



Network Oriented Risk-assessment by In-situ Screening of Contaminated sites

NORISC

Human health risk assessment framework for decision-making

Eleonora Wcislo, Jacek Dlugosz, Marek Korcz,
Institute for Ecology of Industrial Areas, Katowice, Poland

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City of Cologne, COC, D

University of Cologne, UC, D

Clayton Umweltschutz GbR., Clayton, D

Geological Survey of Sweden, SGU, S

Institute of Geology and Mineral Exploration, IGME, EL

Agruniver Koerneyezetvedelmi Szolgáto es Vallalkozo Kft., AGRUNIVER Kft., HU

Universita' Degli Studi di Ferrara, UNIFE, I

Uppsala Universitet, UU, S

Universita' Degli Studi di Firenze, UNIFLORENCE, I

Organisation of Thessaloniki, OTH, EL

City of Stockholm, EHP

Institute for Ecology of Industrial Areas, IETU, PL

CONTENTS

<u>EXECUTIVE SUMMARY</u>	1
<u>1 INTRODUCTION</u>	2
<u>2 THE PLACE OF HRA PROCESS IN CONTAMINATED SITE INVESTIGATION/ASSESSMENT/REVITALISATION STRATEGY</u>	3
<u>3 SITE-SPECIFIC HEALTH RISK ASSESSMENT PROCESS</u>	5
<u>3.1 Baseline human health risk assessment (BHRA)</u>	5
<u>3.1.1 Development of data set</u>	6
<u>3.1.2 Exposure assessment</u>	6
<u>3.1.2.1 Development of site-specific exposure scenarios</u>	7
<u>3.1.3 Toxicity assessment</u>	9
<u>3.1.4 Risk characterisation</u>	10
<u>3.2 Development of site-specific health-based remedial goals (HBRGs)</u>	13
<u>4 HRA RESULTS VISUALISATION (ONLY FOR SOIL)</u>	16
<u>5 ROLE OF THE HRA MODULE IN DECISION MAKING PROCESS</u>	17
<u>6 REFERENCES</u>	19
<u>APPENDIX 1 SITE-SPECIFIC HUMAN HEALTH RISK ASSESSMENT DATABASES</u>	A1-1
<u>1.1 Chemical-specific parameters</u>	A1-2
<u>1.2 Exposure factors</u>	A1-2
<u>1.3 Site-specific soil parameters or default values based on literature data for similar soils</u>	A1-3
<u>1.4 Site –specific meteorological parameters</u>	A1-3
<u>1.5 Other site-specific parameters</u>	A1-3
<u>APPENDIX 2 SOIL EXPOSURE PATHWAYS EQUATIONS FOR CALCULATING INTAKES ALONG WITH DEFAULT VALUES ASSUMED UNDER THE RESIDENTIAL, INDUSTRIAL AND RECREATIONAL EXPOSURE SCENARIOS</u>	A2-1
<u>2.1 Equation 1 - Equation for ingestion exposure to contaminants in surface soil along with default values</u>	A2-2
<u>2.2 Equation 2 - Equation for dermal absorption exposure to contaminants in surface soil along with default values</u>	A2-3
<u>2.3 Equation 3 - Equation for inhalation exposure to contaminants in surface soil (fugitive dusts)</u>	A2-4
<u>2.4 Equation 3a - Calculation of the Particulate Emission Factor</u>	A2-5
<u>2.5 Equation 4 - Equation for inhalation exposure to volatile contaminants in subsurface soil</u>	A2-9
<u>2.6 Equation 4a - Calculation of the Soil-to-Air Volatilisation Factor</u>	A2-10
<u>2.7 Equation 4b - Calculation of the Soil Saturation Limit</u>	A2-11
<u>APPENDIX 3 GROUNDWATER EXPOSURE PATHWAYS EQUATIONS FOR CALCULATING INTAKES ALONG WITH DEFAULT VALUES ASSUMED UNDER THE RESIDENTIAL SCENARIO</u>	A3-1

3.1	Equation 1 - Intake calculation for drinking water ingestion	A3-2
3.2	Equation 2 - Absorption dose calculation for dermal contact with groundwater while showering/bathing	A3-2
3.3	Equation 3 - Intake calculation for inhalation of vapour-phase chemicals from household water use	A3-4

APPENDIX 4 HUMAN HEALTH RISK ASSESSMENT SOFTWARE MODULE

<u>DESCRIPTION – USER’S GUIDE</u>		A4-1
4.1	Introduction	A4-2
4.2	Parameters requested by HRA module	A4-2
4.3	Internal HRA Tables	A4-8
4.4	HRA software module description	A4-10
4.5	Future HRA software improvement	A4-38

LIST OF TABLES

Table 3-1. Summary of soil and groundwater exposure pathways for urban exposure scenarios	9
Table 3-2. Summary of human health risk assessment: An example – Current industrial land use/soil/adult	13
Table A3-1 Default parameter values for oral, dermal and inhalation exposure to chemicals in water under the residential exposure scenario	A3-5
Table A4-2 Parameters requested for risk calculation	A4-3

LIST OF FIGURES

Fig. 2.1 The place of HRA in contaminated site investigation/assessment/revitalisation strategy	4
Fig. 4.1 User Soil Concentration Table	6
Fig. 4.2 User Groundwater Concentration Table	7
Fig. 4.3 User General Site Parameters Table	8
Fig. 4.4 Chemical/Physical Properties Table	9
Fig. 4.5 Site Parameters Default Values Table	9
Fig. 4.6 The basic HRA module options – “What to do?”	11
Fig. 4.7 Land use scenario selection	11
Fig. 4.8 Exposure pathways selection	12
Fig. 4.9 Soil data source selection	13
Fig. 4.10 Groundwater data source selection	14
Fig. 4.11 Setting general site-specific parameters (surface soil)	15
Fig. 4.12 Setting general site-specific parameters (subsurface soil)	15
Fig. 4.13 Toxicity values setting	19
Fig. 4.14 Chemical/physical properties parameters setting	21
Fig. 4.15 Exposure parameter setting - Industrial scenario, receptor - adult	24
Fig. 4.16 Exposure parameter setting – Residential scenario, receptor - young child	27
Fig. 4.17 Exposure parameter setting – Residential scenario, receptor - adult	29
Fig. 4.18 Exposure parameter setting – Recreational scenario, receptor – adult	31
Fig. 4.19 Exposure parameter setting – Recreational scenario, receptor - young child	33

Fig. 4.20 Exposure parameter setting – Residential/Groundwater scenario, receptor - young child.....	34
Fig. 4.21 Exposure parameter setting - Residential/Groundwater scenario, receptor – adult.....	34
Fig. 4.22 Setting target risk values.....	35
Fig. 4.23 Risk characterisation outputs.....	36
Fig. 4.24 Analysis of the RBC values.....	37

Executive summary

The human health risk assessment (HRA) framework has been designed as a tool to assist decision-making at contaminated sites. The HRA framework offers an established procedure, which follows site investigation, and provides information on potential risk to humans posed by contaminated sites, as well as health-based remedial goals for environmental media.

The HRA procedure has been developed in the form of a user-friendly software module as a part of the NORISC Decision Support Software System (DSS). However, the HRA software module can be used in a stand-alone form. It is recommended to use the HRA module when national soil and groundwater limit values are exceeded. The HRA software module is intended to provide sufficient technical and procedural support to conduct simple site-specific risk assessment.

The HRA module has been generally based on US EPA risk assessment procedures, which have been especially well developed and documented in recent years.

The HRA procedure may be defined as simple site-specific. It means that only a few site-specific parameters, obtained during site characterisation, are required as input. Soil and groundwater exposure pathways considered in the HRA module are associated with three land use patterns – residential, industrial/commercial and recreational. The set of exposure pathways can be considered as typical for the majority of urban contaminated sites. However, depending on site conditions, human activities and identified receptors, these exposure pathways can be modified.

The HRA software package allows to determine the level and spatial distribution of human health risks at a given site, as well as site-specific health-based remedial goals (HBRGs)/Risk-based Concentrations (RBCs). The output is presented in the form of tables and maps. Risk results are visualised to assist in the decision-making process, and facilitate communication between different stakeholder groups.

The HRA module incorporated into NORISC DSS will serve as an additional tool for contaminated land management in urban areas. Providing HBRGs for environmental media, the HRA module may also be used as a basis for selecting the appropriate remediation option, and for designing and conducting the revitalisation of contaminated sites. It will allow for a more comprehensive decision-making process, especially in cases where complex contamination of soil and groundwater occurs.

1 Introduction

European countries have different legislative and procedural approaches to contaminated site assessment and remediation, or relevant legislation is under development. To evaluate contaminated sites, they have incorporated different assessment procedures, including risk assessment. Some of them have adopted US EPA procedures, which are especially well documented with respect to human receptors.

This document presents a human health risk assessment (HRA) framework for decision-making at contaminated sites, developed within WP 9 of the NORISC project as Deliverable 20. The HRA framework offers an established procedure, which follows the site investigation, and allows the evaluation of current and potential human adverse effects, resulting from contaminated environmental media (e.g., soil, groundwater), and the development of health-based remedial goals.

The HRA procedure has been developed in the form of a user-friendly software module as a part of the NORISC Decision Support Software System (DSS) that provides a link between site investigation and remediation/revitalisation decision-making. However, the HRA software module can be used in a stand-alone form.

This document along with the HRA software package is intended to provide sufficient technical and procedural support to conduct the HRA process. It may also serve as the procedural documentation for the HRA software package to guide the user through this process.

Although risk assessments, performed on contaminated sites, usually refer to both human health and the environment, the methods and other information contained herein are specific only to human health risk assessments. If it is necessary to satisfy country- or site-specific requirements, concerning contaminated site assessment and management (including ecological risk assessments), other methods and also commercially available software packages could be used as supplementary tools to the NORISC DSS.

2 The place of HRA process in contaminated site investigation/assessment/revitalisation strategy

The HRA process is viewed as an element of the strategy developed for the revitalisation/remediation of contaminated sites. The place of the HRA process in this strategy is presented in Figure1. The HRA process follows the site investigation. It is proposed to use the module when national soil and groundwater limit values are exceeded.

Thus, the HRA process employs a **two-step approach**:

Step 1

Step 1 refers to the comparison of media-specific **maximum** contaminant concentrations, detected at a site, with national limit values for soil and groundwater contaminants. It is used as a starting point for evaluating site contamination. The use of limit values can direct the further (or remedial) investigation and risk assessment on aspects that need more concern. It facilitates prompt identification of contaminants of the greatest risk to human health, and the identification of contaminated sub-areas, which require additional investigation.

If the on-site **maximum** chemical concentrations do not exceed the national limit value, the assessment is completed. In the case of soil, chemical concentrations detected in samples collected from all depths are compared.

Step 2

Step 2 employs a site-specific HRA process, if **maximum on-site concentrations** of contaminants, detected in soil and groundwater, exceed relevant national limit values.

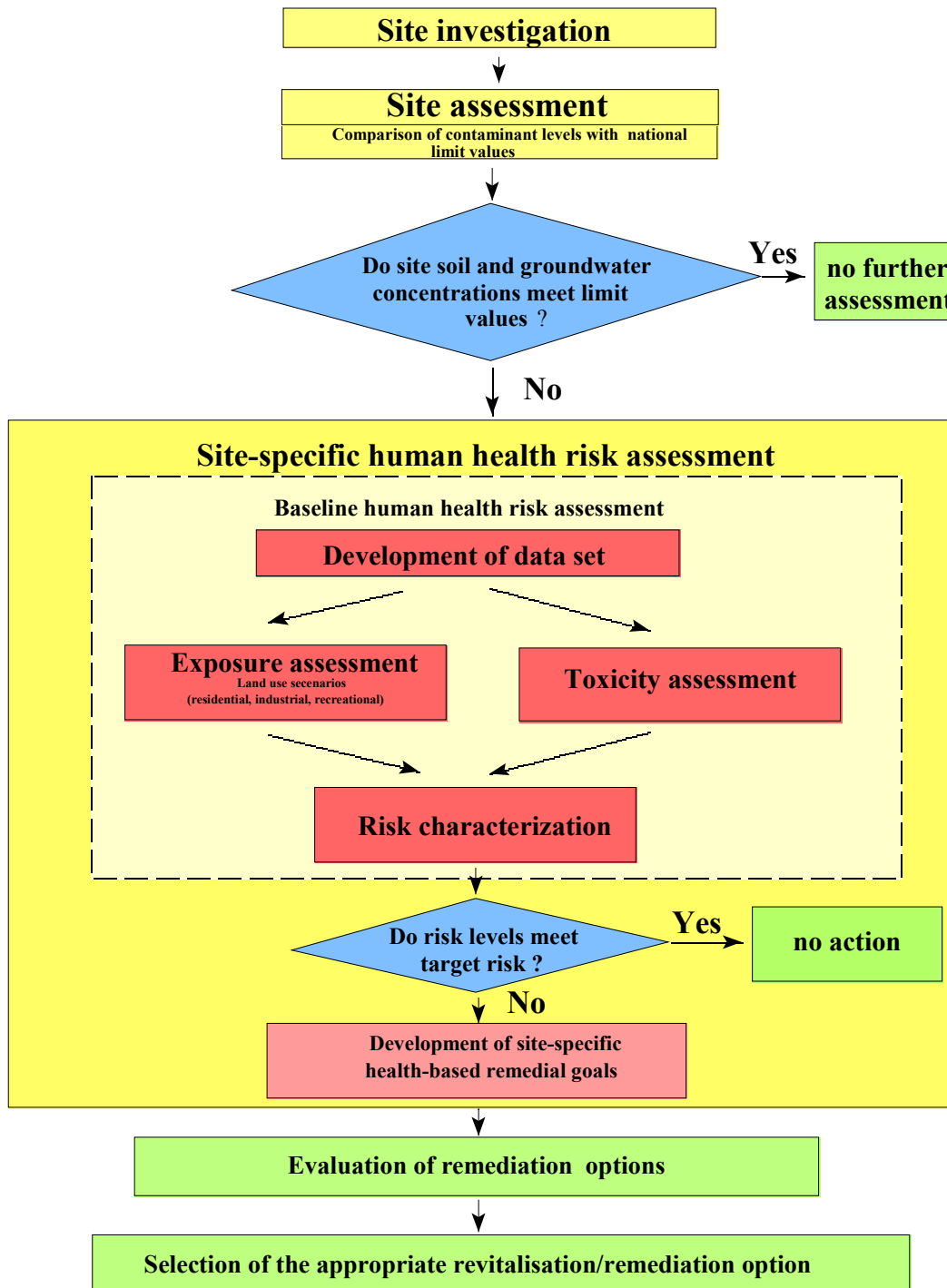


Fig. 2.1 The place of HRA in contaminated site investigation/assessment/revitalisation strategy

3 Site-specific health risk assessment process

The HRA process is to be used to determine the risks that sites pose, and/or may pose, in the future to human health, and to assist in decision-making on the level of remediation, necessary to protect human health, and to select the most appropriate remedial option for the site.

Taking into consideration that in recent years human health risk assessment procedures have become especially well developed and documented by US EPA (US EPA 1989; 1991a; 1995; 1996a; 1996b; 2001a; 2001b, 2001c), they have been adapted in the development of the HRA module within the NORISC project. The proposed HRA procedure may be adjusted to site-specific circumstances, including different land use scenarios and different types of contaminants, and may be used in accordance with principles and requirements of NORISC DSS.

The HRA procedure may be defined as **simple site-specific**. It means that only a few site-specific parameters values are required as input values concerning, for example, soil and meteorological conditions. This approach is more rigorous and precise than the simplest conservative, generic approach using guideline limit values for comparing site contamination levels, and less rigorous than a more site-specific modelling approach, using mostly site-specific data. The simple site-specific risk assessment seems to be the most useful in the context of a compromise between site-specificity and costs and efforts.

The site-specific HRA process comprises two main areas: baseline human health risk assessment (BHRA), and development of health-based remedial goals (HBRGs).

The purpose of BHRA is to:

- assess potential risks to human health
- determine the need for remedial action
- determine measures needed to eliminate or mitigate health and environmental effects.

The purpose of the HBRGs calculation is to provide a basis for the selection of an appropriate remedial/revitalisation option for a given site.

3.1 Baseline human health risk assessment (BHRA)

BHRA is an analysis of the potential adverse health effects, caused by exposure to hazardous substances, released from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no action) (US EPA 1989).

To estimate BHRA, the following steps are undertaken (Fig. 2.1):

- development of data set,
- exposure assessment,
- toxicity assessment,
- risk characterisation.

3.1.1 Development of data set

The site-specific data set development is composed of a few sub-steps:

(1) Collection of data on geochemical concentrations produced during a site investigation. Each sampling point is characterised by x, y coordinates, sample depth and concentrations of chemicals in soil and groundwater.

(2) Gathering of data on site-specific parameters such as: site area, extent of the site defined as coordinates of boundary points, present and future land uses, neighbourhood land use patterns, average wind velocity, height of anemometric measurements, fraction of surface cover (vegetative, asphalt, buildings), soil particle density, soil bulk density, organic carbon fraction, granulometric composition – as coarse, sand and silt fractions, soil moisture content, air-filled soil porosity and water-filled soil porosity (see Appendix 1). These parameters should be estimated for surface and sub-surface soil layers. In case these site-specific parameter values are lacking, they can be replaced with default values (see Appendices 2 and 3).

(3) Chemicals of potential concern are grouped by environmental medium and identified land uses (as representative of exposure areas of concern). Soil concentrations are grouped according to sampling depths relevant to land use patterns and type of chemicals (e.g., surface concentrations for metals and PAHs, and/or subsurface concentrations for volatiles). Chemical concentrations in water are averaged for the relevant water bearing horizon.

(4) Collection of chemical-specific data for chemicals of potential concern, such as chemical abstract number, type of chemical (inorganic, organic, volatile, non-volatile), soil organic carbon-water partition coefficient, diffusivity in air, diffusivity in water, Henry's law constant, molecular weight, water solubility, fraction absorbed, dermal permeability coefficient and octanol/water partition coefficient (see Appendix 1).

During the first step of baseline risk assessment, the risk assessor should also make a preliminary identification of potential human exposure at the site (detailed exposure assessment is described in Section 3.1.2.).

3.1.2 Exposure assessment

The exposure assessment stage estimates the magnitude of actual and/or potential human exposure, the frequency and duration of exposure, and pathways by which humans are potentially exposed (US EPA 1989).

During this step, site-specific exposure scenarios are developed for both current and/or intended future land use patterns (e.g., residential, industrial). Results of the exposure assessment are pathway-specific contaminant intakes, under developed exposure scenarios. Standard intake equations and suggested values of exposure parameters are provided by the US EPA; however, site-specific factors and expert judgement can influence the final selection thereof.

In the classical approach, exposure parameters, such as body weight, exposure duration, ingestion or inhalation rates, can be selected to estimate "reasonable maximum exposure" (RME), defined as the highest exposure that is reasonably expected to occur at a given site (US EPA 1989). The goal of RME is to combine upper-bound and mid-range exposure factors in the equation so that the result represents an expo

sure scenario that is both protective and reasonable, not the worst possible case (US EPA 1991b).

The quantification of exposure is based on an estimate of the average daily intake, i.e., the average amount of the contaminant entering the receptor's body per day.

The generic equation for calculating chemical intakes is as follows:

$$I = C \times \frac{CR \times EF \times ED}{BW} \times \frac{1}{AT}$$

where:

- I - intake (mg/kg body weight/day),
- C - chemical concentration in soil or groundwater; the average concentration during human contact over the exposure period (mg/kg soil or mg/L water);
- CR - contact rate; the amount of a contaminated medium in contact with humans per time unit or event (soil - mg/day or water - l/day) (upper-bound value),
- EF - exposure frequency (days/year) (upper-bound value),
- ED - exposure duration (years) (upper-bound value),
- BW - body weight; the average value over the exposure period (kg),
- AT - averaging time (equal to ED for non-carcinogens and 70 years for carcinogens) (days).

In the current release of NORISC-HRA module the intake is calculated for each measurement point based on:

- maximum concentration of volatiles found in a soil sampling point profile,
- concentration value of non-volatiles determined in the sample taken from the top-soil layer,
- average concentration of chemicals in the whole site water horizon.

3.1.2.1 Development of site-specific exposure scenarios

Development of site-specific exposure scenarios is subsequent to identification of current and/or anticipated future land use patterns for a given site. It enables identification of soil and groundwater receptors and activities that determine the exposure pathways of concern.

In the HRA module three typical urban land use categories are considered: residential, industrial, and recreational.

Residential exposure scenario

A residential exposure scenario is used when the area is residential, or housing is planned on the site, or adjacent to it. Residents are expected to be exposed continuously over long period to residential contaminated soil and groundwater (if groundwater is planned to be used in households).

For a residential setting the exposure frequency (EF) is equal to 350 days/year. It results from the common assumption that residents spend two weeks per year away from home. In terms of exposure duration (ED), a resident is assumed to live in the

same home for 30 years (US EPA 1991b) – as a child for 6 years and adult for 24 years).

Relevant to this land use category and environmental media, the following exposure pathways are evaluated:

Soil exposure pathways:

Surface soil

- incidental soil and dust ingestion
- dermal contact with soil
- inhalation of fugitive dust.

Subsurface soil

- inhalation of volatiles outdoors.

Groundwater exposure pathways (if it is planned to use groundwater in households):

- ingestion of groundwater used as a tap water
- dermal contact while showering or bathing
- inhalation of volatiles from groundwater during household use.

Under the residential scenario, exposure is the highest, because it is the most frequent and its duration is the longest.

According to US recommendations, exposure to soil contaminants is calculated separately for non-carcinogenic and carcinogenic effects (US EPA 1996a, 1996b, 2001a; Tonner-Navarro et al. 1998).

Industrial/commercial exposure scenario

An industrial/commercial scenario should be used for occupational exposure of adults who may be exposed to soil/dust driven from soil during their outdoor work-related activities at the site. For outdoor workers, a default exposure frequency of 225 days/year, and a default exposure duration of 25 years, were established (US EPA 2001a). Under this scenario exposure is lower than under the residential scenario, because it is limited to 8 hours a day for 225 days per year.

Soil exposure pathways evaluated under this scenario include:

Surface soil

- incidental soil and dust ingestion
- dermal contact with soil
- inhalation of fugitive dusts.

Subsurface soil

- inhalation of volatiles outdoors.

Recreational exposure scenario

This scenario is developed for potential recreational use of a site. It refers to both children and adults, who spend time at the site engaged in sport activities.

Exposure pathways evaluated under this scenario refer only to soil and include:

Surface soil

- incidental soil and dust ingestion
- dermal contact with soil
- inhalation of fugitive dust.

Subsurface soils

- inhalation of volatiles outdoors.

Table 3-1 summarises soil and groundwater exposure pathways for each of the three exposure scenarios: residential, industrial/commercial and recreational. This set of exposure pathways can be considered as typical for the majority of urban contaminated sites. However, depending on site conditions, human activities and identified receptors, these exposure pathways may be modified or new ones be added.

Table 3-1. Summary of soil and groundwater exposure pathways for urban exposure scenarios

Exposure pathway	Exposure scenario								
	Residential			Industrial/Commercial			Recreational		
	Surface soil	Sub-surface soil	Ground water	Surface soil	Sub-surface soil	Ground water	Surface soil	Sub-surface soil	Ground water
Incidental soil and dust ingestion	x			x			x		
Dermal contact with soil	x			x			x		
Inhalation of fugitive dust	x			x			x		
Inhalation of volatiles outdoors		x			x			x	
Ingestion of groundwater used as a tap water			x						
Dermal contact while showering or bathing			x						
Inhalation of volatiles from groundwater during household use			x						

Remarks:

Surface soil is defined as the top 25 cm of soil layer according to the NORISC soil sampling strategy.
Subsurface soil is defined as soil located beneath the surface soil.

Equations for calculating soil contaminant intakes, along with default values assumed under developed exposure scenarios (residential, industrial/commercial and recreational) are included in Appendix 2.

Equations for calculating groundwater contaminant intakes under the residential exposure scenario are included in Appendix 3. Table 3-1 presents default parameter values for oral, dermal and inhalation exposure to chemicals in water, assumed under the residential exposure scenario.

In cases where site-specific conditions strongly differ from standard ones, it will be necessary to develop site-specific exposure parameters values. In other cases, it is recommended to use default values of exposure parameters.

3.1.3 Toxicity assessment

This step evaluates the toxicity of chemicals of potential concern. Toxicity assessment is based on available scientific data on potential adverse health effects of the

contaminants in humans, which are usually compiled in the form of a toxicological profile for each contaminant. This step includes also identification of important measures of toxicity, i.e., reference doses (RfDs) to evaluate non-carcinogenic effects, and cancer slope factors (CSFs) for carcinogenic effects.

RfDs and CSFs have been developed by the US EPA and published in the Integrated Risk Information System (IRIS) (IRIS 2003), and Health Effects Assessment Summary Tables (HEAST) databases. IRIS is recommended as a preferred source of toxicity information. HEAST is used when data is not available in IRIS (US EPA 1989, 2003).

The US EPA has also developed provisional values of RfDs and CSFs, which are used for specific purposes (US EPA 2003). If no RfDs and CSFs are available, the chemicals can be evaluated only qualitatively.

Various types of RfD are available depending on the exposure route (oral or inhalation), and the length of exposure (chronic, subchronic or single event) (US EPA 1989). Chronic RfDs are used to evaluate the potential non-carcinogenic effects, associated with exposure periods between seven years and a lifetime. Subchronic RfDs are useful for characterising potential non-carcinogenic effects associated with short-term exposure periods between two weeks and seven years. The NORISC-HRA module refers only to chronic exposure.

Within toxicity assessment step, chemical-specific toxicological data are collected which include: chronic oral and inhalation RfDs, oral and inhalation CSFs, chemical-specific gastrointestinal absorption factors (ABS_{GI}), carcinogen class, as well as primary target organs or critical effects for non-carcinogens for oral/dermal and inhalation exposures (see Appendix 1).

No RfDs and CSFs are available for the direct evaluation of dermal exposures to contaminants. Dermal RfDs and CSFs are calculated by extrapolating oral toxicity values with the use of ABS_{GI} (US EPA 2001a, 2001b), as presented below:

$$RfD_d = RfD_o \times ABS_{GI}$$

where:

RfD_d - Dermally adjusted Reference Dose (mg/kg/day)

RfD_o - Oral Reference Dose (mg/kg/day)

ABS_{GI} - Gastrointestinal Absorption Factor (unitless)

$$CSF_d = CSF_o / ABS_{GI}$$

where:

CSF_o - Dermally adjusted Carcinogenic Slope Factor (mg/kg/day)⁻¹

CSF_o - Oral Carcinogenic Slope Factor (mg/kg/day)⁻¹

ABS_{GI} - Gastrointestinal Absorption Factor (unitless).

3.1.4 Risk characterisation

Risk characterisation combines toxicity assessment with exposure assessment, in order to quantify risks posed by a contaminated site under a given set of conditions.

Risk characterisation is considered separately for carcinogenic and non-carcinogenic effects, and includes identification of sources of uncertainty. Chemicals, which produce both non-carcinogenic and carcinogenic effects are evaluated in both groups.

Risks are quantified under the present site conditions for present and/or future exposure scenarios relevant to the land use pattern. Risk characterisation should also include a discussion on accompanying uncertainties.

Non-cancer risk

Potential non-cancer risks are evaluated by comparison of the estimated contaminant intakes from each exposure route (oral, dermal, inhalation) with the relevant Reference Dose (RfD) to produce the Hazard Quotient (HQ), defined as follows (US EPA 1989):

$$\mathbf{HQ=CDI/RfD}$$

where:

- HQ –Hazard Quotient (unitless),
- CDI –Chemical Daily Intake (mg/kg/day),
- RfD –Reference Dose (mg/kg/day).

CDI and RfD represent the same exposure route (i.e., oral, dermal and inhalation CDIs are divided by oral, dermal and inhalation RfDs, respectively), and the same exposure period.

The Hazard Quotient assumes that there is a level of exposure (i.e., RfD) below which it is unlikely to experience adverse health effects, even for sensitive populations. If the HQ exceeds unity (a value of 1), there may be a concern for potential non-carcinogenic effects.

To assess the overall potential for non-carcinogenic health effects posed by more than one chemical, the HQs calculated for each chemical are summed (assuming additivity of effects), and expressed as a Hazard Index (HI) (US EPA 1989).

$$\mathbf{HI = HQ_1 + HQ_2 + \dots + HQ_n}$$

In cases where the non-cancer HI does not exceed unity ($HI < 1$), it is assumed that no chronic risks are likely to occur at the site (US EPA 1989).

If the HI is higher than unity, as a consequence of summing several hazard quotients, the compounds are segregated by effect, target organs, and by mechanism of action and separate HIs are derived for each group. Because of the potential for different health effects/target organs via oral/dermal and inhalation exposures, they are evaluated separately for these routes (see Table 3-2).

To assess the overall potential for non-carcinogenic effects, posed by several exposure pathways, HIs for each exposure pathway contributing to exposure of the same individual or subpopulation are summed up and expressed as a Total Hazard Index (HITot). When HITot exceeds unity, there may be concern for potential non-cancer health effects.

Under the residential and recreational scenarios, i.e., scenarios which refer to different group receptors (children, adults), HIs are generated separately for children and adults.

Cancer risk

Cancer risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., incremental or excess individual lifetime cancer risk). The following linear low-dose carcinogenic risk equation is used for each exposure route (US EPA 1989):

$$\text{Cancer Risk} = \text{CDI} \times \text{CSF}$$

where:

- CDI –Chemical Daily Intake averaged over 70 years (mg/kg/day),
- CSF –Cancer Slope Factor (mg/kg/day)⁻¹; a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime.

CDI and CSF represent the same exposure route (i.e. oral, dermal and inhalation CDIs are multiplied by oral, dermal and inhalation CSFs, respectively).

The risk number represents the probability of occurrence of additional cancer cases. For example, if it is expressed as 1E-06, it means that one additional case of cancer is expected in a population of one million people exposed to a certain level of a given chemical over their lifetime.

If a site has multiple carcinogenic contaminants, cancer risks for each carcinogen are added (assuming additivity of effects), and the cancer risk for each exposure pathway is calculated.

For multiple exposure pathways, the total cancer risk is calculated by summing up the pathway-specific cancer risks:

$$\text{Risk}_t = \sum \text{Risk}_i$$

where:

- Risk_t –the Total Cancer Risk,
- Risk_i –the risk estimate for the ith exposure pathway.

The total cancer risk is compared with the acceptable risk.

Risks in the range of 1E-06 to 1E-04 are generally accepted by regulatory agencies, e.g., US EPA (US EPA 1990b, 1991a, 1991c). A risk-based remedial decision can be superseded by the presence of a non-carcinogenic impact or environmental impact requiring action at the site.

Remedial action is generally required at a site, when a cumulative carcinogenic risk exceeds 100 in a million (1E-04, excess cancer risk) or the cumulative non-carcinogenic HI exceeds 1, based on RME assumptions (US EPA 1991a, 1991c). If the cumulative risk is less than 1E-04, action generally is not required, but may be warranted if a risk-based chemical-specific standard (e.g., drinking water standards) is violated.

Setting up 1E-06 risk levels for individual chemicals and pathways, it should generally lead to cumulative site risks within the 1E-04-1E-06 risk range for the combinations of chemicals.

In European countries, the value of 1E-05 is most commonly used as the carcinogenic acceptable risk level (e.g., Sweden, Italy, Germany).

The NORISC HRA module allows comparison of calculated cancer risks with different acceptable risk levels, e.g., 1E-04, 1E-05, 1E-06.

Under the scenarios, which refer to both receptors – a child and an adult (i.e., residential and recreational), cancer risks are calculated separately for these receptors, and then summed up to yield the Total Cancer Risk for the aggregate resident/recreational user.

Table 3-2 presents an example of the human health risk assessment summary.

Table 3-2. Summary of human health risk assessment: An example – Current industrial land use/soil/adult

Medium	Exposure point	Chemical	Carcinogenic Risk				Non-carcinogenic Hazard Quotient					
			Ingestion	Inhalation	Dermal	Exposure routes total	Primary target organ	Ingestion	Inhalation	Dermal	Exposure routes total	
Soil	Point 1	Chemical 1	----	----	----	----	CNS	x	----	x	x	
		Chemical 2	x	----	x	x	Skin	x	----	x	x	
		Chemical 3	----	----	----	----	Heart	x	----	x	x	
		Chemical 4	----	----	----	----	CNS	x	----	x	x	
		Chemical 5	x	----	x	x	Liver	x	----	x	x	
	Exposure point/Chemical total	Chemical 1	----	----	----	----	CSN	----	x	----	x	
		Chemical 3	----	----	----	----	Fetus	----	x	----	x	
		Chemical 5	----	x	----	x	Liver	----	x	----	x	
	Exposure point/Chemical total			x	x	x	xx		x	x	x	xx
	Point 2	Chemical 6	----	----	----	----	Gastrointestinal	x	----	x	x	
Exposure point/Chemical total			----	----	----	----	x	----	x	xx		
Total Cancer Risk (soil, all exposure routes)						xxx	Total HI (soil, all exposure routes)				xxx	

Total liver HI (soil) =	x
Total CNS HI soil) =	x
Total skin HI (soil) =	x
Total fetus HI (soil) =	x
Total heart HI (soil) =	x
Total gastrointestinal HI (soil) =	x

Concerning **soil**, HQs, HIs and Cancer Risks, as well as Total HI and Total Cancer Risk, are calculated separately for a child and an adult for **each sampling point** under the residential and recreational scenarios, and only for an adult under the industrial scenario. Under the residential/recreational scenarios, Total Cancer Risk is calculated for an aggregate resident/recreational user.

Concerning **groundwater**, HQs, HIs and Cancer Risks as well as Total HI and Total Cancer Risk are calculated as **site values** for a water-bearing horizon, separately for the child and the adult only under the residential scenario (if it is planned to use groundwater in households. Under this scenario, Total Cancer Risk is calculated for an aggregate resident.

If site-specific risk estimates exceed Target Risks (TR) (e.g., 1E-06 risk for carcinogens or HQ of 1 for non-carcinogens, preliminary site-specific health-based remedial goals (HBRGs) are developed.

3.2 Development of site-specific health-based remedial goals (HBRGs)

Health-based Remedial Goals (HBRGs), termed also Risk-based Concentrations (RBCs), are concentration levels for individual chemicals that correspond to

Target Risk (TR), i.e., a specific cancer risk level (e.g., 1E-06) or Hazard Quotient (HQ) or Hazard Index (HI) (e.g., less than or equal to 1) (US EPA 1991a).

RBCs are usually calculated under all developed scenarios for the purpose of guiding remedial activities at a site; they are used during analysis and selection of remedial alternatives.

In the HRA module a simplified method based on site-specific exposure data is used for calculating RBCs (US EPA, 1995). This method uses the ratio between the Target Risk and Calculated Risk due to a specific chemical in a given medium:

$$\frac{C}{\text{Calculated Risk}} = \frac{RBC}{\text{Target Risk}}$$

where:

- C –Chemical Concentration in soil or groundwater
- RBC –Risk-based Concentration (oral/dermal or inhalation).

Rearranging this equation, RBC is calculated as follows:

$$RBC = C \times \frac{\text{Target Risk}}{\text{Calculated Risk}}$$

RBCs are calculated for both carcinogenic and non-carcinogenic substances, and only for those contaminants for which the calculated site-specific risk is above acceptable risk (Target Risk). For carcinogens, RBCs can be calculated for Target Risks of 1E-06, 1E-05 or 1E-04. Concerning non-carcinogenic risk, target HQs of 0.1 or 1 can be substituted for Target Risk, and the calculated HQs substituted for Calculated Risks.

Concerning non-carcinogens, if more than one chemical is detected at a site affecting the same target organ/system, RBCs calculated for individual chemicals will be divided by the number of chemicals with the same target organs/effects. In that way, RBCs will be adjusted to reflect the potential for additive risks:

$$ARBC = RBC/n$$

where:

- ARBC –Risk-based Concentration adjusted for exposure to multiple contaminants with the same target organs/effects
- RBC –Risk-based Concentration for an individual non-carcinogen
- n –number of contaminants with the same target organs/effects.

According to the US EPA recommendations, RBCs are calculated separately for oral/dermal and inhalation exposures, because of the potential for different health effects (target organs) via these routes (US EPA 2001a).

If the calculated RBC exceeds soil saturation concentration (C_{sat}) and the contaminant is liquid at typical soil temperatures, the RBC should be established as equal to C_{sat} . Equation 4b is used for calculating C_{sat} , i.e., the contaminant concentration at which all soil pore space (both air-and water-filled) is saturated with the compound, and the adsorptive limits of the soil particle have been reached (see Appendix 2). If

compound concentrations exceeds C_{sat} , it means that the compound may be present in a free phase. RBC values are reliable when they are less than or equal to C_{sat} .

If both carcinogenic and non-carcinogenic RBCs are calculated for a given contaminant under the industrial scenario (only an adult receptor), then the lower of the two values is considered to be appropriate RBC.

If both carcinogenic and non-carcinogenic RBCs are calculated for a given contaminant under the residential/recreational scenarios, then RBCs are estimated separately for child and adult receptors for non-carcinogenic effects and for an aggregate resident/recreational user for carcinogenic effects. Then, for a given chemical, the lowest of these values should be applied as the remediation goal. A similar solution is applied, where both RBCs ($RBC_{oral/dermal}$ and $RBC_{inhalation}$) are calculated.

Remarks:

The above presented procedure for human health risk assessment, and for developing site-specific health-based remedial goals is not applicable for lead, dioxin and Polychlorinated Biphenyls (PCB). For these contaminants, classified as special case, other guidance documents are recommended, i.e., for lead - US EPA 1994, 1996c; for PCBs – US EPA 1990c; for dioxins – US EPA 1998, 2000.

4 HRA results visualisation (only for soil)

Results of Cancer Risks and HIs, obtained at each sampling point, after classification into two classes – below and above Target Risk levels can be simply visualised as a point map.

Next, site delineation into risk zones is carried out. This step of visualisation strongly depends on the sampling pattern, and the values of analysed variables (Cancer Risks and HIs). Site delineation into risk zones is carried out by looking for points that are closest to each other, taking into account the point class (below and above Target Risk level) and distance to the neighbouring point. The division of a site into zones is obtained as a result of point grouping (clustering) and site tessellation. A site is characterised by two independent sets of risk zones: one is a collection of zones with exceeded Total Cancer Risk, and the second one - with exceeded Total HI.

At the next step, for each established zone (block), a summary of health risk assessment is presented (see Table 3-2) based on mean value (arithmetic).

Calculated RBCs are also visualised. The point map is displayed for each substance for which the target risk is exceeded at least at one point. The points are divided into two concentration classes: below and above calculated RBC. These points are grouped into special related zones.

5 Role of the HRA module in decision making process

Contaminated site problems, and the subsequent revitalisation and remediation activities should be realised in accordance with the principles of sustainable development. Each decision, connected with planning a future remediation/revitalisation activity, should be assessed with regard to sustainability impact. It means that different factors should be taken into account in the decision-making process, e.g., human health risk, ecological risk, market needs, social factor or acceptance of local community. One of the better documented factors is the human health risk, which has also been used in establishing the national or regional soil and water guideline values.

Using precautionary guidelines, trigger or limit values, or quality criteria for the more common soil and groundwater contaminants as screening levels is the most popular practice in contaminated site assessment nowadays. However, such an assessment does not provide a comprehensive picture of health or environmental risks, in particular if very complex contamination occurs. Therefore, in such situations screening levels should not be used in an unqualified fashion as remedial goals. Remedial goals appropriate for a particular site could be established, based on site-specific conditions using risk assessment methods. At sites where conditions are similar to those used to establish guideline values site-specific remedial goals may not be significantly different. However, at sites where risk-based remedial goals established for site-specific land use scenarios are higher than generic limit values, remediation costs could be saved.

For assessing and, consequently, guiding revitalisation or remediation activities, the different tools including site-specific human health risk assessment procedures are still being developed and refined. The HRA module incorporated to NORISC DSS can be considered as one of such tools. Using an established procedure, the HRA module provides decision-makers, investors, city planners and stakeholders with information on actual and potential risk to humans, posed by contaminated sites. Additionally, the HRA module provides health-based remedial goals for environmental media and, thus, serves to select an appropriate remediation option at a given site. In such a way, the HRA module will provide the risk information that is necessary to support decision-making at contaminated sites, in accordance with the principles of sustainable development.

Risk assessment results will facilitate the decision-making process to take appropriate actions to protect human health. Such actions could include for example site closure, removal of contaminant sources, removal and disposal of contaminated soil, paving or capping the site, changing the land use pattern (e.g., from more into less sensitive), applying a specific remedial technology, or combination of different corrective actions/remedial technologies.

Providing site-specific HBRGs for environmental media, the HRA module can also be used as an auxiliary tool to select the appropriate remediation option, and to design and conduct revitalisation of contaminated sites (input to WP7 Revitalisation module).

The HRA module provides stakeholders with a detailed scientific and technical framework that can be used in revitalisation programmes. It allows for a more comprehensive decision-making process, especially in cases where complex contamination of soil and groundwater occurs.

It will also allow decision-makers to design and conduct their revitalisation actions/initiatives, and to implement a well-defined methodology into an effective environmental management process.

It may assist decision-making at contaminated sites in urban areas by taking into account site-specific conditions. The revitalisation decisions, based on results of site-specific HRA, would be better fitted to the local conditions than when general limit values are used as remediation levels. In that way these decisions can be more cost-effective.

The HRA module requires that the user has a good knowledge of the risk assessment, as well as the limiting conditions and assumptions made within each considered land-use scenario. Its user should also remember that the human health risk factor is only one among many others to be taken into account in the decision-making process.

6 References

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Appendices

APPENDIX 1
SITE-SPECIFIC HUMAN HEALTH RISK ASSESSMENT DATABASES

1.1 Chemical-specific parameters

Soil

D_i	-	Diffusivity in air (cm^2/s)
D_w	-	Diffusivity in water (cm^2/s)
K_{oc}	-	Soil organic carbon-water partition coefficient (organics) (cm^3/g)
H'	-	Henry's law constant (unitless)
MW	-	Molecular weight (g/mol)
S	-	Water solubility (mg/l)

Groundwater

for calculating of DA_{event} - Absorbed dose per event ($\text{mg}/\text{cm}^2\text{-event}$)

FA	-	Fraction absorbed (unitless)
K_p	-	Dermal permeability coefficient of compounds in water (cm/hr)
K_{ow}	-	Octanol/water partition coefficient (unitless)
MW	-	Molecular weight (g/mole)

Toxicological parameters

RfD_o	-	Oral reference dose ($\text{mg}/\text{kg}\text{-day}$)
RfC	-	Reference concentration (mg/m^3)
RfD_i	-	Inhalation reference dose ($\text{mg}/\text{kg}\text{-day}$)
SF_o	-	Oral slope factor ($\text{mg}/\text{kg}\text{-day}$)
SF_i	-	Inhalation slope factor ($\text{mg}/\text{kg}\text{-day}$)
ABS_{GI}	-	Gastro-intestinal absorption factor (unitless)
ABS_d	-	Dermal absorption fraction (unitless)
AF	-	Skin-soil adherence factor ($\text{mg}/\text{cm}^2\text{/day}$)
$TR_{noncarc}$	-	Target risk for noncarcinogens (HQ-Hazard Quotient or HI-Hazard Index)
TR_{carc}	-	Target risk for carcinogens (unitless)
Carcinogen class		
Primary target organ/effect for oral/dermal exposure		
Primary target organ/effect for inhalation exposure		

1.2 Exposure factors

Soil

EF	-	Exposure frequency (days/year)
ED	-	Exposure duration (years)
EV	-	Event frequency (events/day)
BW	-	Body weight (kg)
LT	-	Lifetime (yr)
IR_o	-	Ingestion rate (mg/day)
IR_i	-	Inhalation rate (m^3/day)
SA	-	Skin surface area available for contact (cm^2)
$AT_{noncarcin.}$	-	Averaging time for noncarcinogens $AT=ED \times 365$ d/yr (days)
$AT_{carcin.}$	-	Averaging time for carcinogens $AT= 70 \times 365$ d/yr (days)

CF ₁	-	Conversion factor (kg/mg)
T	-	Exposure interval (s)

Groundwater

EF	-	Exposure frequency (days/yr)
ED	-	Exposure duration (yr)
BW	-	Body weight (kg)
LT	-	Lifetime (yr)
IR _o	-	Ingestion rate (l/day)
IR _i	-	Inhalation rate (m ³ /day)
K	-	Volatilisation factor (unitless)
SA	-	Skin surface area exposed (cm ²)
EV	-	Event frequency (events/day)
t _{event}	-	Event duration (hr/event)
AT _{noncarcin.}	-	Averaging time for noncarcinogens AT=EDx365 d/yr (days)
AT _{carcin.}	-	Averaging time for carcinogens AT= 70x365 d/yr (days)
l _{sc}	-	Apparent thickness of stratum corneum (cm)
t _{sc}	-	Average turnover time of the stratum corneum – (days)
CF ₂	-	Conversion factor (l/m ³)
CF ₃	-	Conversion factor (cm ³ /l)

1.3 Site-specific soil parameters or default values based on literature data for similar soils

f _{oc}	-	Fraction of organic carbon in soil (g/g)
w	-	Average soil moisture content ((kg _{water} /kg _{soil})
ρ _b	-	Dry soil bulk density(g/cm ³)
ρ _s	-	Soil particle density (g/cm ³)
θ _w	-	Water-filled soil porosity (l _{water} /l _{soil})
θ _a	-	Air-filled soil porosity (l _{air} /l _{soil})
coarse% (surface soil)	-	percentage of soil particle fraction coarser than 2 mm
sand% (surface soil)	-	percentage of soil particle fraction 2 mm - 0.1 mm

1.4 Site –specific meteorological parameters

(e.g., from the closest meteorological station; if not available – a default value which represents average regional conditions)

U _m	-	Mean annual wind speed (m/s)
h	-	Height of anemometric measurements (m)

1.5 Other site-specific parameters

A	-	Area of contamination (m ²)
V	-	Fraction of vegetative or man-made cover (unitless), e.g., 0.5 (50%)
Type of neighbourhood		(see Equation 3a3 – Appendix 2)

APPENDIX 2
SOIL EXPOSURE PATHWAYS
Equations for calculating intakes along with default values assumed under
the residential, industrial and recreational exposure scenarios

2.1 Equation 1 - Equation for ingestion exposure to contaminants in surface soil along with default values

$$CI = \frac{CS \times EF \times ED \times FC \times IR_0 \times CF_1}{BW \times AT} \quad (1)$$

Parameter	Description	Residential scenario		Industrial/ Commercial scenario (adult)	Recreational scenario	
		Young child	Adult		Young child	Adult
CI	Contaminant Ingestion expressed in mg/kg/day	Chemical-specific equation objective				
CS	Concentration in Soil expressed in mg/kg	Chemical-specific				
EF	Exposure Frequency expressed in days/yr	350	350	225	214*	214*
ED	Exposure Duration expressed in years	6	24	25	6	24
FC	Fraction Contacted (ingested) from contaminated source	1	1	1	0.08**	0.08**
IR₀	Ingestion Rate for soil expressed in mg/day	200	100	100	200	100
CF₁	Conversion Factor expressed in kg/mg	1E-6	1E-6	1E-6	1E-6	1E-6
BW	Body Weight expressed in kg	15	70	70	15	70
AT (noncarcinogens)	Averaging Time for noncarcinogens (period over which exposure is averaged) expressed in days	2 190	8760	9 125	2 190	8760
AT (carcinogens)	Averaging Time for carcinogens (period over which exposure is averaged) expressed in days	25 550	25 550	25 550	25 550	25 550

* Every day from April to October – assumed as a professional judgement

** Assumed 2 hours exposure per day

Adapted from: US EPA 1991b; Tonner-Navarro et al. 1998; US EPA 2001a

2.2 Equation 2 - Equation for dermal absorption exposure to contaminants in surface soil along with default values

$$AD = \frac{CS \times EF \times ED \times FC \times SA \times AF \times ABS_d \times CF_1}{BW \times AT} \quad (2)$$

Parameter	Description	Scenario-chemical-specific values				
		Residential scenario		Industrial/Commercial scenario	Recreational scenario	
		Young child	Adult	Adult	Young child	Adult
AD	Absorbed Dose (dermal) expressed in mg/kg/day	Chemical-specific equation objective				
CS	Concentration in Soil expressed in mg/kg	Chemical-specific				
EF	Exposure Frequency expressed in days/yr	350	350	225	214*	214*
ED	Exposure Duration expressed in years	6	24	25	6	24
FC	Fraction Contacted (absorbed) from contaminated source	1	1	1	0.08**	0.08**
SA	Skin Surface Area available for daily contact expressed in cm ²	2 800	5 700	3 300	2 800	5 700
AF	Soil-to-skin Adherence Factor expressed in mg/cm ² /day	0.2	0.07	0.2	0.2	0.07
ABS_d	Dermal Absorption Fraction (dimensionless)	Chemical-specific				
CF₁	Conversion Factor expressed in kg/mg	1E-6	1E-6	1E-6	1E-6	1E-6
BW	Body Weight expressed in kg	15	70	70	15	70
AT (noncarcinogens)	Averaging Time for noncarcinogens (period over which exposure is averaged) expressed in days	2 190	8760	9 125	2 190	8760
AT (carcinogens)	Averaging Time for carcinogens (period over which exposure is averaged) expressed in days	25 550	25 550	25 550	25 550	25 550

* Every day from April to October – assumed as a professional judgement

** Assumed 2 hours exposure per day

Adapted from: Tonner-Navarro et al. 1998; US EPA 2001a; US EPA 2001b; US EPA 2003

2.3 Equation 3 - Equation for inhalation exposure to contaminants in surface soil (fugitive dusts)

$$PI_{fd} = \frac{CS \times EF \times ED \times FC \times IR_i \times \frac{1}{PEF}}{BW \times AT} \quad (3)$$

Parameter	Description	Scenario-chemical-specific values				
		Residential scenario		Industrial/ Commercial scenario	Recreational scenario	
		Young child	Adult	Adult	Young child	Adult
PI_{fd}	Pulmonary Intake of soil (fugitive dusts) expressed in mg/kg/day	Chemical-specific equation objective				
CS	Concentration in Soil expressed in mg/kg	Chemical-specific				
EF	Exposure Frequency expressed in days/yr	350	350	225	214*	214*
ED	Exposure Duration expressed in years	6	24	25	6	24
FC	Fraction Contacted (inhaled) from contaminated source (assumed 100%)	1	1	1	0.08**	0.08**
IR_i	Inhalation rate expressed in m ³ /day	10	20	20	10	20
PEF	Particulate Emission Factor expressed in m ³ /kg (see: Figure 3a)	1.36E+09	1.36E+09	1.36E+09	1.36E+09	1.36E+09
BW	Body Weight expressed in kg	15	70	70	15	70
AT (noncarcinogens)	Averaging Time for noncarcinogens (period over which exposure is averaged) expressed in days	2 190	8760	9 125	2 190	8760
AT (carcinogens)	Averaging Time for carcinogens (period over which exposure is averaged) expressed in days	25 550	25 550	25 550	25 550	25 550

* Every day from April to October – assumed as a professional judgement

** Assumed 2 hours exposure per day

Adapted from: Tonner-Navarro et al. 1998; US EPA 2001a

2.4 Equation 3a - Calculation of the Particulate Emission Factor

In the current release of NORISC-HRA software, the calculation of risk related to fugitive dust emission, and connected with dust carcinogenic and non-carcinogenic non-volatile and semi-volatile chemicals, is possible with the use of the default values of Particulate Emission Factor (PEF), or it is possible to calculate site-specific PEF values according to the equation:

$$PEF(m^3/kg) = \frac{Q}{C} \times \frac{3600 \frac{s}{h}}{0.036 \times (1-V) \times \left(\frac{U_m}{U_t}\right)^3 \times F(x)} \quad (3a)$$

where

- PEF – particulate emission factor [m^3/kg],
- Q/C – inverse of mean concentration at centre of a site [g/m^2 -s per kg/m^3],
- V – fraction of vegetative cover [unitless],
- U_m – mean annual wind velocity [m/s],
- U_t – equivalent threshold value of wind velocity at 7m [m/s],
- $F(x)$ – function dependent on U_m/U_t derived using Cowherd et al. (1985) [unitless].

In the described equation the following parameters are site-specific:

- 1) V – fraction of vegetative or man made cover (e.g., buildings, asphalt) that limit the potential of fugitive dust emission,
- 2) U_m – mean annual wind velocity at 7m,
- 3) U_t – equivalent threshold value of wind velocity at 7m,
- 4) $F(x)$ – value of integration function derived from relation of the vertical transport of particles and horizontal wind velocity,
- 5) Q/C – dependent on the climatic zone and the site area.

Calculation of parameters:

- 1) V – fraction of vegetative or man made cover [unitless] - this value should be derived from direct vegetation cover assessment within neighbourhood of measuring point or as one factor for the whole site:

$$V = A_v/A \quad (3a1.1)$$

where:

- A_v – site area with vegetation and man made cover [m^2],
- A – site area [m].

In the case of the calculation is based on a single measuring point the similar factor can be calculated with Equation 3a1.2:

$$V = A_{pv}/A_p \quad (3a1.2)$$

where:

- A_{pv} - area covered with vegetation and/or man made cover within the surface represented by measuring point,
 A_p - area of surface represented by measuring point.

In the current software release, factor V is calculated for the whole site assessed and should be introduced into the site-specific data table (see HRA General Site Parameters Table).

- 2) U_m – the mean annual wind velocity at 7 m (m/s)– this value should be established by the user, based on the multi-annual archival data. Since the anemometric station can measure the velocity at different height the user should recalculate the obtained value for the same reference height using the following equation:

$$U_m = U_{mt} * (7/h)^{0.15} \quad (3a2)$$

where:

- h - the height of wind velocity measurement at anemometric station [m],
 U_{mt} - measured wind velocity [m/s],
 7 - the reference height [m].

- 3) U_t - Equivalent threshold value of wind velocity at 7 m (m/s) – This value is calculated, based on data provided by the user, with Equation 3a3:

$$U_t = U_{th} / 0.4 * \ln(700/z_0) \quad (3a3)$$

where:

- U_{th} - threshold friction velocity [m/s] – calculated from Equation 3a3.1,
 z_0 - surface roughness length by Cowherd et al. (1985) [cm] (default values are presented in the table below),
 0.4 - von Karman constant [unitless],
 700 - the reference height above the surface [cm].

Default values of z_0 [cm] (modified for NORISC-HRA module, based on Cowherd at all-1985):

Type of neighbourhood	Zo	ld
open area	0.5	1
arable land	4	2
grassland	3	3
built-up rural, suburban areas	5	4
urban-buildings up to 5 floors	70	5
urban-buildings 5-30 floors	400	6
urban-buildings > 30 floors	1000	7
forest	60	8

Equation for threshold friction velocity is as follows:

$$U_{th} = \frac{N \times \exp[0.412 \times \ln(d) + 4.17]}{100} \quad (3a3.1)$$

where:

U_{th} - threshold friction velocity [m/s]
 d - aggregate size distribution [mm] – calculated with Equation 3a3.2

$$d = 0.0106 * sand\% + 0.05 \quad (3a3.2)$$

N = non-erodible elements correction factor [unitless]:
 N = 2 if *Coarse%-surface* > 50%
 N = 1.5 if *Coarse%-surface* >= 25%
 N = 1.25 if *Coarse%-surface* >= 12.5%
 N = 1 if *Coarse%-surface* < 12.5%

where:

coarse%-surface - percentage of soil particle fraction coarser than 2 mm,
sand% - percentage of soil particle fraction 2mm - 0.1mm.

The variables N , z_0 , *coarse%-surface*, *sand%* are provided by the user.

- 4) $F(x)$ - Integration function - it comes from cubic relationship of the vertical transport of particles and the wind velocity developed by Cowherd et al. (1985). This relationship can be broken down into the following discrete parts:

$F(x) = 0.0$ if $x < 0.0$
 $F(x) = 1.91$ if $0.0 \leq x < 0.5$
 $F(x) = 1.9 - (x - 0.5) * 0.6$ if $0.5 \leq x < 1$
 $F(x) = 1.6 - (x - 1.0) * 1.3$ if $1.0 \leq x < 2.0$
 $F(x) = 0.18x(8x^2 + 12)e^{-x^2}$ if $x \geq 2.0$

where:

$x = 0.886 * (U_t / U_m)$ - [unitless].

- 5) Q/C – inverse of geometric mean concentration at centre of a site [g/m²-s per kg/m³].

In the current version of the software, this value is calculated based on default values with the possibility of correction for the site area.

$$Q/C = 16.2302 \cdot e^{\frac{(\ln(A/4047) - 18.7762)^2}{216.108}} \quad (3a5)$$

where:

A - site area [m^2],
 4047 - conversion factor (from metres into acres),
 16.2302, 18.7762, 216.108 – default values of constants based on air dispersion modelling for 29 meteorological stations (US EPA 2001a).

Default values of parameters used for calculating PEF default value are presented below.

It is recommended to use PEF default value in all cases, where site-specific parameters cannot be calculated or derived from local measurement.

Parameter	Description	Default values
PEF	Particulate Emission Factor expressed in m^3/kg	1.36E+09
Q/C	Inverse of the mean concentration at the centre of a 0.5-acre- square source expressed in $g/m^2 \cdot s$ per kg/m^3	93.77
CF	Conversion Factor expressed in s/hour	3 600
RF	Respirable Fraction expressed in $g/(m^2 \cdot hr)$.	0.036
V	Fraction of vegetative or man made cover (e.g., buildings, asphalt; [unitless])	0.5
U_m	Default mean annual wind velocity at 10 m height expressed in m/s	4.69
U_t	Equivalent threshold value of wind velocity at 7 m expressed in m/s	11.32
F(x)	Function dependent on U_m and U_t [$F(x) = 0.18(8x^3 + 12x)e^{-x^2}$]	0.194
x	Unitless variable, equivalent to $0.886(U_t/U_m)$	2.14

Adapted from US EPA 2001a

2.5 Equation 4 - Equation for inhalation exposure to volatile contaminants in subsurface soil

$$PI_{vol} = \frac{CS \times EF \times ED \times FC \times IR_i \times \frac{1}{VF}}{BW \times AT} \quad (4)$$

Parameter	Description	Scenario-chemical-specific values				
		Residential scenario		Industrial/Commercial scenario	Recreational scenario	
		Young child	Adult	Adult	Young child	Adult
PI_{vol}	Pulmonary Intake of volatiles expressed in mg/kg/day	Chemical-specific equation objective				
CS	Concentration in Soil expressed in mg/kg	Chemical-specific				
EF	Exposure Frequency expressed in days/yr	350	350	225	214*	214*
ED	Exposure Duration expressed in years	6	24	25	6	24
FC	Fraction Contacted (inhaled) from contaminated source (assumed 100%)	1	1	1	0.08**	0.08**
IR_i	Inhalation rate (m ³ /day)	10	20	20	10	20
VF	Volatilisation Factor expressed in m ³ /kg (see: Fig. 4a)	Chemical-specific				
BW	Body Weight expressed in kg	15	70	70	15	70
AT (noncarcinogens)	Averaging Time for noncarcinogens (period over which exposure is averaged) expressed in days	2 190	8760	9 125	2 190	8760
AT (carcinogens)	Averaging Time for carcinogens (period over which exposure is averaged) expressed in days	25 550	25 550	25 550	25 550	25 550

* Every day from April to October – assumed as a professional judgement

** Assumed 2 hours exposure per day

Adapted from: Tonner-Navarro et al. 1998; US EPA 2001a

2.6 Equation 4a - Calculation of the Soil-to-Air Volatilisation Factor

$$VF = \frac{Q/C_{vol} \times (3.14 \times D_A \times T)^{1/2} \times CF}{2 \times \rho_b \times D_a} \quad (4a)$$

where:

$$Q/C_{vol} = 11.9110 \cdot e^{\frac{(\ln(A/4047) - 18.4385)^2}{209.7845}} \quad (4a1)$$

where:

A - site area [m^2],

4047 - conversion factor (from metres into acres),

11,911, 18.4385, 209.7845 - default values of constants based on air dispersion modelling for 29 meteorological stations (US EPA 2001a).

$$D_A = \frac{[(\theta_a^{10/3} \times D_i \times H') + (\theta_w^{10/3} \times D_w)] / n^2}{(\rho_b \times K_d) + \theta_w + (\theta_a \times H')} \quad (4a2)$$

apparent diffusivity [cm^2/s] (All site-specific parameters should be provided by the user).

When a site characteristic is unavailable it is allowed to use default parameters as presented below:

Parameter	Description	Chemical-/ soil -specific values
VF	Volatilisation Factor expressed in m^3/kg	Chemical-specific
Q/C_{vol}	Inverse of the mean concentration at the centre of a 0.5-acre-square source expressed in $g/m^2 \cdot s$ per kg/m^3	68.18
D_A	Apparent diffusivity expressed in cm^2/s	Chemical-specific
T	Exposure interval expressed in seconds	ED*3.15E+07
ρ_b	Dry soil bulk density expressed in g/cm^3	1.50
CF	Conversion Factor expressed in m^2/cm^2	1.0E-04
θ_a	Air-filled soil porosity (I_{air}/I_{soil})	$n - \theta_w$
D_i	Diffusivity in air expressed in cm^2/s	Chemical-specific
H'	Dimensionless Henry's Law Constant	Chemical-specific
θ_w	Water-filled soil porosity (I_{water}/I_{soil}); ($w \cdot \rho_b$)	0.15
D_w	Diffusivity in water expressed in cm^2/s	Chemical-specific
n	Total soil porosity (I_{pore}/I_{soil})	$1 - (\rho_b/\rho_s)$
K_d	Soil-water partition coefficient expressed in cm^3/g (for organics- $K_d = K_{oc} \cdot f_{oc}$)	Chemical-specific
K_{oc}	Organic carbon partition coefficient expressed in cm^3/g .	Chemical-specific
f_{oc}	Fraction of organic carbon in soil (g/g)	0.006 (0.6%)
ρ_s	Soil particle density expressed in g/cm^3	2.65
w	Soil moisture content (dimensionless)	0.1

Adapted from: US EPA 1996b; US EPA 2001a

2.7 Equation 4b - Calculation of the Soil Saturation Limit

$$C_{\text{sat}} = \frac{S}{\rho_b} \times (K_d \times \rho_b + \theta_w + H' \times \theta_a) \quad (4b)$$

Parameter	Description	Chemical-/ soil -specific values
C_{sat}	Soil saturation concentration in mg/kg	Chemical-specific equation objective
S	Solubility in water in mg/l _{water}	Chemical-specific
ρ_b	Dry soil bulk density expressed in kg/l	1.50
K_d	Soil-water partition coefficient expressed in l/kg (for organics - $K_d = K_{oc} * f_{oc}$)	Chemical-specific
K_{oc}	Organic carbon partition coefficient expressed in l/kg	Chemical-specific
f_{oc}	Fraction of organic carbon in soil (g/g)	0.006 (0.6%)
θ_w	Water-filled soil porosity (l _{water} /l _{soil}); ($w * \rho_b$)	0.15
H'	Dimensionless Henry's Law Constant	Chemical-specific
θ_a	Air-filled soil porosity (l _{air} /l _{soil})	$n - \theta_w$
n	Total soil porosity (l _{pore} /l _{soil})	$1 - (\rho_b / \rho_s)$
ρ_s	soil particle density expressed in kg/L	2.65

Adapted from: US EPA 1996b; US EPA 2001a

Remark:

The equation 4b is used for calculating C_{sat} , i.e., the contaminant concentration at which all soil pore space (both air-and water-filled) is saturated with the compound, and the adsorptive limits of the soil particle have been reached. If compound concentration exceeds C_{sat} it means that the compound may be present in free phase, which does not adhere to the principles of the VF-model (see Equation 4). $RBC_{i\text{-vol}}$ is reliable when they are less than or equal to C_{sat} . If the calculated $RBC_{i\text{-vol}}$ exceeds C_{sat} and the contaminant is liquid at typical soil temperatures, the $RBC_{i\text{-vol}}$ should be established as equal to C_{sat} .

APPENDIX 3
GROUNDWATER EXPOSURE PATHWAYS
Equations for calculating intakes along with default values assumed under the
residential scenario

3.1 Equation 1 - Intake calculation for drinking water ingestion

$$CI = \frac{CW \times EF \times ED \times FC \times IR_o}{BW \times AT} \quad (1)$$

where:

- CI –Contaminant intake [mg/kg/day],
- CW –Chemical concentration in water [mg/l],
- EF –Exposure frequency [days/yr],
- ED –Exposure duration [years],
- FC –Fraction contacted (ingested) from contaminated source (assumed 100%) [unitless],
- IR_o –Oral ingestion rate for an adult [l/day],
- BW –Body weight [kg],
- AT (noncarcinogens) –Averaging time for noncarcinogens AT=ED x 365 d/yr [days],
- AT (carcinogens) –Averaging time for carcinogens AT=70 years x 365 d/yr [days].

3.2 Equation 2 - Absorption dose calculation for dermal contact with groundwater while showering/bathing

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times FC \times SA}{BW \times AT} \quad (2)$$

where:

- DAD –Dermal absorbed dose [mg/kg/day],
- DA_{event} –Dermal absorbed dose per event [mg/cm²-event],
- EF –Exposure frequency [days/yr],
- ED –Exposure duration [years],
- EV –Event frequency [events/day],
- SA –Skin surface area available for daily contact [cm²],
- BW –Body weight [kg],
- AT (noncarcinogens) –Averaging time for noncarcinogens AT=ED x 365 d/yr [days],
- AT (carcinogens) –Averaging time for carcinogens AT=70 years x 365 d/yr [days],
- FC –Fraction contacted (absorbed) from contaminated source (assumed 100%) [unitless].

Equations 2a and 2b show the calculation of the dose per event for organic and inorganic compounds, respectively.

For organic compounds, dermal absorbed dose per event is calculated as follows:

if $t_{event} \leq t^*$

$$DA_{event} = \frac{2FA \times K_p \times C_w \times \sqrt{\frac{6 \times \tau \times t_{event}}{\pi}}}{CF_3} \quad (2a')$$

if $t_{event} > t^*$

$$DA_{event} = \frac{FA \times K_p \times C_w \times \left[\frac{t_{event}}{1+B} + 2\tau \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]}{CF_3} \quad (2a'')$$

(Equation 2a)

where:

- DA_{event} – Dermal absorbed dose per event [mg/cm^2 -event],
- FA – Fraction absorbed [unitless],
- K_p – Dermal permeability coefficient of compound in water [cm/hr],

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056 MW \quad (2a1)$$

- K_{ow} – Octanol/water partition coefficient [unitless],
- C_w – Chemical concentration in water [mg/l],
- τ – Lag time per event [hr/event],

$$\tau = l_{sc}^2 / 6D_{sc} = 0.105 \times 10^{(0.0056 MW)} \quad (2a2)$$

- l_{sc} – Apparent thickness of stratum corneum [cm],
- D_{sc} – Effective diffusion coefficient for chemical transfer through the stratum corneum [cm^2/hr],

$$D_{sc} = l_{sc} \times 10^{(-2.80 - 0.0056 MW)} \quad (2a3)$$

- B – Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis [unitless],

$$B = K_p \frac{\sqrt{MW}}{2.6} \quad (2a4)$$

- t_{event} – Event duration [hr/event],
- t^* – Time to reach steady-state [hr],

if $B \leq 0.6$ then

$$t^* = 2.4\tau \quad (2a5')$$

if $B > 0.6$ then

$$t^* = 6(b - \sqrt{b^2 - c^2})\tau \quad (2a5'')$$

where:

$$b = \frac{2}{\pi}(1 + B)^2 - c \quad (2a6)$$

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \quad (2a7)$$

MW –Molecular weight [g/mole],

CF₃ –Conversion factor [cm³/l].

For inorganic compounds, dermal absorbed dose per event is calculated as follows:

$$DA_{\text{event}} = \frac{K_p \times C_w \times t_{\text{event}}}{CF_3} \quad (2b)$$

where:

DA_{event} –Dermal absorbed dose per event [mg/cm²-event],

C_w –Chemical concentration in water [mg/l],

K_p –Dermal permeability coefficient of compound in water [cm/hr],

t_{event} –Event duration [hr/event],

CF₃ –Conversion factor [cm³/l].

3.3 Equation 3 - Intake calculation for inhalation of vapour-phase chemicals from household water use

$$PI = \frac{CW \times FC \times EF \times ED \times CF_2 \times IR_i \times K}{AT \times BW} \quad (3)$$

where:

PI –Pulmonary intake from water [mg/kg/day],

CW –Chemical concentration in water [mg/l],

EF –Exposure frequency [days/yr],

ED –Exposure duration [years],

FC –Fraction contacted (inhaled) from contaminated source (assumed 100%) [unitless],

CF₂ –Conversion factor [l/m³],

IR_i –Inhalation rate for an adult [m³/day],

K –Volatilisation factor [unitless],

BW –Body weight [kg],

AT (noncarcinogens) –Averaging time for noncarcinogens AT=ED x 365 d/yr [days],

AT (carcinogens) –Averaging time for carcinogens AT=70 years x 365 d/yr [days].

Table A3-1 Default parameter values for oral, dermal and inhalation exposure to chemicals in water under the residential exposure scenario

Parameter	Definition/unit	Residential exposure scenario – default values	
		Adult	Child
BW	Body weight (kg)	70	15
AT(noncarcinogens)	Averaging time for noncarcinogens AT=ED x 365 d/yr [days]	8 760	2 190
AT (carcinogens)	Averaging time for carcinogens AT=70 years x 365 d/yr [days]	25 550	25 550
EF	Exposure frequency [days/yr]	350	350
ED	Exposure duration [years]	24	6
FC	Fraction contacted (ingested, absorbed or inhaled) from contaminated source (assumed 100%) [unitless]	1	1
IR _o	Oral ingestion rate for an adult [l/day]	2	1
EV	Event frequency [events/day]	1	1
SA	Skin surface area available for daily contact [cm ²]	18 000	6 600
t _{event}	Event duration [hr/event]	0.58 (showering)	1.0 (bathing)
FA	Fraction absorbed [unitless]	Chemical-specific	
K _p	Dermal permeability coefficient of compound in water [cm/hr]	Chemical-specific	
K _{ow}	Octanol/water partition coefficient [unitless]	Chemical-specific	
τ	Lag time per event [hr/event]	Chemical-specific	
l _{sc}	Apparent thickness of stratum corneum [cm]	0.001	0.001
D _{sc}	Effective diffusion coefficient for chemical transfer through the stratum corneum [cm ² /hr]	Chemical-specific	
t [*]	Time to reach steady-state [hr]	Chemical-specific	
B	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis [unitless]	Chemical-specific	
MW	Molecular weight [g/mole]	Chemical-specific	
CF ₃	Conversion factor [cm ³ /l]	1 000	1 000
CF ₂	Conversion factor [l/m ³]	1 000	1 000
IR _i	Inhalation rate [m ³ /day]	20	10
K	Volatilisation factor [unitless]	0.0005	0.0005

Adapted from: US EPA 1990a, 1991a, 1991b, 2001a, 2001b

APPENDIX 4
HUMAN HEALTH RISK ASSESSMENT SOFTWARE MODULE
DESCRIPTION – User’s Guide

4.1 Introduction

The human health risk assessment (HRA) software module has been developed as a part of the NORISC Decision Support Software System (DSS) to link the site investigation and remediation/revitalisation decision-making. It may be also used in a stand-alone form.

The HRA software module as an integral module of the NORISC DSS is also an element of a strategy for the revitalisation of contaminated sites.

The HRA software module has been developed as a tool for site assessors to support conducting simple site-specific risk assessment in urban areas.

The HRA software package allows determining the level and spatial distribution of human health risks at a given site as well as setting up site-specific health-based remedial goals (HBRGs)/Risk-based Concentrations (RBCs). The output is presented in the form of tables and maps. Risk results are visualised to assist the decision-making process and communication between different stakeholder groups.

4.2 Parameters requested by HRA module

The HRA module uses two sets of tables: Set I - **Internal HRA Tables**, prepared as an internal part of the HRA module, and Set II - **User Tables**, to be provided by the user. Current release of the HRA software uses data provided in MS Access format.

Generally, the parameters are divided into three basic groups (see Table A4-2):

- Group Ch : chemical-specific parameters,
- Group ST: site characterisation parameters,
- Group S,R: scenario-receptor specific parameters.

The role of each parameter in risk analysis is characterised in Appendices 1, 2 and 3.

Chemical-specific parameters comprise chemical and physical properties and toxicological characteristics for over 700 chemicals, and are included in HRA Tables. However, due to the fact that the requested parameter values are not available for all chemicals, the chemical-specific HRA Tables are not completely filled with relevant values. The list of contaminants is not closed. Since a review of the parameter values (mainly toxicological) is still ongoing and updated, the module provides an option to modify the values of the chemical-specific parameters within the parameter-setting step.

Scenario-Receptor specific parameters values are included into HRA Tables as default values. Modification of these parameters values is allowed to provide the user with a possibility to adjust them to the site-specific situation.

Table A4-2 Parameters requested for risk calculation

Variable	Description	Source ¹⁾	User modification	Group
K_{ow}	Octanol/water partition coefficient	HRA Table	allowed	Ch
H'	Henry's law constant	HRA Table	allowed	Ch
D_i	Diffusivity in air	HRA Table	allowed	Ch
D_w	Diffusivity in water	HRA Table	allowed	Ch
K_{oc}	Soil organic carbon-water partition coefficient organics	HRA Table	allowed	Ch
MW	Molecular weight	HRA Table	allowed	Ch
ABS_d	Dermal absorption fraction	HRA Table	allowed	Ch
ABS_{GI}	Gastro – intestinal absorption factor	HRA Table	allowed	Ch
CSF_i	Cancer slope factor – inhalation	HRA Table	allowed	Ch
CSF_o	Cancer slope factor – oral	HRA Table	allowed	Ch
PTOI	Primary inhalation target organ	HRA Table	allowed	Ch
PTOO	Primary oral target organ	HRA Table	allowed	Ch
RfD_i	Inhalation reference dose	HRA Table	allowed	Ch
RfD_o	Oral reference dose	HRA Table	allowed	Ch
IsVolatile	True if the substance is volatile, False elsewhere	HRA Table	Allowed	Ch
IsOrganic	True if the substance is organic, False elsewhere	HRA Table	Allowed	Ch
CAS Number	Chemical Abstract Number –link HRA Table with User Tables of Concentrations	HRA Table & User Table	Not allowed	Ch
Chemical Name	The name of substance – link HRA Table with User Tables of Concentrations	HRA Table & User Table	Not allowed	Ch
t_{sc}	Average turnover time of the <i>stratum corneum</i>	HRA Table	allowed	R
K	Volatilisation factor	HRA Table	allowed	S, R
IR_o	Ingestion rate – water	HRA Table	allowed	S, R
t_{event}	Event duration	HRA Table	allowed	S, R
IR_o	Ingestion rate – soil	HRA Table	allowed	S, R
S.A.	Skin surface area exposed	HRA Table	allowed	S, R
BW	Body weight	HRA Table	allowed	S, R

Variable	Description	Source ¹⁾	User modification	Group
ED	Exposure duration	HRA Table	allowed	S, R
EF	Exposure frequency	HRA Table	allowed	S, R
EV	Event frequency	HRA Table	allowed	S, R
IR _i	Inhalation rate	HRA Table	allowed	S, R
AT _{carcin.}	Averaging time for carcinogens AT= 70 x 365 d/yr	HRA Table	allowed	S, R
AT _{noncarcin.}	Averaging time for noncarcinogens AT=ED x 365 d/yr	HRA Table	allowed	S, R
AF	Skin - soil adherence factor	HRA Table	allowed	S, R
θ _a -Teta_a_surf	Air-filled surface soil porosity [cm ³ /cm ³]	Calculated/ User Table/ HRA Table	allowed	ST
θ _w -Teta_w_surf	Water- filled soil porosity of surface soil	Calculated/ User Table/ HRA Table	allowed	ST
θ _{ws} -Teta_w_subsur	Water-filled subsurface soil porosity	Calculated/ User Table/ HRA Table	allowed	ST
N	Total soil porosity	Calculated/ User Table/ HRA Table	allowed	ST
TR _{carc.}	Target risk for carcinogens	HRA Table	allowed	ST
TR _{noncarc.}	Target risk for noncarcinogens (HQ - Hazard Quotient or HI - Hazard Index)	HRA Table	allowed	ST
H-U _m	Height of U _m measurement	User Table	allowed	ST
Type of neighbourhood	Site neighbourhood characteristic (open area, arable land, greenland, built-up rural and suburban areas, urban areas - dense, medium and low buildings, urban areas – dense height buildings)	User Table	allowed	ST
Coarse%-surface	Quantity of particles larger than 2 mm	User Table	allowed	ST
Sand%-surface	Sand (fraction < 2mm and > 0.05mm) in surface soil	User Table	allowed	ST
A	Area of the site	User Table	allowed	ST
C _s	Concentration in soil	User Table	Not allowed	ST
C _w	Concentration in groundwater	User Table	Not allowed	ST

Variable	Description	Source ¹⁾	User modification	Group
X	X – coordinate	User Table	Not allowed	ST
Y	Y – coordinate	User Table	Not allowed	ST
Depth	Depth of sampling	User Table	Not allowed	ST
U_m	Mean annual wind speed	User Table/ HRA Table	allowed	ST
V	Fraction of vegetative or man-made cover	User Table/ HRA Table	allowed	ST
f_{oc}	Fraction of organic carbon in soil	User Table/ HRA Table	allowed	ST
$\rho_{s-ro_s_surface}$	Particle density of surface soil	User Table/ HRA Table	allowed	ST
$\rho_{ss-ro_s_subsurface}$	Particle density of subsurface soil	User Table/ HRA Table	allowed	ST
ρ_b	Dry soil bulk density	User Table/ HRA Table	allowed	ST
$\rho_{b-ro_b_surface}$	Dry bulk density of surface soil	User Table/ HRA Table	allowed	ST
$\rho_{bs-ro_b_subsurface}$	Dry bulk density of subsurface soil	User Table/ HRA Table	allowed	ST
W1	Average soil moisture content in surface layer	User Table/ HRA Table	allowed	ST
W2	Average soil moisture content in subsurface layer	User Table/ HRA Table	allowed	ST

¹⁾ – Type of data source

1 – calculated – variable is calculated by the HRA module, based on other variables

2 – User table – variable is read from the table provided by the user (general site parameters, concentrations in soil, concentrations in groundwater)

3 – HRA Table - variable is read from the internal HRA database

Order of sources indicates importance – first source is the user's best choice.

Site characterisation parameters include the following parameters :

- concentrations of chemicals in soil (Soil Concentration Table),
- concentrations of chemicals in groundwater (Groundwater Concentration Table),
- geometry and physical site properties responsible for contaminants migration (General Site Parameters).

The above mentioned tables form a set of User Tables. It is assumed that the User Tables are filled with data obtained during the site characterisation phase. Some of the parameters included in the General Site Parameters Table may be calculated by the HRA module, replaced by default values, provided in HRA Tables or entered manually by the user during programme operation. The assumed sources of each parameter value are presented in the column “Source” (see Table A4-2).

During calculations, the user cannot modify the parameters that characterise contaminant concentrations and the location of the measuring points.

4.2.1 User Tables

The set of **User Tables** consists of three tables :

- Soil Concentration Table,
- Groundwater Concentration Table,
- General Site Parameters Table.

The current release of the HRA module does not provide an option to import data from sources other than Access database. The user is obliged to collect all data and import them into Access database using own tools. The order of fields in a given table is not important. The user will be asked to indicate a proper field in which a requested parameter is located during the parameter-setting phase. The tables may contain additional fields not used by the HRA software module.

Fig. 4.1 presents an example of **User Soil Concentration Table**. The minimum information that has to be provided by the user to describe soil concentration is limited to contaminant name, location and its concentrations in soil.

It is assumed that one location can be represented by several samples taken from different depths. The CAS number is not an obligatory field, similarly as the ID field.

ID	Chemical name	CAS number	x coordinate	y coordinate	Depth	contaminant concentration
42	Barium	7440393	27774.75	23640	0.1	62.3
43	Arsenic	7440382	28310.25	23400	0.1	5.7
44	Arsenic	7440382	28935	23460	0.25	18.3
45	Barium	7440393	28200	22560	0.15	101.7
46	Barium	7440393	28700	22500	0.25	92.1
47	Barium	7440393	27200	22380	0.1	43.3

Fig. 4.1 User Soil Concentration Table

Fig. 4.2 provides an example of the **User Groundwater Concentration Table**. The minimum information is limited to the name of the chemical and its concentration expected in the analysed water-bearing horizon. This concentration is represented by one statistics (e.g., mean or UCL95), selected by the user.

	site_id	chemical nam	CAS number	contaminant concen
▶	4	Arsenic	7440382	0.9
	4	Barium	7440393	12
*	0			0

Rekord: 1 z 2

Fig. 4.2 User Groundwater Concentration Table

An assumption was made that one value shall represent the groundwater chemical characteristic within the site boundary. The current release of the HRA module cannot be applied to more complex situations e.g. for very large sites where recognition of water movement is necessary.

Fig. 4.3 presents **User General Site Parameters Table**. In the current HRA version, the following fields are optional: site name, site_id, x_min, x_min, x_max, y_max, date, d, silt%-surface, clay%-surface, ro_b_surface, ro_s_surface, teta_a_surface, teta_w_surface, w1. If volatile contaminants have not been detected at the site, the fields concerning parameters characterising subsurface layers may also be omitted.

Field Name	Data type	Description
Site name	Text	Name of the site
Site id	Number	
x_min	Number	coordinate of the site extent [m]
y_min	Number	coordinate of the site extent [m]
x_max	Number	coordinate of the site extent [m]
y_max	Number	coordinate of the site extent [m]
Date	Date / Hour	Date of measuring campaign
A	Number	area [m ²]
V	Number	vegetation and covered fraction
Um	Number	Average annual wind speed [m/s]
H-Um	Number	Height of Um measurement
type of neighbourhood	Number	site neighbourhood characteristic (open area, arable land)
Coarse%-surface	Number	Quantity of particles larger than 2 mm - estimated as lo
Sand%-surface	Number	Percent of sand (fraction < 2mm and > 0.05mm) in surf
Silt%-surface	Number	Percent of silt (fraction <0.05 and > 0.002mm)
Clay%-surface	Number	Percent of clay (fraction < 0.002mm)
ro_b_surface	Number	Bulk density of surface soil (average of measurements in
ro_s_surface	Number	Density of surface soil
ro_b_subsurface	Number	Bulk density of subsurface soil
ro_s_subsurface	Number	Density of subsurface soil
Teta_a_surf	Number	Air-filled surface soil porosity [cm ³ /cm ³]
Teta_w_surf	Number	Water-filled surface soil porosity[cm ³ /cm ³]
Teta_a_subsur	Number	Air-filled subsurface soil porosity[cm ³ /cm ³]
Teta_w_subsur	Number	Water-filled subsurface soil porosity [cm ³ /cm ³]
W1	Number	Average water content -surface [g/g]
W2	Number	Average water content -subsurface[g/g]
Foc1	Number	Fraction of organic carbon in surface soil [g/g]
Foc2	Number	Fraction of organic carbon in subsurface soil [g/g]
d	Number	Depth of the clean soil layer

Fig. 4.3 User General Site Parameters Table¹

4.3 Internal HRA Tables

The set of **Internal HRA Tables** consists of the following tables:

- Chemical/Physical Properties Table,
- Exposure Parameters Tables,
- Site Parameters Default Values.

The procedure for managing HRA Tables is not included to the HRA module. Direct access to HRA Tables is allowed only for permission-granted users.

The **Chemical/Physical Properties Table** provides values of parameters from the Group Ch (chemical-specific). Fig. 4.4 gives an example of the Chemicals/Physical Properties Table.

¹ Original version of database description is developed under Polish version of MS Access 2000. For the needs of this report the original view of the screen was changed by introducing the English translation of the names of fields and types of data.

ID	chemical	Chemical second name	CASNr	ANATYPE	ANATYPE2
180	BENZO[K]FLUORANTHENE	Benzo[k]fluoranthene	207089	Organics	PAH
680	Total Petroleum Hydrocarbons (Arom:	Total Petroleum Hydrocarbons (Arom	NA-lat12	Organics	PAH
420	INDENO[1,2,3-C,D]PYRENE	Indeno[1,2,3-c,d]pyrene	193395	Organics	PAH
494	NAPHTHALENE	NAPHTHALENE	91203	Organics	PAH
556	Phenanthrene	Phenanthrene	85018	Organics	PAH
369	FLUORANTHENE	Fluoranthene	206440	Organics	PAH
137	ANTHRACENE	ANTHRACENE	120127	Organics	PAH
265	CHRYSENE	Chrysene	218019	Organics	PAH
679	Total Petroleum Hydrocarbons (Arom:	Total Petroleum Hydrocarbons (Arom	NA-lat11	Organics	PAH
226	CARBON DISULFIDE	CARBON DISULFIDE	75150	Organics	Nonaromatics
116	ACRYLONITRILE	ACRYLONITRILE	107131	Organics	Nonaromatics
113	ACROLEIN	Acrolein	107028	Organics	Nonaromatics
1	**1,3-BUTADIENE	Butadiene, 1,3-	106990	Organics	Nonaromatics
379	FORMALDEHYDE	Formaldehyde	50000	Organics	Nonaromatics
598	Propylene Oxide	Propylene Oxide	75569	Organics	Nonaromatics
800	Ethylene	Ethylene	74851	Organics	Nonaromatics
160	BARIUM	BARIUM	7440393	Inorganics	Metals
152	ARSENIC	Arsenic inorganic	7440382	Inorganics	Metals
138	ANTIMONY	ANTIMONY	7440360	Inorganics	Metals
630	STRONTIUM, STABLE	STRONTIUM, STABLE	7440246	Inorganics	Metals
127	ALUMINIUM	ALUMINIUM	7429905	Inorganics	Metals

Fig. 4.4 Chemical/Physical Properties Table

The **Exposure Parameters Table** includes default values established for child and adult receptors under residential and recreational land use scenarios, and adult receptors under an industrial scenario. Default values are included in Appendices 2 and 3.

The **Site Parameters Default Values Table** includes standard default values that are proposed to be used when site-specific values have not been obtained during site characterisation. This table is presented in Fig. 4.5.

qc_vol	ro_b	theta_a	theta_w	n	f_oc	ro_s	w
68.18	1.5	0.284	0.15	0.434	0.006	2.65	0.1
	0	0	0	0	0	0	0

Fig. 4.5 Site Parameters Default Values Table

HRA Tables were developed based on information available from US EPA documents and databases (US EPA Region III – RBC Tables², RAIS³, RIVM⁴).

4.4 HRA software module description

4.4.1 Technical information

Operating System: Windows 98 or higher / Windows 2k or higher.
Hardware limitations: standard personal computer.
Software requirements: MS Office 2k or higher - for reports in MS Excel format.

The NORISC-HRA software has been developed using Borland C++ Builder 6 compiler. Datasets have been built using MS Access 2000. The set-up programme has been created with InstallShield.

Installation

Simple open folder with executable set-up programme and a double-click the icon to install the programme. The set-up creates a folder and items in menu start and copies requested files. After installing the application, the software can be directly run without re-starting the system.

4.4.2 Program flow and its steps

4.4.2.1 “What to do”

The first steps are connected with basic decisions on the type of user needs.

The user may choose among three options (Fig. 4.6):

“**Risk Calc.**” button – pressed when the user wants to set up risk calculation and calculate risk within a new project,

- “**Load User Def.**” button - pressed when the user wants to replace default HRA parameters with a modified user data set,
- “**Load Project**” button - pressed when the user wants to load the previous risk assessment results.

² <http://www.epa.gov/reg3hwmd/risk/>

³ http://risk.lsd.ornl.gov/homepage/rap_tool.shtml, http://risk.lsd.ornl.gov/tox/latest_nonrad.xls;
<http://risk.lsd.ornl.gov/tox/metadata.shtml>

⁴ Lijzen J.P.A., Baars A.J., Otte P.F., Rikken M.G.J., Swartjes F.A., Verbruggen E.M.J., Wezel van A.P.;2001; Technical evaluation of the intervention values for soil/sediment and groundwater; RIVM report 711701 023.

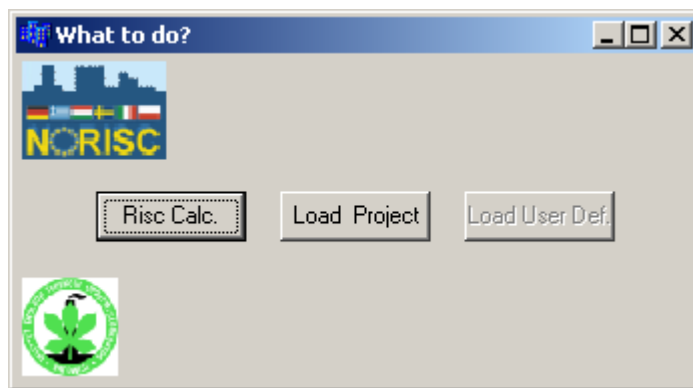


Fig. 4.6 The basic HRA module options – “What to do?”

4.4.2.2 Risk Calculation Setup

The risk calculation set-up is composed of several steps which allow to gather information needed to generate risk outputs. Data may be provided by linking to the HRA Tables and Users Table. Within these steps the user should make decisions about data sources and the way of conducting the risk calculation.

4.4.2.2.1 Selection of land use scenarios and exposure pathways

The user selects the land use scenarios on the “**Land Use Scenario Selection**” window as presented in Fig. 4.7.

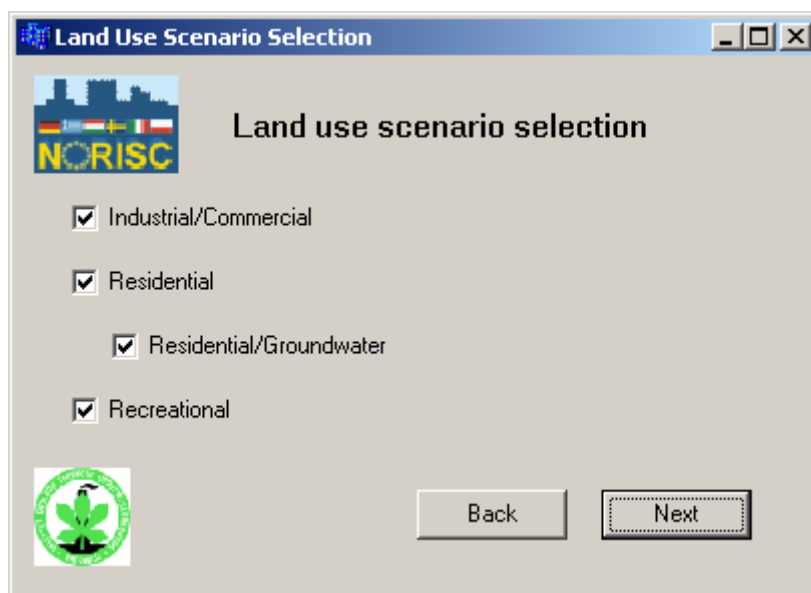


Fig. 4.7 Land use scenario selection

The land use scenarios considered in the HRA module include: industrial, recreational and residential. The exposure parameters for each of the scenarios may be set up for present or future land use patterns. For both present and future land uses the site-specific risk assessment is performed based on current contaminant concentrations. The unchecked scenario will be omitted in the next steps of analysis. The user may choose

between an analysis of one scenario or scenario combinations to obtain comparison of risk assessment for different land uses. It is assumed that all three scenarios are related to exposure from soil. When the use of groundwater in households is planned under residential scenario, then this option is activated by checking the “**Residential/Groundwater**” box. The “**Next**” button becomes active after checking at least one scenario.

In the next step of the calculation set-up, the user is asked to select the soil exposure pathways to be analysed. The user is given the following options: oral, dermal or inhalation pathways separately, or together. Fig. 4.8 presents the “**Exposure Pathways Selection**” window. After selection of at least one of the provided pathways, the button “**Next**” is activated to progress to the next step – “**Setting up user data source**”.



Fig. 4.8 Exposure pathways selection

The exposure parameters are set for selected land use scenario and relevant receptors (child and adult or adult only).

4.4.2.2.2 Setting up user data source

At the beginning of this step, the user should indicate the location of the User Tables along with the relevant fields. This step is guided by the “**Soil Data Source Selection**” window (Fig. 4.9).

Fig. 4.9 Soil data source selection

After pressing the “**Select DB**” button at the left side of the screen, the user starts a routine of directory browsing. The user has to indicate the name of the .mdb file in which the User Table with chemical concentrations in soil is located. After selection of the user .mdb file, it is possible to select the name of the proper table in which the results of soil investigation are collected. The combo box on the top of the right side of the screen contains all tables available in the .mdb file. After choosing the proper table name, other combo boxes are feed with field names of this table. Application tries to find correct field name for each combo box. If it is impossible, the first field name is displayed. Then the user must decide which field contains the requested data. Each box is described on the screen. The check box, situated at the right side of CAS Number combo box, should be checked by the user if the table contains CAS Number values. After filling all the boxes with the properly selected unique names, the “**Next**” button is activated to proceed to the next step of the configuration procedure.

Selection of “**Residential/Groundwater**” scenario requires introduction of the site data concerning groundwater and chemical/physical properties within two separate windows: “**Groundwater Data Source Selection**” window (Fig. 4.10) and “**Chemical/Physical Properties Parameters Setting**” window (Fig. 4.14).

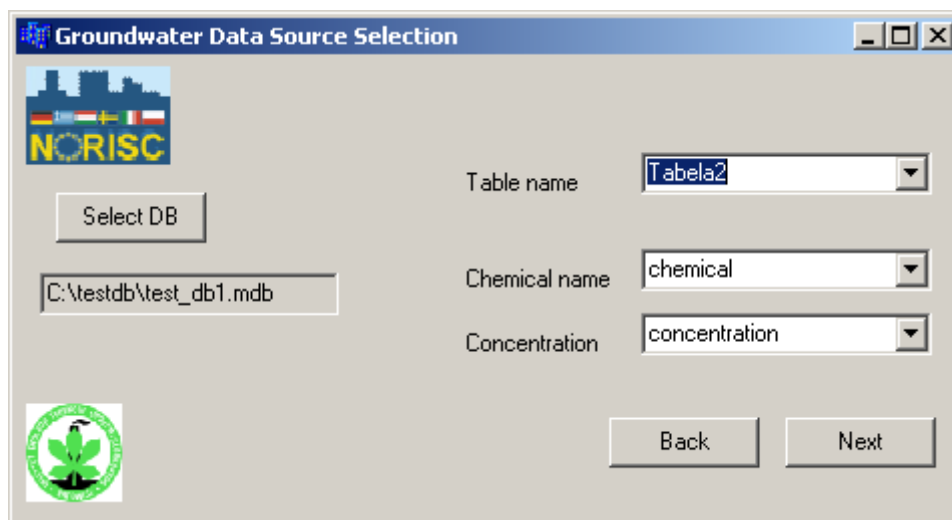


Fig. 4.10 Groundwater data source selection

After opening of the “**Groundwater Data Source Selection**” window, the user must press the upper left button “**Select DB**” and select the proper .mdb file in which data on chemicals concentration in groundwater have been gathered by the user. At the right side of the screen there are three combo boxes which allow to select the proper table (“**Table name**”) and indicate two fields – one with chemicals name, the other with chemicals concentrations. As it is presented in Section (4.2.1), the groundwater concentration represents statistical estimates (e.g., mean, maximum, UCL95) for the whole water-bearing horizon. It is necessary to provide field names for requested data to activate the “**Next**” button.

4.4.2.2.3 Setting up general site-specific parameters

The general site-specific parameters set-up is carried out in two “**Site characterization**” windows. One of them is related to the surface soil (Fig. 4.11), the other one – to subsurface soil (Fig. 4.12).

The surface soil parameters are necessary to calculate Particulate Emission Factor (PEF). The user may choose between default and site-specific PEF values. Figure 4.11 presents the window with the default PEF value. When the other option is selected, the user must choose the source of information and indicate the table and names of the fields in which, general site-specific data are located. If the data are not collected in a separate Access table, the step of table selection may be omitted. The site-specific values may be also introduced manually. Depending on the completeness of the collected values, the user may select different options of PEF calculation. The threshold (critical) wind velocity may be calculated based on the values provided by the user in proper boxes located at right side of the screen. If these parameters are not available, a default value of critical wind speed should be selected. The second value important for the fugitive dust emission calculation is the mean of annual wind velocity. This value should be recalculated due to differences among possible heights of wind velocity measurements. Similarly as in the previous case the user may select a default value of annual wind speed. The third parameter (Q/C) value -may be recalculated to account the impact of contaminated surface area on Q/C. The mode of user operation is common for all setting-up steps. The boxes at the left side contain values picked up from tables while the boxes at the right side (editing boxes) provide

the user with the possibility to edit the value of a given variable. The calculations are based on the equations presented in Appendix 2.

Fig. 4.11 Setting general site-specific parameters (surface soil)

Fig. 4.12 Setting general site-specific parameters (subsurface soil)

Setting up the general site-specific parameters related to subsurface soil is carried out in the case of soil contamination with volatile substances (Fig. 4.12). The upper part of the screen contains the default value of the Q/C_{vol} parameter. It is possible to adjust this value to the site area. This option is selected with the “**Value normalized by a site area**” radio button. When selecting this option, the user is obliged to insert the site area. The lower part of the window provides the possibility to establish general site-specific parameters such as: dry soil bulk density, air-filled soil porosity, water-filled soil porosity and fraction of organic carbon in soil. The first column is composed of the names of requested variables. The next column is composed of radio buttons connected with the default values picked-up by the programme from HRA Tables. By clicking on the radio button, the user may select an established default value. The next three columns of the buttons and the boxes allow the user to select other sources of general site-specific soil parameter values. By pressing the radio button, the user activates the boxes to indicate name of the field and value linked with its parameter. The boxes in the last columns form a basic set of global soil parameters values that will be used for calculation.

All values, beside those calculated, may be replaced. This option enables flexibility to develop a more sophisticated analysis.

When all non-calculated edit boxes in the columns of accepted values have been filled with numbers, the “**Next**” button becomes activated.

4.4.2.2.4 Setting up chemical-specific parameters

This step is initiated with the “**Toxicity Values Setting**” window (Fig. 4.13) and repeated as many times as there are chemicals identified during the site characteristic campaign.

NORISC default toxicity values		Accepted values	
Chemical name	ARSENIC		arsenic
RfD _o	0.0003	<input checked="" type="checkbox"/>	0.0003
CSF _o	1.5	<input checked="" type="checkbox"/>	1.5
RfD _i	NA	<input type="checkbox"/>	NA
CSF _i	15.1	<input checked="" type="checkbox"/>	15.1
ABS _d	0.001		0.001
ABS _{GI}	0.95		0.95
		<input type="checkbox"/>	Chemical disabled

Fig. 4.13 Toxicity values setting

The confirmation of the chemical name of a potential concern is realised on this screen and is provided by the lower right check box “**Chemical disabled**”. It allows the user to remove one or more of the chemicals from the calculation. However, this option should be used carefully.

The names of toxicological parameters are displayed on the left side of the screen, while the column on the right side presents default values of these parameters automatically picked-up from HRA Table. The values correspond to the chemical name that is displayed in the first row of the selection boxes.

Contaminant names in HRA Tables and User Tables are matched automatically by the HRA module. Contaminant name found in the User Table is compared with the contaminant name in HRA Tables. If a chemical name or CAS number analogue to the HRA one is not found, the user must choose the correct substance manually using a combo box.

The user is responsible for the proper linking of the name of a chemical in the User Table and in the HRA Table. Name matching confirmed by the user is registered by the HRA module and used during setting chemical-specific parameters values.

The user is requested to input proper data into the boxes at the right side of the screen. The software provides two alternatives of fulfilling this request for some of the parameters:

Alternative 1: The user can accept HRA default values by pressing the button with an arrow. This action is possible when the values are available in the HRA Table. In the other case the user has to provide his own values manually;

Alternative 2: The user can introduce all values manually based on his knowledge.

The column of the check box at the left side of the accepted values column provides the user with an option to enforce risk calculation for the given chemicals despite their lack in HRA Tables concerning reference doses or cancer slope factors. Checking this box enables the user to insert relevant toxicity values and change the NA (not available) value into the numeric one. This option services the situation when the user's state of knowledge about toxicological parameters values is more up to date than the HRA Tables provide. As it is presented in the "**Toxicity Values Setting**" window (Fig. 4.13), the user has decided to switch off the calculation of inhalation of non-cancer risk for arsenic. The calculation for this chemical will be made for inhalation, oral and dermal cancer risks, and for oral and dermal non-cancer risks.

Then the "**Next**" button becomes activated.

Fig. 4.14 presents an example of a window for setting chemical/physical parameters values needed to calculate inhalation risk from soil and risk from groundwater. Depending on the previously selected options, some objects in the window may become enabled or disabled. Names of requested parameters are displayed in the left column. The next column of the boxes contains default values of these parameters picked-up from the HRA Tables. In the central part of the screen, the columns of buttons with arrows enable the user to select which default value will be accepted. The "**All**" buttons allow to accept default values connected with inhalation soil risk or groundwater risk at once. The accepted values are displayed at the right side of the screen. Each value may be replaced manually by the user. The user has to replace this value with a proper number in the right column. It is possible not to calculate groundwater risk for selected chemicals by checking the "**Chemical disabled...**" box. After filling up all enabled boxes with numerical values, the "**Next**" button becomes activated to progress to the next step.

NORISC default chemical values		Accepted values
Chemical name	1,1,1-Trichloro-ethane	
Volatile?	yes	Yes
D _i Diffusivity in air (cm ² /s)	0.078	0.078
D _w Diffusivity in water (cm ² /s)	8.8E-6	8.8E-6
H' Henry's law constant (dimensionless)	0.705	0.705
Organic?	yes	Yes
K _d Soil to water partition coefficient (cm ³ /g)	NA	
K _{oc} Organic carbon partition coefficient (cm ³ /g)	110	110
All -->		
<input type="checkbox"/> Chemical disabled from groundwater risk calculation		
K _{ow} Octanol/water partition coefficient (dimensionless)	33.784	33.784
MW Molecular weight (g/mol)	133.41	133.41
All -->		
		Back Next

Fig. 4.14 Chemical/physical properties parameters setting

4.4.2.2.5 Setting up scenario-receptor specific parameters

Fig. 4.15 presents an example of exposure parameters setting under the industrial land use scenario.

	NORISC default values		Accepted values
Exposure frequency [days/year]	225	-->	225
Exposure duration [years]	25	-->	25
Fraction contacted [unitless]	1	-->	1
Body weight [kg]	70	-->	70
Ingestion rate for soil [mg/day]	100	-->	100
Skin surface area [cm ²]	3300	-->	3300
Soil to skin adherence factor [(mg/cm ²)/day]	0.2	-->	0.2
Inhalation rate [m ³ /day]	20	-->	20
Averaging time (noncarcinogenic) [days]	9125	-->	9125
Averaging time (carcinogenic) [days]	25550	-->	25550

Buttons: Back, Next, All -->

Fig. 4.15 Exposure parameter setting - Industrial scenario, receptor - adult

The names of parameters are in the first left column. The next column of grey boxes displays HRA default values picked up from HRA Tables. After pressing the button with an arrow the user may copy a default value into the white right box of an accepted value. If all default values are adequate to the analysed situation, the user may use the “**All**” button and copy all default values to the column “**Accepted values**”. The boxes in this right column may be filled manually with values other than default values. This option allows the user to simulate other receptor parameters as well as other conditions.

When all boxes are filled with non-zero values the “**Next**” button becomes activated.

If the selected scenarios are residential or recreational, the user is asked to consider two potential receptors: a child and an adult. The analysis is then carried out on two separate windows, one for an adult and one for a child receptor. Both windows are presented in Fig. 4.16 and Fig. 4.17 for the residential scenario and in Fig. 4.18 and Fig. 4.19 for the recreational one.

Exposure Parameters Setting

Residential scenario
Young child

	NORISC default values		Accepted values
Exposure frequency [days/year]	350	-->	350
Exposure duration [years]	6	-->	6
Fraction contacted [unitless]	1	-->	1
Body weight [kg]	15	-->	15
Ingestion rate for soil [mg/day]	200	-->	200
Skin surface area [cm ²]	2800	-->	2800
Soil to skin adherence factor [(mg/cm ²)/day]	0.2	-->	0.2
Inhalation rate [m ³ /day]	10	-->	10
Averaging time (noncarcinogenic) [days]	2190	-->	2190
Averaging time (carcinogenic) [days]	25550	-->	25550

Back
Next
All -->

Fig. 4.16 Exposure parameter setting – Residential scenario, receptor - young child

	NORISC default values	Accepted values
Exposure frequency [days/year]	350	350
Exposure duration [years]	24	24
Fraction contacted [unitless]	1	1
Body weight [kg]	70	70
Ingestion rate for soil [mg/day]	100	100
Skin surface area [cm ²]	5700	5700
Soil to skin adherence factor [(mg/cm ²)/day]	0.07	0.07
Inhalation rate [m ³ /day]	20	20
Averaging time (noncarcinogenic) [days]	8760	8760
Averaging time (carcinogenic) [days]	25550	25550

Navigation buttons: Back, Next, All -->

Fig. 4.17 Exposure parameter setting – Residential scenario, receptor - adult

	NORISC default values		Accepted values
Exposure frequency [days/year]	214	-->	214
Exposure duration [years]	24	-->	24
Fraction contacted [unitless]	0.08	-->	0.08
Body weight [kg]	70	-->	70
Ingestion rate for soil [mg/day]	100	-->	100
Skin surface area [cm ²]	5700	-->	5700
Soil to skin adherence factor [(mg/cm ²)/day]	0.07	-->	0.07
Inhalation rate [m ³ /day]	20	-->	20
Averaging time (noncarcinogenic) [days]	8760	-->	8760
Averaging time (carcinogenic) [days]	25550	-->	25550

Buttons: Back, Next, All -->

Fig. 4.18 Exposure parameter setting – Recreational scenario, receptor – adult

	NORISC default values		Accepted values
Exposure frequency [days/year]	350	-->	350
Exposure duration [years]	6	-->	6
Fraction contacted [unitless]	1	-->	1
Body weight [kg]	15	-->	15
Ingestion rate for soil [mg/day]	200	-->	200
Skin surface area [cm ²]	2800	-->	2800
Soil to skin adherence factor [(mg/cm ²)/day]	0.2	-->	0.2
Inhalation rate [m ³ /day]	10	-->	10
Averaging time (noncarcinogenic) [days]	2190	-->	2190
Averaging time (carcinogenic) [days]	25550	-->	25550

Buttons: Back, Next, All -->

Fig. 4.19 Exposure parameter setting – Recreational scenario, receptor - young child

The user is asked to provide parameters values, i.e., either to confirm the proposed default values or to enter own ones. The accepted values will be used for risk calculations. When all boxes are filled with non-zero values the “Next” button becomes activated.

The last type of the scenario parameters setting is connected with “**Residential/ Groundwater**” scenario. Fig. 4.20 and Fig. 4.21 present relevant exposure parameters along with the default values under this scenario for a child and an adult, respectively. The window appears, if the groundwater scenario option was selected in one of the previous steps. Exposure is evaluated taking into account all assumed exposure pathways, i.e., ingestion of groundwater used as a tap water, dermal contact while showering or bathing and inhalation of volatiles from groundwater during household use.

Exposure Parameters Setting

Additional exposure parameters for Residential/Groundwater scenario

Young child

Oral ingestion rate [l/day]	1	-->	1
Skin surface area [cm ²]	6600	-->	6600
Event frequency [events/day]	1	-->	1
Avg. turnover time of the stratum corneum [days]	14	-->	14
Event duration [event/hr]	1	-->	1
Volatilisation factor [unitless]	0.0005	-->	0.0005

All -->

Back Next

Fig. 4.20 Exposure parameter setting – Residential/Groundwater scenario, receptor - young child

Exposure Parameters Setting

Additional exposure parameters for Residential/Groundwater scenario

Adult

Oral ingestion rate [l/day]	2	-->	2
Skin surface area [cm ²]	18000	-->	18000
Event frequency [events/day]	1	-->	1
Avg. turnover time of the stratum corneum [days]	14	-->	14
Event duration [event/hr]	0.58	-->	0.58
Volatilisation factor [unitless]	0.0005	-->	0.0005

All -->

Back Next

Fig. 4.21 Exposure parameter setting - Residential/Groundwater scenario, receptor – adult

4.4.2.2.6 Setting the target risk values

In this step of parameter-setting, the user is responsible for establishing Target Risk values for non-carcinogenic and carcinogenic effects. The user is allowed to establish own Target Risk values instead of the proposed values (1E-6 for Target Cancer Risk and 1 for Target Hazard Index), which will be used for comparing with the calculated risks. This will be done within the “**Setting Target Risk Values**” window (Fig. 4.22).

After filling the right boxes with proper values and pressing the “Next” button, the process of risk calculation will be initiated.

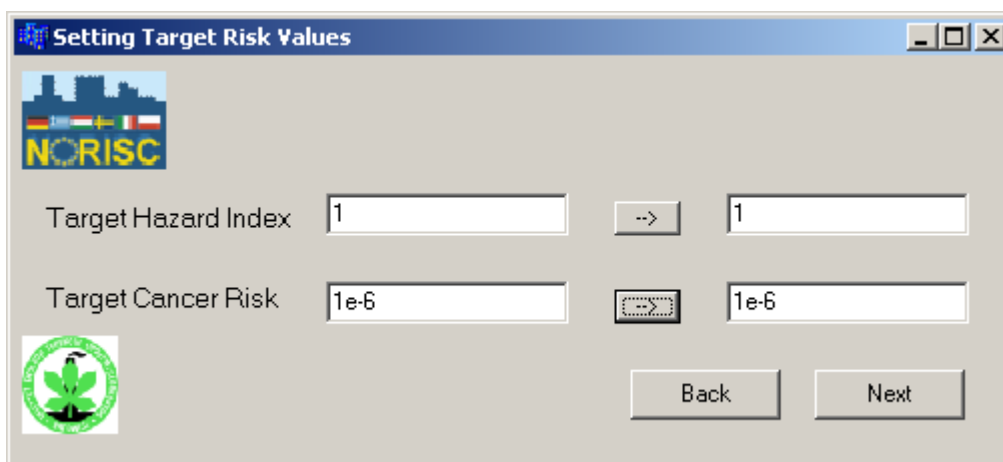


Fig. 4.22 Setting target risk values

4.4.2.3 Risk characterisation - output data generation

The calculation of risks is carried out using relevant equations as presented in Section 3.1.4. and Appendices 2 and 3. As results of this step, the values of Hazard Quotients (HQ), Hazard Indices (HI) and Cancer Risk (CR) and also Total HI and Total Cancer Risk are generated. Total HI and Total CR are calculated by summing HIs and CRs across all chemicals and exposure pathways for the selected land use scenario and relevant receptors (for an adult under industrial scenario and separately for a child and adult under residential and recreational scenario). Under residential and recreational scenarios, Total CR is calculated additionally for an aggregate resident/recreational user (see Section 3.1.4.)

As far as **soil** is concerned, risk calculation outputs are obtained for each sampling point.

As for **groundwater** (only for planned residential groundwater use) – risk calculation outputs represent site values for water-bearing horizon (based on general site parameters for water horizon derived from the sampling points).

The next step is connected with the analysis of risk calculation outputs, and includes:

- Querying and displaying points with HIs and Cancer Risks above/below Target Risk levels,
- Segregating chemicals by effect/target organ and summing the related HIs for cases where Total HI > 1.

An example of the window of risk characterisation outputs is presented in Fig. 4.23.

Table with the results of risk calculation is presented at the left side of the window while a simplified map of the site occupies the right part of the screen. Radio buttons at

the bottom of the left side provide the user with a possibility to switch the displayed map among total carcinogenic and total non-carcinogenic risk calculated to both receptors (child and adult), and total carcinogenic risk for an aggregate receptor. It is also possible to choose an intended scenario. For industrial scenario (example presented in Fig. 4.23) only two buttons are active as the child receptor is excluded from this scenario. A simplified map shows the location of the sampling points and the corresponding Voronoi polygons. The polygons with exceeded target risk level are displayed in red and the polygons in which the calculated risk is below the target risk level are displayed in green. The data simultaneously displayed in the left table are represented on the map as larger white dots and the polygon outline corresponding to them are yellow.

The analysis of spatial risk distribution is initiated from the first listed point. The user may move from point to point by pressing the “**Next Point**” button. The displayed table contains HI and CR for each chemical and each pathways as well as a Total Hazard Index (summed by pathways and chemicals) and Total Cancer Risk (summed by pathways and chemicals).

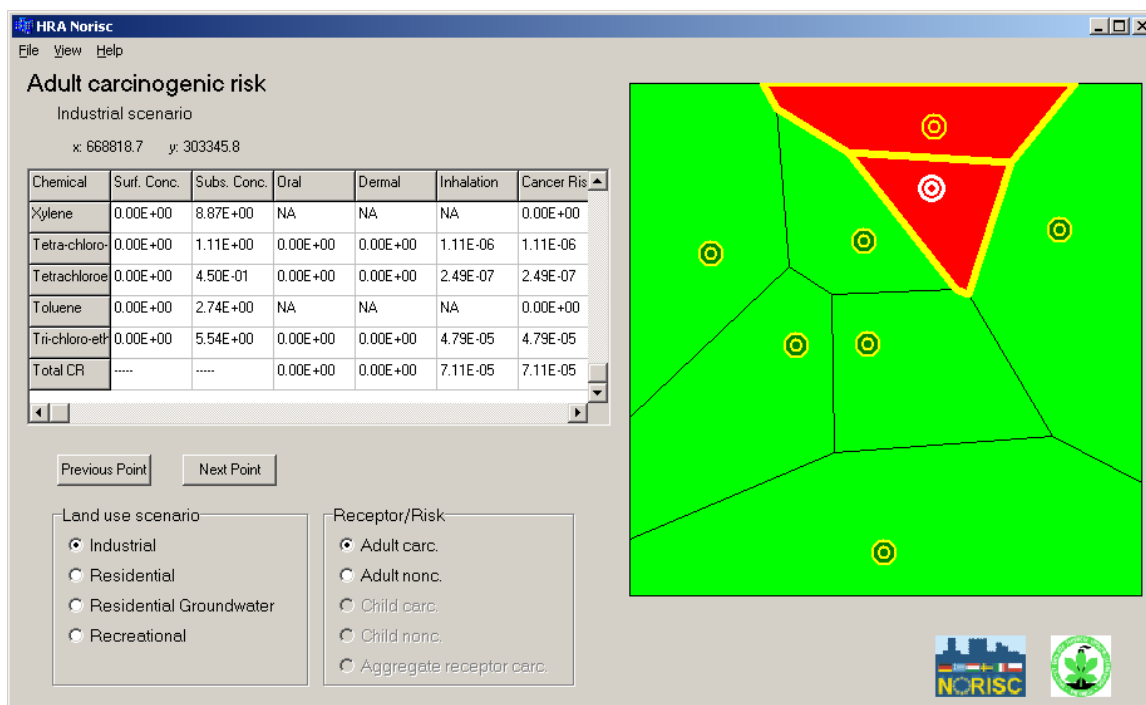


Fig. 4.23 Risk characterisation outputs

The HRA module helps the user to establish zones of exceeded Target Risk values. This step is performed by a cluster analysis of points grouped into two classes: below and above Target Risk levels. The applied algorithm allows connecting the points that are in the same group and neighbour each other. Non-polluted points are used to split primary polluted cluster into smaller ones. Final delineation of the zones is made using the Voronoi polygons algorithm.

Each zone is characterised by a set of **risk characterisation outputs** that is the same as for point data. Average risk levels calculated for each zone represent spatially correct estimates.

As it was mentioned earlier, risk resulting from groundwater contamination is calculated based on average contaminant concentrations for water-bearing horizon without spatial analysis. Due to this reason it is not presented on a separate map. The groundwater risk values calculated for appropriate land use scenario (Residential/Groundwater) can be displayed after checking the “**Residential/Groundwater**” radio button.

4.4.2.4 Developing site-specific health-based remedial goals (HBRGs)/Risk-based-Concentrations (RBCs)

The user has an alternative to switch between “**Risk View**” and “**RBC View**” by choosing proper option from the application menu.

Besides calculating the site-specific health risk, the current release of the HRA module helps the user establish risk-based preliminary goals. The calculation of RBC is carried out by an application that uses the algorithms described earlier. The RBC calculations are performed automatically without user action.

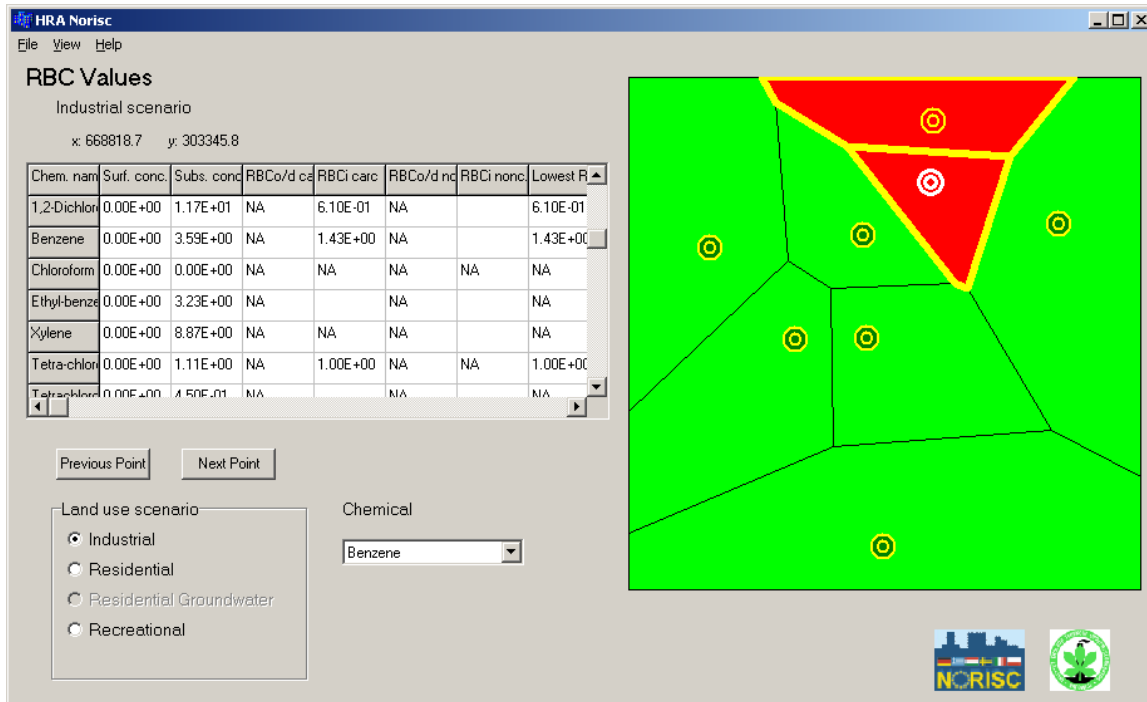


Fig. 4.24 Analysis of the RBC values

The window of RBC values analysis presented in Fig. 4.24 works in a way similar to that of the window for the analysis of the risk calculation results presented earlier. The screen is divided into three sections. The names of scenario and table with corresponding RBC values are displayed at the upper left side of the screen.

The table is composed of eight columns. The first column contains the names of all analysed chemicals. The next two columns present the concentrations of chemicals measured in surface and subsurface soil, respectively. The next four columns contain RBC values for carcinogenic and non-carcinogenic chemicals. The RBC values are displayed in two columns because they are calculated separately for oral/dermal exposure route and inhalation route. The RBC values are verified by soil saturation concentration. The last column contains the lowest RBC value, selected as a preliminary health-based remedial level.

The bottom-left part of the screen contains buttons that facilitate navigation between sampling points and scenarios and allow selecting a chemical for displaying on the map at the right side of the window. The selected points are displayed as larger white dots and the corresponding polygon outlines are displayed in yellow. Polygons in which the estimated concentrations are below the calculated RBC are displayed in green, while polygons for which a remediation activity should be undertaken are marked red.

Maps of zones delineated in such a way determine the remediation goals.

4.4.2.5 Creating report

The set of data developed during HRA module session can be saved as a preformatted MS WORD document. The generated maps are included into the report as pictures. The user may select an option of report generating from the bar menu (“**File**” - “**Create Report**”). The report is generated for the selected land use scenario and is composed of the description and tables with appropriate maps.

The description includes:

- site name,
- main site parameters.

The tables include:

- Concentrations of Contaminants of Potential Concern (COPC) – min., max values,
- Chemical/Physical parameters of COPC, used for risk analysis,
- Values of toxicological parameters,
- Land use scenario/Receptor/Exposure parameters,
- Results of human health risk assessment for established zones,
- Results of RBC for established zones.

The maps include:

- maps of risk zones,
- maps of zones with chemical concentrations exceeding RBC values.

4.5 Future HRA software improvement

It is planned to introduce corrections/modifications and updates into the current version of HRA software module.