which introduces more sophisticated modeling techniques. Please note that Level 3 is not codified in ROME V. 2.1.

APPENDIX 1: FORMULAS USED TO CALCULATE GALs

This technical Appendix provides the mathematical equations used to calculate surface soil GALs that are protective of human receptors and groundwater resources.

These equations are based on simplified transportation and exposure models that offer a schematic, conservative representation of the problem.

All equations used to calculate GALs originate from the inversion of the formulas used to calculate risk (R), exposure (E) to contaminants and toxicity (T) of contaminants. The relationship between risk, exposure and toxicity can be generically expressed as: $R = E \times T$. Exposure E is thus calculated by combining the observed contaminant concentration with the exposure parameters. GALs, general acceptability limits can be obtained by inverting these equations, and setting a risk R equal to the acceptable value.

Please consult the Unichim 196/1 Manual for further information on the equations used to calculate exposure and risk. To facilitate use of this document, only the formulas used to calculate GALs will be provided in the following paragraphs.

These equations contain numerous conversion factors (mainly multiples of 10) to ensure consistency with units of measurement.

AP1.1 Calculation of GALs for Human Receptors

The general formula used to quantify soil GAL for carcinogenic substances is as follows:

$$GAL = \frac{0.00001}{\sum CDI_I \cdot SF_I + \sum CDI_O \cdot SF_O}$$

Whereas the one employed to define soil GALs for non-carcinogenic substances is:

$$GAL = \frac{1}{\frac{\sum MDI_I}{TDI_I} + \frac{\sum MDI_O}{TDI_O}}$$

where:

0.00001 = risk acceptability value for carcinogenic substances (1×10^{-5});
 $\sum CDI_{I/O}$ = sum of daily chronic intakes per single carcinogenic contaminant concentration by inhalation/ingestion (I/O) from active exposure paths;
 $MDI_{I/O}$ = maximum daily intake per single contaminant concentration;
 1 = HI acceptability value for non-carcinogenic substances;
 $\sum MDI_{I/O}$ = sum of daily chronic intakes per single non-carcinogenic contaminant by inhalation/ingestion (I/O) from active exposure paths;
 SF_I, SF_O, TDI_I, TDI_O = toxicological parameters for single chemical substances.

The exposure has been numerically calculated in terms of maximum daily intake (MDI). For carcinogenic substances only, for which it is necessary to average the exposure over a person's average lifetime, the MDI value is used to calculate the chronic daily intake (CDI) value. The formula below is used to transform MDI into CDI:

$$CDI = \frac{(MDI_{children} \cdot ED_{children}) + (MDI_{adults} \cdot ED_{adults})}{AT}$$

where:

$MDI_{children}$ = maximum daily intake calculated for children;
 MDI_{adults} = maximum daily intake calculated for adults;
 $ED_{children}$ = exposure duration for children;
 ED_{adults} = exposure duration for adults;
 AT = averaging time

The example below illustrates the formula used to calculate the GAL for Toluene (a non-carcinogenic substance) considering surface soil and an industrial land use. The general formula becomes thus:

GAL (Toluene_{industrial use surface soil}) =

1

$$= \frac{\text{MDI}_{I(\text{ind. dusts.})} + \text{MDI}_{I(\text{out. dusts})} + \text{MDI}_{I(\text{ind. vapours})} + \text{MDI}_{I(\text{out. vapours})}}{\text{TDI}_I} + \frac{\text{MDI}_{O(\text{ingestion})} + \text{MDI}_{O(\text{dermal contact})}}{\text{TDI}_O}$$

As demonstrated above, TDI_O is valid both for dermal contact and for ingestion, thus these two types of intake can be summed.

The following paragraphs describe the equations used to calculate MDIs for each exposure path of interest. In most cases these formulas are taken from "RBCA" (ASTM, 1995) or from USEPA (USEPA, 1996).

When calculating GALs, as already mentioned, MDIs refer to unit contaminant concentrations and, therefore, the value "1" will be used in place of the parameter C_s (Soil Concentration) in all the following formulas.

AP1.1.1 MDI from Soil Ingestion

The equation to assess the maximum daily intake (MDI) for soil ingestion is based on the amount of soil that can be taken in a 24 hour period. This equation contains an oral bioavailability factor that reflects the difference between intake and ingestion of chemical compounds from soil. GALs have been calculated on the basis of a precautionary assumption that places this factor equal to 1 (assuming that all the contaminant is bio-available). The MDI calculation for soil ingestion is performed using the following formula and default values for parameters:

IR	Ingestion rate (mg/day)
EF	Exposure frequency (days/year)
BW	Body weight (kg)
ED	Exposure Duration (years)
AT	Averaging Time (years) (for carcinogens AT = 70 years, for non-carcinogens AT = ED)

Shallow soil ingestion

Human exposure assumptions

Scenario: Residential

	Adults	Children	Workers
Body weight (kg)	70	15	70
Soil ingestion rate (mg/day)	100	200	50
Exposure frequency (days/year)	350	350	240
Exposure duration (years)	24	6	25

Formula

$$\text{MDI} = \frac{C_s * \text{IR} * 0.000001 * \text{EF} * \text{ED}}{\text{BW} * 365 * \text{AT}}$$

MDI = Maximum Daily Intake (mg/kg/day)

C_s = Soil concentration (mg/kg)

IR = Soil ingestion (mg/day)

EF = Exposure frequency (days/year)

BW = Body weight (kg)

ED = Exposure time (years)

AT = Averaging time (years)

Ref: (ASTM, 1995)

(*) For carcinogenics: AT = 70 years
For non carcinogenics: AT = ED

Hide formula

AP1.1.2 MDI from Dermal Contact with Soil

The equation used to calculate the MDI for dermal contact is based upon the following parameters: surface of exposed skin, amount of soil in contact with skin, and evaluation of the skin's capacity to adsorb such compounds.

The MDI calculation for Dermal Contact is performed using the following equation and default values for relevant parameters:

SA	Skin Surface Area (cm ² /day)
Fs	Fraction of skin exposed (-)
SL	Soil to Skin Adherence Factor (%)
J	Dermal Absorption Factor (%)

Dermal contact with shallow soil			
Human exposure assumptions			
	Scenario		Industrial Workers
	Residential Adults	Children	
Body weight (kg)	70	15	70
Skin surface (cm ² /day)	17938	6381	17938
Fraction of exposed skin (unit less)	0,2	0,5	0,2
Adherence factor (mg/cm ²)	1		
Exposure frequency (days/year)	350	350	240
Exposure duration (years)	24	6	25

Hide formula

Formula

$$MDI = \frac{C_s * SA * F_s * SL * J * 0.0000001 * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)
 Cs = Soil concentration (mg/kg)
 SL = Adherence factor (mg/cm²)
 Fs = Fraction of exposed skin (unit less)
 EF = Exposure frequency (days/year)
 BW = Body weight (kg)
 J = Adsorption factor (%)
 SA = Exposed skin surface (cm²/day)
 ED = Exposure time (years)
 AT = Averaging time (years)

(*) For cancerogenics: AT = 70 years
 For non cancerogenics: AT = ED

Ref: (ASTM, 1995)

The Skin Surface value (SA) can be derived from Body Weight (BW) value using the following formula:

$$SA = \frac{(4 \times BW) + 7}{BW + 90}$$

AP1.1.3 MDI for Indoor Inhalation of Dust from Soil

The MDI calculation for indoor inhalation of dust is performed using the following equation and default values for relevant parameters:

Cid Concentration of soil particles in indoor air (mg/m³)
 Bi Rate of inhalation of indoor air (m³/day)

Indoor dust inhalation from shallow soil			
Human exposure assumptions			
	Scenario		Industrial Workers
	Residential Adults	Children	
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Indoor inhalation rate (m ³ /day)	15	6	8
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25

Hide formula

Environmental parameters

Soil particles in dust (unit less) 1

Outdoor dust concentration (mg/m³) 0,07

Indoor dust fraction (adim.) 1

Formula

$$MDI = \frac{Cid * Bi * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)
 Cid = Soil particles concentration in indoor dust (mg/m³) (Cid = Cs (mg/kg) * PMi (mg/m³) * Fsd * 10⁻⁶) (Ref. USEPA, 1996)
 BW = Body weight (kg)
 EF = Exposure frequency (days/year)
 Bi = Indoor inhalation rate (m³/day)
 PMi = Indoor dust level (= PMo (mg/m³) * Fi)
 AT = Averaging time (years)
 Cs = Soil concentration (mg/kg)
 ED = Exposure time (years)
 Fi = Indoor dust fraction (unit less)

(*) For cancerogenics: AT = 70 years
 For non cancerogenics: AT = ED

Ref: (ASTM, 1995)

AP1.1.4 MDI for Outdoor Inhalation of Dust from Soil

The MDI calculation for outdoor inhalation of dust from soil is performed using the following formula and default values for parameters:

Cod Concentration of soil particles in outdoor air (mg/m³)
 Bo Rate of inhalation of outdoor air (m³/day)

Outdoor dust inhalation from shallow soil

Human exposure assumptions

Scenario: Residential

	Adults	Children	Industrial Workers
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Outdoor dust concentration (mg/m ³)	0,07		
Outdoor inhalation rate (m ³ /day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25

Environmental parameters

Soil particles in dust (unit less): 1

Formula

$$MDI = \frac{Cod * Bo * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)
 Bo = Outdoor inhalation rate (m³/day)
 EF = Exposure frequency (days/year)
 BW = Body weight (kg)
 ED = Exposure time (years)
 AT = * Averaging time (years)

Cod = Soil particles concentration in outdoor dust (mg/m³) (Cod= Cs (mg/kg) * PMo (mg/m³) * Fsd * 10⁻⁶) (Ref. USEPA, 1996)
 Fsd = Fraction of soil particles in dust (unit less)
 Cs = Soil concentration (mg/kg)
 PMo = Outdoor dust concentration (mg/m³)
 Ref: (ASTM, 1995)

(*): For cancerogenics: AT = 70 years For non cancerogenics: AT = ED

AP1.1.5 MDI for Indoor Inhalation from Soil Vapours

Models for vapour migration from soil to buildings or other enclosed spaces, which generally involve precautionary assumptions and simplified features, result, in most cases, in calculated vapour concentrations that are higher than the effectively measured ones. The methods employed for this calculation are based on those reported in "RBCA" (ASTM, 1995), which set out the following calculation assumptions:

- Linear equilibrium partitioning of the contaminant between the adsorbed, dissolved and vapour phases. The partitioning is a function of constant chemical parameters for substances, and of specific parameters for soil;
- Concentrations of contaminants in soil do not decrease over time
- Steady-state vapour diffusion through the un-saturated zone and cracks in walls.
- Chemical or biological degradation processes do not decrease concentrations during the diffusion process towards the surface;
- Steady, well-mixed atmospheric dispersion within closed spaces.

The MDI calculation for indoor inhalation of soil vapours is performed using the following equation and default values for parameters:

V_{si} Indoor concentration of contaminant vapour from soil (mg/m³)

Indoor vapours inhalation from shallow soil

Human exposure assumptions

Scenario: Residential

	Adults	Children	Industrial Workers
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Indoor inhalation rate (m ³ /day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25

Vadose zone parameters

Bulk density (g/cm³): 1,7 Air content in soil (unit less): 0,26
 Fraction of organic Carbon (unit less): 0,01 Water content in soil (unit less): 0,12
 Contamination depth (cm): 50 [<100cm]

Building parameters

Air content in cracks (unit less): 0,26 Air exchange rate (1/h) res. land use: 0,504
 Water content in cracks (unit less): 0,12 Air exchange rate (1/h) ind. land use: 0,828
 Surface crack fraction (unit less): 0,01 Residential building height (cm): 200
 Foundation/wall thickness (cm): 15 Industrial building height (cm): 300

Formula

$$MDI = \frac{V_{si} * B_i * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)
 V_{si} = Indoor vapours concentration from soil (mg/m³)
 B_i = Indoor inhalation rate (m³/day)
 EF = Exposure frequency (days/year)
 BW = Body weight (kg)
 ED = Exposure time (years)
 AT = * Averaging time (years)
 Ref: (ASTM, 1995)

(*): For cancerogenics: AT = 70 years For non cancerogenics: AT = ED

The equation to calculate V_{si} is as follows:

Formula Indoor vapour concentration from soil shallow

$$V_{si} = \frac{H \rho_s}{\theta_{ws} + (K_{oc} F_{oc}) \rho_s + H \theta_{as}} \left[\frac{D_s^{eff} / L_s}{ER L_B} \right] \times 10^3 \times C_s$$

where: $D_s^{eff} = D^{air} \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^{wat} \frac{1}{H} \frac{\theta_{ws}^{3.33}}{\theta_T^2}$

where: $D_{crack}^{eff} = D^{air} \frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^{wat} \frac{1}{H} \frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$

Rif: (ASTM, 1995)

V_{si} = Indoor vapours concentration from soil (mg/m ³)	D^{wat} = Diffusion coefficient in water (cm ² /s)
θ_{ws} = Water content in soil (unit less)	θ_{acrack} = Air content in wall cracks (unit less)
ρ_s = Soil bulk density (kg/l)	θ_{wcrack} = Water content in wall cracks (unit less)
θ_{as} = Air content in soil (unit less)	L_s = Contamination depth (cm)
D_s^{eff} = Effective diffusion coefficient in soil on the basis of vapour phase concentration (cm ² /s)	L_B = Building height (cm)
D_{crack}^{eff} = Effective diffusion coefficient in foundation/wall cracks (cm ² /s)	ER = Air exchange rate in enclosed space (1/s)
L_{crack} = Thickness of building foundation/wall (cm)	K_{oc} = Organic Carbon partition coefficient (unit less)
η = Foundation/wall crack fraction (cm ² /cm ²)	F_{oc} = Fraction of organic Carbon in soil (unit less)
D^{air} = Air diffusion coefficient (cm ² /s)	H = Henry's law coefficient (unit less)
θ_T = Total soil porosity (unit less)	C_s = Soil concentration (mg/kg)

θ_{ws}	water content in soils (-)
ρ_s	soil bulk density (kg/l)
θ_{as}	air content in soils (-)
D_s^{eff}	effective diffusion coefficient through soil (cm ² /s)
D_{crack}^{eff}	effective diffusion coefficient through foundation cracks (cm ² /s)
L_{crack}	thickness of foundation/wall (cm)
η	fraction of fractions in foundation (cm ² /cm ²)
D^{air}	ambient air mixing zone height (cm)
θ_T	total porosity of soils
D^{wat}	diffusion coefficient in water (cm ² /s)
θ_{acrack}	air content in fractures in foundations/walls (-)
θ_{wcrack}	water content in fractures in foundations/walls (-)
A	Area of site (cm ²)
L_s	depth to contamination (cm)
L_B	building height (cm)
K_{oc}	carbon-water sorption coefficient (-)
F_{oc}	fraction of organic carbon in soil (-)
H	Henry's Law Constant (-)

AP1.1.6 MDI for Outdoor Inhalation of Soil Vapours

The method employed to calculate outdoor concentrations of soil vapours is based on the assumption that, once the volatile phase reaches the surface, there should be dilution of vapours, which takes place in an imaginary "Box". The dilution level will, thus, be a function of the dimensions of this hypothetical box, and the wind speed. The following assumptions are made in the calculation:

- Chemical concentrations in soil are constant;
- Linear equilibrium partitioning of the contaminant between the adsorbed, dissolved and vapour phases. The partitioning is a function of constant chemical parameters for substances, and of specific parameters for soil;
- Steady-state vapor diffusion through the vadose zone;
- Chemical or biological processes do not influence the concentration's decay during the diffusion process towards the surface;

- Steady, well-mixed atmospheric dispersion takes place .

The MDI calculation for outdoor inhalation of soil vapours is performed using the following equation and default values for parameters:

V_{so} Outdoor concentration of contaminant vapour from soil (mg/m^3)

Outdoor vapours inhalation from shallow soil			
Human exposure assumptions			Environmental parameters
Scenario: Residential (Adults, Children, Workers) / Industrial (Workers)			
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Outdoor inhalation rate (m^3/day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25
Vadose zone parameters Bulk density (g/cm^3) 1,7 Fraction of organic Carbon (unit less) 0,01 Contamination depth (cm) 50 [$\leq 100\text{cm}$] Air content in soil (unit less) 0,26			Wind speed (cm/s) 225 Mixing zone height (cm) 200 Water content in soil (unit less) 0,12 Source length parallel to wind direction (m) 1000 Source width perpendicular to wind direction (cm) 1000
Formula $MDI = \frac{V_{so} \times B_o \times EF}{BW \times 365}$ MDI = Maximum Daily Intake ($\text{mg}/\text{kg}/\text{day}$) V_{so} = Outdoor vapours concentration from soil (mg/m^3) B_o = Outdoor inhalation rate (m^3/day) EF = Exposure frequency (days/year) BW = Body weight (kg) ED = Exposure time (years) AT = Averaging time (years) Ref: (ASTM, 1995) (*): For cancerogenics: AT = 70 years For non cancerogenics: AT = ED			

The equation to calculate V_{so} is as follows:

Formula Outdoor vapours concentration from shallow soil	
$V_{so} = \frac{10^{-9} \times E_i}{U_{air} \times W \times \delta_{air}}$	and:
$E_i = \frac{C_s \times \rho_s \times H}{1 \times 10^6 \times \left((\theta_{as} \times H) + \theta_{ws} + (\rho_s \times K_{oc} \times F_{oc}) \right)} \times A \times D_s^{eff} \times \frac{1}{L_s}$	
U_{air} = Wind speed in the mixing zone (cm/s) δ_{air} = Outdoor mixing zone height (cm) H = Henry's law coefficient (unit less) θ_{ws} = Water content in soil (unit less) θ_{as} = Air content in soil (unit less) D_s^{eff} = Effective diffusion coefficient in soil on the basis of vapour phase concentration (cm^2/s) ρ_s = Soil bulk density (kg/l)	W = Source width in wind direction (cm) E_i = Vapours emission rate from soil (g/s) L_s = Contamination depth (cm) K_{oc} = Organic Carbon partition coefficient (unit less) F_{oc} = Fraction of organic Carbon in soil (unit less) A = Site area (cm^2) C_s = Soil concentration (mg/kg) V_{so} = Outdoor vapours concentration from soil (mg/m^3) Ref. (Farmer et al. 1978, 1980)

U_{air} Wind speed above ground surface in ambient mixing zone (cm/s)
 δ_{air} Ambient air mixing zone height (cm)
 H Henry's Law Constant (-)
 θ_{ws} Water content in soils (-)
 θ_{as} Air content in soils (-)
 D_s^{eff} Effective diffusion coefficient through soil (cm^2/s)

ρ_s	Soil bulk density (kg/l)
L_s	Depth to contamination (cm)
K_{oc}	Carbon-water sorption coefficient (-)
F_{oc}	Fraction of organic carbon in soil (-)
A	Area of site (cm ²)

AP1.2 GAL Calculation for a Groundwater Receptor

The calculation of soil GALs (both surface and deep soil) for the protection of groundwater resources assumes that the compliance point of the aquifer is located below the contaminated soil source. Infiltrating rain waters wash the contaminated soil and the solution that reaches groundwater is then diluted by the groundwater flow. The GALs are the concentration of contaminant in soil, such that the concentration of the contaminant in the aquifer coincides with the current, relevant applied LC for groundwater. This model can be represented through the formula below, based on calculations presented by ASTM, 1995:

$$GAL_{soil} = LC_{groundwaters} \div \left[\frac{\rho_s}{\left(\theta_{ws} + (K_{oc} \times F_{oc} \times \rho_s) + H \times \theta_{as} \right) \left(1 + \frac{U_{gw} \times d}{I \times L} \right)} \right]$$

where:

LC	=	limit concentration for under groundwaters fixed by the D.M. 471/99;
ρ_s	=	dry soil bulk density;
θ_{ws}	=	water content in soil;
K_{oc}	=	organic carbon partition coefficient;
F_{oc}	=	fraction organic carbon;
H	=	Henry's constant;
θ_{as}	=	air content in soil;
U_{gw}	=	organic carbon partition coefficient;
d_a	=	mixing zone layer in groundwater;
I	=	effective infiltration;
L	=	source length parallel to the flow direction of groundwater.

The thickness of the mixing zone layer in groundwater is less than the thickness of the aquifer's saturated layer, and can be calculated with the following equation (UKDoE, 1994):

$$d_a = (0,0112 L^2)^{0.5} + d * \{1 - \exp[(-L * I)/(K * i * d)]\}$$

where:

d	=	aquifer layer;
k	=	hydraulic conductivity;
i	=	hydraulic gradient.

AP1.3 Comparison between GALS and Soil Saturation Limits

The calculated GAL value, before it can be used, must be compared to the saturation limit of the relevant organic substance present in the soil. This saturation limit, or concentration, corresponds to the limit concentration above which the contaminant is found as free product.

The saturation limit C_{sat} is calculated with the following formula (ASTM, 1995):

$$C_{sat} = \frac{S}{\rho_s} \left((H \times \theta_{as}) + \theta_{ws} + (K_{oc} \times F_{oc} \times \rho_s) \right),$$

where:

S	=	solubility in water;
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ρ_s	=	dry soil bulk density;
H	=	Henry's constant;
θ_{as}	=	air content in soil;
θ_{ws}	=	water content in soil;
K_{oc}	=	organic carbon partition coefficient;
F_{oc}	=	fraction organic carbon.

In the event that the $GAL > C_{sat}$ for a contaminant in soil, the necessary conditions exist for the presence of free product. To avoid this situation, in such cases, the GAL value is set equal (reduced) to the limit concentration for soil saturation. Where applicable, this value is shown in *italics* in [Table 5](#).

AP1.4 Transformation of GALs from “unit weight” to “d.s.” (dry substance)

The last operation that has to be performed prior to using GALs for the various land use assignments and receptors identified on the site is a transformation, which is required to perform a comparison between GALs calculated with risk analysis and the LCs specified in D.M. 471/99. This comparison is performed during the table-based comparison phase.

Since the formulas for the risk analysis are based on the assumption that soil concentrations are input as “unit weight” (i.e. with a water content reflecting field conditions), the resulting GALs will also refer to a concentration for the “unit weight” of soil. The formula described below allows the transformation from GALs “unit weight” to GALs “d.s.” (dry substance):

$$GAL_{d.s.} = GAL_{(unit\ weight)} * (1 + \theta_{ws})$$

where:

θ_{ws}	=	water content in soil (default value).
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APPENDIX 2: FORMULAS USED TO CALCULATE SALs

This Appendix provides a detailed description of the formulas employed to calculate MDIs for exposure paths based on consideration of site-specific conditions. These formulas can be used both for risk analysis, using direct calculation methods, and for SALs assessment, using inverse calculation methods. The considerations discussed in the preceding paragraphs for GALs are also valid for site-specific risk assessment (direct calculation). Please consult [Appendix 1](#) for the formulas used to calculate exposure paths for GALs.

The formulas describe exposure processes and paths that can be activated in given conditions on the basis of the defined SCM (Site-Specific Conceptual Model). These exposure paths were not considered in the GCM (General Conceptual Model) used to develop GALs.

Since all the formulas employed for the risk analysis are based on the assumption that the soil concentration is specified as “unit weight” (i.e. with a water content as sampled in the field), the numerical values for SALs are also calculated on this basis (i.e. assuming concentration for “unit weight” of soil). ROME V. 2.1. automatically transforms this “unit weight” data to “dry substance (d.s.)” data using the site-specific value of water content in soil, which can be specified by the User, or set to a default value.

This procedure is executed using the formula described in detail in [Appendix 1](#).

AP2.1 Calculation of SALs for Human Receptors

The equations used to calculate exposure, site-specific risk, and SALs described in the following paragraphs, employ numerous conversion factors to ensure consistency of measurement units.

AP2.1.1 MDI for Indoor Inhalation of Vapours from Groundwaters

The method used to calculate indoor concentrations of vapours from groundwater at a given depth from the soil's surface, is based on the following assumptions:

- chemical concentrations dissolved in groundwater remain constant over time;
- linear equilibrium partitioning of contaminants in groundwater between the dissolved and vapour phase;
- steady-state vapour diffusion through the capillary fringe and the unsaturated zone;
- chemical or biological processes do not influence the contaminant concentration during the diffusion process towards the surface;
- steady, well-mixed vapour dispersion in atmosphere.

The calculation of MDI for indoor inhalation of vapours from groundwaters is performed using the following equation and default values for parameters:

V_{gi}	concentration of vapour in indoor air (mg/m^3)
B_i	rate of inhalation of indoor air (m^3/day)
EF	exposure frequency (days/year)
BW	body weight (kg)
ED	exposure duration (years)
AT	averaging time (years) (for carcinogens AT = 70 years, for non-carcinogens AT = ED)

Indoor vapours inhalation from groundwater			
Human exposure assumptions			
Scenario: Residential			
Body weight (kg)	Adults: 70	Children: 15	Industrial Workers: 70
Exposure frequency (days/year)	350	350	240
Indoor inhalation rate (m³/day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25
Vadose zone parameters			
Groundwater depth (cm)	300	Water content in soil (unit less)	0,12
Thickness of capillary fringe (cm)	5	Air content in capillary fringe (unit less)	0,038
Air content in soil (unit less)	0,26	Water content in capillary fringe (unit less)	0,342
Building parameters			
Air content in cracks (unit less)	0,26	Air exchange rate (1/h) res. land use	0,504
Water content in cracks (unit less)	0,12	Air exchange rate (1/h) ind. land use	0,828
Surface crack fraction (unit less)	0,01	Residential building height (cm)	200
Foundation/wall thickness (cm)	15	Industrial building height (cm)	300
Hide formula			

Formula

$$MDI = \frac{V_{gi} * B_i * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)

V_{gi} = Indoor vapours concentration from groundwater (mg/m³)

B_i = Indoor inhalation rate (m³/day)

EF = Exposure frequency (days/year)

BW = Body weight (kg)

ED = Exposure time (years)

AT = Averaging time (years)

Ref.: (ASTM, 1995)

(*) For cancerogenics: AT = 70 years
For non cancerogenics: AT = ED

The equation to calculate V_{gi} is as follows:

Formula Indoor vapours concentration from groundwater	
$V_{gi} = \frac{H \left[\frac{D_{ws}^{eff} / L_{GW}}{ER L_B} \right]}{1 + \left[\frac{D_{ws}^{eff} / L_{GW}}{ER L_B} \right] + \left[\frac{D_{ws}^{eff} / L_{GW}}{(D_{crack}^{eff} / L_{crack}) \eta} \right]} \times 10^3 \times C_{gw}$	<p>where: $D_{ws}^{eff} = (h_{cap} + h_v) \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$</p> <p>where:</p> $D_{cap}^{eff} = D^{air} \frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^{wat} \frac{1}{H} \frac{\theta_{wcap}^{3.33}}{\theta_T^2}$
<p>Ref.: (ASTM, 1995)</p> <p>D_{ws}^{eff} = Effective diffusion coefficient between groundwater and ambient air (cm²/s)</p> <p>L_{GW} = Groundwater depth (cm)</p> <p>h_{cap} = Thickness of capillary fringe (cm)</p> <p>h_v = Vadose zone thickness (cm)</p> <p>θ_{acap} = Soil air content in capillary fringe (cm³/cm³)</p> <p>θ_{wcap} = Soil water content in capillary fringe (cm³/cm³)</p> <p>L_B = Building height (cm)</p> <p>D^{wat} = Diffusion coefficient in water (cm²/s)</p> <p>θ_T = Total soil porosity (unit less)</p> <p>C_{gw} = Groundwater concentration (mg/l)</p>	<p>ER = Air exchange rate in enclosed space (1/s)</p> <p>D_{crack}^{eff} = Effective diffusion coefficient in cracks (cm²/s)</p> <p>L_{crack} = Building walls thickness (cm)</p> <p>η = Foundation/wall cracks areal fraction (cm²/cm²)</p> <p>D_s^{eff} = Effective diffusion coefficient in soil based on vapour phase concentration (cm²/s)</p> <p>D_{cap}^{eff} = Effective diffusion coefficient in capillary fringe (cm²/s)</p> <p>D^{air} = Air diffusion coefficient (cm²/s)</p> <p>H = Henry's law coefficient (unit less)</p>

D_{ws}^{eff}	effective diffusion coefficient between groundwater and soil surface (cm²/s)
L_{GW}	depth to groundwater (cm)
h_{cap}	thickness of capillary fringe (cm)
h_v	thickness of vadose zone (cm)
θ_{acap}	air content in capillary fringe soils (cm³/cm³)
θ_{wcap}	water content in capillary fringe soils (cm³/cm³)
L_B	building height (cm)
D^{wat}	diffusion coefficient in water (cm²/s)
θ_T	total porosity of soils
C_{gw}	concentration in groundwater (mg/l)

ER	enclosed-space air exchange rate (l/s)
$D_{\text{crack}}^{\text{eff}}$	effective diffusion coefficient through foundation cracks (cm^2/s)
L_{crack}	thickness of foundation/wall (cm)
η	fraction of fractions in foundation (cm^2/cm^2)
D_s^{eff}	effective diffusion coefficient in soil (cm^2/s)
$D_{\text{cap}}^{\text{eff}}$	effective diffusion coefficient through the capillary fringe (cm^2/s)
D_{air}	ambient air mixing zone height (cm)
H	Henry's Law constant (-)

AP2.1.2 MDI for Outdoor Inhalation of Vapours from Groundwaters

The method employed to calculate outdoor concentrations of vapours from groundwater at a given depth from the soil's surface is based on the one specified by ASTM (1995), and assumes the following:

- chemical concentrations dissolved in groundwater remain constant over time;
- linear equilibrium partitioning of contaminants in groundwater between the dissolved and vapour phase;
- steady-state vapour diffusion through the capillary fringe and the unsaturated zone;
- chemical or biological degradation processes do not influence the contaminant concentration during the diffusion process towards the surface;
- steady, well-mixed vapour dispersion in the atmosphere (modeled as a box).

The MDI for outdoor inhalation of vapours from groundwaters is calculated using the following equation and default values for parameters:

V_{go}	outdoor concentration of contaminant vapour from groundwater (mg/m^3)
B_o	rate of inhalation of outdoor air (m^3/day)

Outdoor vapours inhalation from groundwater

Human exposure assumptions

Scenario: Residential (Adults, Children), Industrial (Workers)

Parameter	Adults	Children	Workers
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Outdoor inhalation rate (m^3/day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25

Environmental parameters

Wind speed (cm/s): 225

Mixing zone height (cm): 200

Vadose zone parameters

Groundwater depth (cm): 300

Thickness of capillary fringe (cm): 5

Air content in soil (unit less): 0,26

Air content in capillary fringe (unit less): 0,038

Water content in soil (unit less): 0,12

Water content in capillary fringe (unit less): 0,342

Source width perpendicular to groundwater flow direction (m): 15

Formula

$$MDI = \frac{V_{go} * B_o * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake ($\text{mg}/\text{kg}/\text{day}$)

V_{go} = Outdoor vapour concentration from groundwater

B_o = Outdoor inhalation rate (m^3/day)

EF = Exposure frequency (days/year)

BW = Body weight (kg)

ED = Exposure time (years)

AT = Averaging time (years)

Ref: (ASTM, 1995)

(*): For cancerogenics: AT = 70 years

For non cancerogenics: AT = ED

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The equation to calculate V_{go} is as follows:

Formula Outdoor vapours concentration in groundwater

$$V_{go} = \frac{H * 10^3 C_{gw}}{1 + \left(\frac{U_{air} * \delta_{air} * L_{gw}}{S_{wp} * D_{ws}^{eff}} \right)}$$

Ref: (ASTM, 1995)

H = Henry's law coefficient (unit less)	L _{gw} = Groundwater depth (cm)
C _{gw} = Groundwater concentration (mg/l)	D _{ws} ^{eff} = Effective diffusion coefficient between groundwater and ambient air (cm ² /s)
U _{air} = Average wind speed in mixing zone (cm/s)	S _{wp} = Source width (cm)
δ _{air} = Height of outdoor air mixing zone (cm)	V _{go} = Outdoor vapour concentration from groundwater



H Henry's Law constant (-)
 U_{air} wind speed above ground surface in ambient mixing zone (cm/s)
 δ_{air} ambient air mixing zone height (cm)
 D_{ws}^{eff} effective diffusion coefficient between groundwater and soil surface (cm²/s)
 L_{GW} depth to groundwater (cm)
 S_{wp} source width (cm)

AP2.1.3 MDI for Indoor Inhalation of Vapours from LNAPL Free Product

The method used to calculate indoor concentrations of vapours from free product floating on groundwater is based on the one provided by ASTM (1995).

The MDI assessment for this parameter is performed using the following equation and default values for parameters:

V_{pi} Indoor concentration of contaminant vapour from product (mg/m³)

Indoor vapours inhalation from free product

Human exposure assumptions

	Residential		Industrial
	Adults	Children	Workers
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Indoor inhalation rate (m ³ /day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25

Vadose zone parameters

Free product depth (cm) 400 Water content in soil (unit less) 0,12
 Air content in soil (unit less) 0,26

Building parameters

Air content in cracks (unit less) 0,26 Air exchange rate (1/h) res. land use 0,504
 Water content in cracks (unit less) 0,12 Air exchange rate (1/h) ind. land use 0,828
 Surface crack fraction (unit less) 0,01 Residential building height (cm) 200
 Foundation/wall thickness (cm) 15 Industrial building height (cm) 300




Formula

$$MDI = \frac{V_{pi} * B_i * EF * ED}{BW * 365 * AT}$$

MDI = Maximum Daily Intake (mg/kg/day)
 V_{pi} = Indoor vapours concentration from free product (mg/m³)
 B_i = Indoor inhalation rate (m³/day)
 EF = Exposure frequency (days/year)
 BW = Body weight (kg)
 ED = Exposure time (years)
 AT = Averaging time (years)

Ref: (ASTM, 1995)

(*) For cancerogenics: AT = 70 years
 For non cancerogenics: AT = ED

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The calculation equation for V_{pi} is as follows:

Formula of vapour indoor concentration from free product


$$V_{pi} = \frac{C_{si} \times \left(\frac{D_s^{eff}}{L_s \times ER \times L_B} \right) \times 1 \times 10^9}{1 + \left(\frac{D_s^{eff}}{L_s \times ER \times L_B} \right) + \left(\frac{L_{crack}}{L_s \times \eta} \right)}$$

where: $D_s^{eff} = D^{air} \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^{wat} \frac{1}{H} \frac{\theta_{ws}^{3.33}}{\theta_T^2}$

and: $C_{si} = \frac{X \times \rho \times MW}{R \times T}$

Rif: (ASTM, 1995)

V_{pi} = Indoor vapours concentration from free product (mg/m ³)	ER = Air exchange rate in enclosed space (1/s)
C_{si} = Vapour concentration at saturation (g/cm ³)	L_{crack} = Thickness of building foundation/wall (cm)
ρ = Vapour pressure (mm Hg)	η = Cracks areal fraction in foundations/walls (cm ² /cm ²)
MW = Molecular weight (g/mole)	D_s^{eff} = Effective diffusion coefficient in soil based on vapour phase concentration (cm ² /s)
R = Gas molar constant (62,361 cm ³ mm Hg-cm ² /mole-°K)	D^{wat} = Diffusion coefficient in water (cm ² /s)
T = Absolute temperature (293°K outdoor)	D^{air} = Air diffusion coefficient (cm ² /s)
X = Molar fraction of toxic component of material = 1 (fixed value) (unit less)	θ_T = Total soil porosity (unit less)
L_B = Building height (cm)	H = Henry's law coefficient (unit less)
L_s = Free product depth (cm)	θ_{as} = Air content in soil (unit less)
	θ_{ws} = Water content in soil (unit less)





Csi	saturated vapour concentration (g/cm ³)
ρ	vapour pressure (mm Hg)
MW	molecular weight (g/mol)
R	gas constant (62,361 cm ³ mm Hg-cm ² /mole-°K)
T	absolute temperature (K)
X	mole fraction of component (-)
Lb	height f building (cm)
Ls	depth to contaminant (cm)
ER	enclosed-s[ace air exchange rate (l/s)
L_{crack}	thickness of foundation/wall (cm)
η	fraction of fractions in foundation (cm ² /cm ²)
D_s^{eff}	effective diffusion coefficient in soil (cm ² /s)
D^{wat}	diffusion coefficient in water (cm ² /s)
D^{air}	ambient air mixing zone height (cm)
θ_T	total porosity of soils
H	Henry's Law constant (-)
θ_{as}	air content in vadose zone soils (cm ³ /cm ³)
θ_{ws}	water content in vazose zone soils (cm ³ /cm ³)


AP2.1.4 MDI for Outdoor Inhalation of Vapours from LNAPL Free Product

The calculation of MDI for outdoor inhalation of vapours from free product is performed using the following equation and default values for parameters:

V_{po} outdoor concentration of contaminant vapour from product (mg/m³)

Outdoor vapours inhalation from free product			
Human exposure assumptions			
	Scenario		
	Residential	Industrial	
	Adults	Children	Workers
Body weight (kg)	70	15	70
Exposure frequency (days/year)	350	350	240
Outdoor inhalation rate (m ³ /day)	5	3	2
Time fraction spent on site	1	1	1
Exposure duration (years)	24	6	25
Vadose zone parameters			
Free product depth (cm)	400	Water content in soil (unit less)	0,12
Air content in soil (unit less)	0,26		
Building parameters			
Wind speed (cm/s)	225	Free product zone width (m)	10
Mixing zone height (cm)	200		
Formula $MDI = \frac{V_{po} * B_o * EF * ED}{BW * 365 * AT}$ <p>MDI = Maximum Daily Intake (mg/kg/day)</p> <p>V_{po} = Outdoor vapour concentration from free product (mg/m³)</p> <p>B_o = Outdoor inhalation rate (m³/day)</p> <p>EF = Exposure frequency (days/year)</p> <p>BW = Body weight (kg)</p> <p>ED = Exposure time (years)</p> <p>AT = Averaging time (years)</p> <p><small>Rf: (ASTM, 1995)</small></p> <p>(*): For cancerogenics: AT = 70 years For non cancerogenics: AT = ED</p>			
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The calculation equation for V_{po} is as following:

Formula Outdoor vapour concentration from free product	
$V_{po} = C_{si} \cdot \frac{D_s^{eff} W_p}{U_{air} \delta_{air} L_s} \cdot 10^9$	where: $C_{si} = \frac{X \cdot \rho \cdot MW}{R \cdot T}$
D_s^{eff} = Effective diffusion coefficient in soil based on vapour phase concentration (cm ² /s) W_p = Source width in wind direction (cm) U_{air} = Wind speed in the mixing zone (cm/s) δ_{air} = Outdoor mixing zone height (cm) L_s = Free product depth (cm) C_{si} = Vapour concentration at saturation (g/cm ³)	X = Molar fraction of toxic component of material = 1 (fixed value) (unit less) ρ = Vapour pressure (mm Hg) MW = Molecular weight (g/mole) R = Gas molar constant (62,361 cm ³ mm Hg-cm ² /mole-°K) T = Absolute temperature (293°K outdoor) V_{po} = Outdoor vapour concentration from free product (mg/m ³)
	

AP2.2 SALs Calculation for a Groundwater Receptor

AP2.2.1 Calculation of the “Substitute D.M. 471” Concentration

For those substances for which the D.M. 471/99 does not specify a LC for groundwaters, ROME software uses, in the risk analysis for groundwater, a specific risk-based concentration named “Substitute D.M. 471” concentration. For each contaminant, this concentration (mg/l) is calculated based on health risk acceptability, assuming a daily intake of 2 litres of water for an adult, and for a period equal to that specified for residential land use.

For a non-carcinogenic substance, the formula is as follows:

$$C_{(\text{substitute D.M. 471})} = TDI_o \frac{BW * 365}{IR_w * 1*10E-6 * EF}$$

where:

TDI _o	=	“Tolerable Daily Intake” by ingestion (mg/kg/day);
BW	=	body weight for an adult (kg);
IR _w	=	water daily ingestion (ml/day);
EF	=	exposure frequency (days/year).

The formula assumes the condition HI = 1 is met for non-carcinogenic substances.

For carcinogenic substances, the software uses the same exposure and acceptability criteria as those adopted for GALs (please see [Appendix 1](#)).

AP2.2.2 Soil Wash and Migration towards the Compliance Point

This path is modeled in three different phases:

- first phase: calculation of the concentration of theoretical soil pore water or leachate (C_w), starting from the soil's concentration as measured or “unit weight”;
- second phase: calculation of the concentration in groundwater (C_{source}) below the contamination source, once the soil pore water or leachate (calculated in the first phase) reaches and is diluted by the groundwater;
- third phase: calculation of the concentration in groundwater at the compliance point (C_x), located a specified distance from the contaminant source. This phase uses Domenico's model.

Calculations for the first and second phase are those used in the calculation of soil GALs that are protective of groundwater resources (see [Appendix 1](#)).

Domenico's model (1987) offers an analytical solution to the advective-dispersive transport of contaminants in groundwater. It takes into account both retardation due to adsorption/de-adsorption between the dissolved contaminant and the soil's solid matrix and first order decay factors (biodegradation of the contaminant). If we consider the maximum propagation direction of the contamination from the groundwater source, the model provides the maximum concentration of the contaminant a certain distance hydrogeologically downgradient of the source for a given source concentration.

The model is based on the following main assumptions:

- the source concentration is constant, and contamination is homogeneously distributed along the saturated layer;
- the aquifer is porous, homogeneous and isotropic;
- groundwater flow takes place at a steady state;
- the hydraulic gradient is uniform;
- the hydraulic motion can be described through Darcy's Law;
- adsorption is linear, instantaneous and reversible;
- dispersion of the contaminant occurs in three dimensions;
- decay can be described by first order law;
- the receptor is located along the maximum propagation direction (conservative assumption);

Formula shallow soil leaching and concentration at compliance point

Phase 1: Phases partition in soil (USEPA, 1994)

$$C_T = C_w (K_d + (\theta_w + \theta_a H) / \rho_s)$$

C_T = Total soil concentration (mg/kg) ρ_s = Soil bulk density (kg/l)
 C_w = Concentration in pore water (mg/l) θ_w = Water content in vadose zone (unit less)
 K_d = Soil/water partition coefficient (unit less) θ_a = Air content in vadose zone (unit less)
 H = Henry's law coefficient (unit less)

Phase 2: Mixing of infiltration water in groundwater

$$C_{source} = \frac{C_w}{DF} * 10^{-6} \quad \text{where: } DF = 1 + \frac{(k i d)}{(I L)}$$

[Thickness of the mixing zone \(DoE, 1994\)](#)
 $d = (0.0112 L^2)^{0.5} + d_a \{1 - \exp[(-LI) / (k i d_a)]\}$

DF = Dilution rate (unitless) d = Thickness of mixing zone (m)
 k = Hydraulic conductivity (m/year) i = Hydraulic gradient (unit less)
 L = Source length parallel to groundwater flow (m) I = Effective infiltration (m/year)
 d_a = Aquifer thickness (m)

Phase 3: Domenico Model (Domenico, 1987)

$$C(x) = C_{source} \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \left(1 + \frac{4\lambda\alpha_x}{u} \right)^{1/2} \right] \right\} \cdot \left(\operatorname{erf} \left[\frac{S_w}{4\sqrt{\alpha_y x}} \right] \right) \cdot \left(\operatorname{erf} \left[\frac{S_d}{4\sqrt{\alpha_z x}} \right] \right)$$

[To take into account the retardation factor ud substitutes u in the above equation \(Phase 3\)](#) [Where the Delay factor:](#) $u_d = \frac{k_s i}{\theta_s R_c}$
[Delay due to absorption](#) $R_c = \left[1 + \frac{K_d \rho_s}{\theta_s} \right]$

α_x = Longitudinal dispersivity (x/10) (ASTM, 1995) $C(x)$ = Concentration at compliance point (g/cm³) S_w = Source width (cm)
 α_y = Transversal dispersivity (ax/3) (ASTM, 1995) $u = k_s i / \theta_s$ S_d = Source depth (cm)
 α_z = Vertical dispersivity (ax/20) (ASTM, 1995) k_s = Hydraulic conductivity (cm/day) erf = Error function
 λ = First order degradation constant X = Distance from down gradient boundary of source plume along the central axis (cm) θ_s = Effective porosity (unit less)
 C_{source} = Source concentration (g/cm³)

C_T	target concentration of surface water resource (mg/l)
C_w	concentration in pore water (mg/l)
K_d	soil water partition coefficient (-)
H	Henry's Law constant (-)
ρ_s	bulk density dry soil(kg/l)
θ_w	water filled soil porosity (-)
θ_a	air filled soil porosity (-)
DF	dilution factor (-)
K	hydraulic conductivity (m/year)
L	length of contaminated site, parallel to direction of groundwater flow(m)
d	thickness of mixing zone in aquifer(m)
i	hydraulic gradient (-)
I	effective infiltration rate (m/year)
d_a	aquifer thickness (m)
$\alpha_{x,y,z}$	dispersion coefficient in three dimensions
λ	decay constant
$C(x)$	concentration at compliance point (g/cm ³)
R_c	retardation factor
u	$K_s i / \theta_s$
K_s	hydraulic conductivity (cm/day)
X	distance to compliance point (cm)
S_w	width of plume at source (cm)
S_d	thickness of plume at source (cm)
Erf	error function
θ_s	effective porosity (-)

AP2.2.3 Migration of Groundwater Contamination towards the Compliance Point

In this case, the contamination is already present in groundwater, and the modeling requires only the third phase described above, i.e. the Domenico model, set out below. The concentration of the contaminant observed in the aquifer at the source can be directly input into this equation.

Formula dissolved phase migration in groundwater to compliance point

Domenico Model (Domenico, 1987)


$$C(x) = C_{\text{source}} \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \left(1 + \frac{4\lambda\alpha_x}{u} \right)^{1/2} \right] \right\} \cdot \left(\operatorname{erf} \left[\frac{S_{\text{wp}}}{4\sqrt{\alpha_y x}} \right] \right) \cdot \left(\operatorname{erf} \left[\frac{S_d}{4\sqrt{\alpha_z x}} \right] \right)$$

To take into account the retardation factor u_d substitutes u in the above equation (Phase 3)

Delay due to absorption (u_d): $u_d = \frac{k_s i}{\theta_s R_c}$

Where the delay factor: $R_c = \left[1 + \frac{K_d \rho_s}{\theta_s} \right]$

$C(x)$ = Concentration at compliance point (g/cm ³)	x = Distance from down gradient boundary of source plume along the central axis (cm)
$u = k_s i \theta_s$	K_s = Hydraulic conductivity (cm/day)
i = Hydraulic gradient (unit less)	C_{source} = Source concentration (g/cm ³)
λ = First order degradation constant	S_{wp} = Source width (cm)
α_x = Longitudinal dispersivity (x/10) (ASTM, 1995)	S_d = Source depth (cm)
α_y = Transversal dispersivity (ax/3) (ASTM, 1995)	erf = Error function
α_z = Vertical dispersivity (ax/20) (ASTM, 1995)	
θ_s = Effective porosity (unit less)	



AP2.2.4 Migration of Dissolved Product Phase in Groundwater towards the Compliance Point

As for the previous cases, the contamination is already present in groundwater and the modeling only requires use of the third phase described above, i.e. the Domenico model, set out below. Since the groundwater contamination is formed by dissolution of free product, by definition, the concentration of the contaminant in groundwater near the source (C_{source}) is equal to the solubility of the substance forming the LNAPL free product.

Formula dissolved phase migration in groundwater to compliance point
Domenico Model (Domenico, 1987)

$$C(x) = C_{\text{source}} \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \left(1 + \frac{4\lambda\alpha_x}{u} \right)^{1/2} \right] \right\} \cdot \left(\operatorname{erf} \left[\frac{S_{wp}}{4\sqrt{\alpha_y x}} \right] \right) \cdot \left(\operatorname{erf} \left[\frac{S_d}{4\sqrt{\alpha_z x}} \right] \right)$$


To take into account the retardation factor u_d substitutes u in the above equation (Phase 3)

Delay due to absorption (u_d): $u_d = \frac{k_s i}{\theta_s R_c}$

Where the delay factor: $R_c = \left[1 + \frac{K_d \rho_s}{\theta_s} \right]$

$C(x)$ = Concentration at compliance point (g/cm³)
 $u = k_s i / \theta_s$
 i = Hydraulic gradient (unit less)
 λ = First order degradation constant
 α_x = Longitudinal dispersivity (x/10) (ASTM, 1995)
 α_y = Transversal dispersivity (ax/3) (ASTM, 1995)
 α_z = Vertical dispersivity (ax/20) (ASTM, 1995)
 θ_s = Effective porosity (unit less)

x = Distance from down gradient boundary of source plume along the central axis (cm)
 K_s = Hydraulic conductivity (cm/day)
 C_{source} = Source concentration (g/cm³)
 S_{wp} = Source width (cm)
 S_d = Source depth (cm)
 erf = Error function



AP2.3 SALs Calculation for a Surface Water Receptor

AP2.3.1 Soil Wash and Migration towards the Compliance Point

This path is modeled according to four different phases:

- first, second and third phase: correspond to the description provided in Paragraph 2.1 “Soil Wash and Migration towards the Compliance Point”;
- fourth phase: calculation of the concentration in the surface water resource (C_{source}) following discharge of contaminated groundwater from the site (i.e. allowing for effects of dilution within the surface water).

The equations and the parameters employed are described below:

Formula shallow soil leaching and surface water dilution factor		
Phase 1: Phases partition in soil (USEPA, 1994)		
$C_T = C_w (K_d + (\theta_w + \theta_a H) / \rho_s)$	C_T = Total soil concentration (mg/kg) C_w = Concentration in pore water (mg/l) K_d = Soil/water partition coefficient (unit less)	ρ_s = Soil bulk density (kg/l) θ_w = Water content in vadose zone (unit less) θ_a = Air content in vadose zone (unit less) H = Henry's law coefficient (unit less)
Phase 2: Mixing of infiltration water in groundwater		
$C_{source} = \frac{C_w}{DF} * 10^{-6} \text{ where: } DF = 1 + \frac{(k i d)}{(I L)}$ <p>Thickness of the mixing zone (DoE, 1994)</p> $d = (0.0112L^2)^{0.5} + d_a (1 - \exp[(-LI) / (ki d_a)])$	DF = Dilution rate (unitless) k = Hydraulic conductivity (m/year) L = Source length parallel to groundwater flow (m)	d = Thickness of mixing zone (m) i = Hydraulic gradient (unit less) I = Effective infiltration (m/year) d_a = Aquifer thickness (m)
Phase 3: Domenico Model (Domenico, 1987)		
$C(x) = C_{source} \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \left(1 + \frac{4\lambda\alpha_x}{u} \right)^{1/2} \right] \right\} \cdot \left(\operatorname{erf} \left[\frac{S_w}{4\sqrt{\alpha_y x}} \right] \right) \cdot \left(\operatorname{erf} \left[\frac{S_d}{4\sqrt{\alpha_x x}} \right] \right)$ <p>To take into account the retardation factor u substitutes u in the above equation (Phase 3)</p> <p>Where the Delay factor:</p> $R_c = \left[1 + \frac{K_d \rho_s}{\theta_s} \right]$ <p>Delay due to absorption</p> $u_d = \frac{k_s i}{\theta_s R_c}$	α_y = Transversal dispersivity (ax/3) (ASTM, 1995) λ = First order degradation constant u = ks / θ ks = Hydraulic conductivity (cm/day) x = Distance from down gradient boundary of source plume along the central axis (cm) erf = Error function α_x = Effective porosity (unit less)	α_x = Longitudinal dispersivity (x/10) (ASTM, 1995) α_z = Vertical dispersivity (ax/20) (ASTM, 1995) $C(x)$ = Concentration at compliance point (g/cm ³) S_w = Source width (cm) S_d = Source depth (cm) C_{source} = Source concentration (g/cm ³)
Phase 4: Surface water resource dilution factor (NRA, 1994)		
$DF2 = \frac{C_t(Q_a + Q_u)}{C_t \cdot Q_a + C_u \cdot Q_u}$	$DF2$ = Surface water resource dilution factor (unit less) C_t = Target concentration of surface water resource (mg/l) C_u = Upstream surface water concentration (mg/l) Q_a = Groundwater flow rate drained by surface water (m ³ /s) Q_u = Upstream surface water flow rate (m ³ /s)	

AP2.3.2 Migration of Groundwater Contamination towards a Surface Water Resource

In this case, the contamination is already present in groundwater and the modeling requires consideration of only the third and fourth phase (dilution in surface waters) described above.

AP2.3.3 Migration of Product Phase Dissolved in Groundwater towards a Surface Water Resource

Again, contamination is already present in groundwater as the result of dissolution of LNAPL, and the modeling requires consideration of only the third and fourth phase. Since the groundwater contamination is formed by dissolution of free product, by definition, the concentration of the contaminant in groundwater near the source (C_{source}) is equal to the solubility of the substance forming the LNAPL free product.

Formula dissolved phase migration in groundwater to surface water

Phase 1: Domenico model (Domenico, 1987)

$$C(x) = C_{source} \exp \left\{ \frac{x}{2\alpha_x} \left[1 - \left(1 + \frac{4\lambda\alpha_x}{u} \right)^{1/2} \right] \right\} \cdot \left(\operatorname{erf} \left[\frac{S_w}{4\sqrt{\alpha_y x}} \right] \right) \cdot \left(\operatorname{erf} \left[\frac{S_d}{4\sqrt{\alpha_x x}} \right] \right)$$

To take into account the retardation factor u substitutes u in the above equation (Phase 3)

Where the delay factor:

$$R_c = \left[1 + \frac{K_d \rho_s}{\theta_s} \right]$$

Delay due to absorption (u_d):

$$u_d = \frac{k_s \cdot 1}{\theta_s R_c}$$

Phase 2: Dilution factor of surface water resource (NRA, 1994)

$$DF2 = \frac{C_t(Q_a + Q_u)}{C_t \cdot Q_a + C_u \cdot Q_u}$$

DF2 = Surface water resource dilution factor (unit less)

C_t = Target concentration of surface water resource (mg/l)

C_u = Upstream surface water concentration (mg/l)

Q_a = Groundwater flow rate drained by surface water (m³/s)

Q_u = Upstream surface water flow rate (m³/s)

$C(x)$ = Concentration at compliance point (g/cm³)

u = k_s / θ_s

i = Hydraulic gradient (unit less)

λ = First order degradation constant

α_y = Transversal dispersivity (ax/3) (ASTM, 1995)

α'_x = Vertical dispersivity (ax/20) (ASTM, 1995)

x = Distance from down gradient boundary of source plume along the central axis (cm)

K_s = Hydraulic conductivity (cm/day)

C_{source} = Source concentration (g/cm³)

α'_x = Longitudinal dispersivity (x/10) (ASTM, 1995)

S_w = Source width (cm)

S_d = Source depth (cm)

erf = Error function

θ_s = Effective porosity (unit less)

