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Contaminated sites: a comparison between the Italian and the Swedish approach

Supervisors: Prof.ssa Ann-Catrine Norrström
Prof.ssa Sabrina Saponaro

Student:
Matteo Luca Tabiadon
Matr. 837038

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Abstract in English

The assessment of the risk posed by a polluted site towards humans and the environment is an important issue. The methodology to define a conceptual model of the site of study and to perform the risk assessment can differ significantly for each country thus, the comparison between different methods to approach polluted sites, can highlight which are the aspects that should be included or modified in the risk assessment methodology to ensure reliable outcomes.

The aim of the study was to compare the Italian and Swedish approaches to deal with contaminated sites and evaluate the respective results. The two risk assessments were performed for the property of Bollnäs Bro 4:4, located in Bollnäs (Sweden). The site presented a diffused contamination by both inorganic and organic pollutants as a consequence to the storage and maintenance of train coaches. Soil samples were taken on site to perform leaching test and determine the site-specific soil to liquid partition coefficient (K_d) of metals. Two software were used: Risk-net 2.0, to determine the threshold concentrations for risk (CSRs), i.e. the Italian remediation goals, and the Software for site-specific soil guidelines by Kemakta AB to calculate the Swedish site-specific soil guidelines.

The outcomes of the two risk assessments were different both considering the value and the driving exposure pathway, but confirmed the critical pollution of the property. The Swedish site-specific guidelines were found smaller than the Italian CSRs for the majority of the contaminants, but it was not possible to define which approach would have determined the highest remediation costs, due to the non-legally-binding character of the Swedish guidelines.

The Italian risk assessment is very detailed, but time consuming. The Swedish methodology, on the contrary, is quick and simple, but is lacking in site-specificity, due to the limited number of editable parameters. Both the approaches have strengths and weaknesses, but further studies, focused both on the physio-chemical and toxicological properties of the pollutants and the mathematical models adopted in each country, are required to perform a deepened comparison between the two methodologies.

Abstract in Italiano

La valutazione del rischio posto dalla presenza di un sito contaminato su uomo ed ambiente è una problematica importante. Il procedimento per definire un modello concettuale del sito ed eseguire l'analisi di rischio possono risultare molto diverse di Paese in Paese. Per questo, il confronto tra diverse metodologie di approccio ad un sito inquinato può essere usato per identificare quali sono gli aspetti che andrebbero inclusi in una procedura di analisi di rischio e quali invece tralasciati, per ottenere risultati realistici e affidabili.

Lo scopo del lavoro è stato quello di comparare l'approccio italiano ad un sito contaminato con quello svedese per poi valutare i risultati corrispondenti. Le due analisi di rischio sono state eseguite per la proprietà Bollnäs Bro 4:4, situata nella cittadina di Bollnäs (Svezia). Il sito in analisi era caratterizzato da un'estesa ed eterogenea contaminazione, costituita sia da inquinanti organici che inorganici, conseguente alla manutenzione delle carrozze di treni, poi tenute in capannoni. Dei campioni di suolo sono stati raccolti sul sito per eseguire un test di cessione e determinare il coefficiente di partizione suolo-acqua (K_d) dei metalli presenti. Due software differenti sono stati utilizzati: Risk-net 2.0, per calcolare le concentrazioni soglia di rischio (CSR), ovvero gli obiettivi di bonifica italiani, e il Software for site-specific soil guidelines by Kemakta AB per calcolare le linee guida sito-specifiche svedesi.

Le due analisi di rischio hanno fornito risultati diversi, sia in termini di valore numerico che considerando la via di esposizione determinante per il contaminante, ma entrambe hanno confermato la criticità della contaminazione del sito. Le linee guida sito-specifiche svedesi sono risultate più basse delle CSR italiane per la maggior parte dei contaminanti, ma non è stato possibile determinare quale tra i due approcci avrebbe comportato i costi di bonifica più elevati, dato che le linee-guida svedesi non costituiscono valori legalmente vincolanti.

L'analisi di rischio italiana è più dettagliata ma richiede tempo per essere eseguita. La metodologia svedese è, invece, semplice e veloce da applicare, ma la simulazione risulta molto meno sito-specifica a causa del numero limitato di parametri che possono essere modificati. Entrambi gli approcci hanno punti di forza e debolezza, ma sono necessari ulteriori studi, incentrati sui modelli matematici e i parametri chimico-fisici e

tossicologici utilizzati in ciascun Paese, per poter fare un paragone più approfondito tra le due metodologie.

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ADI: Acceptable Daily Intake

APAT: Agenzia per la Protezione dell’Ambiente e per i servizi Tecnici

ARPAV: Agenzia Regionale Protezione Ambiente Veneto

AT: Averaging Time

$C_{A.TOXICITY}$: Guideline For Acute Toxicity

CDI: Chronic Daily Intake

$C_{FREEPHASE}$: Concentration Of Contaminant In The Soil

C_{GW}: Acceptable Concentration Of Pollutant In Soil To Not Pose Risk To Groundwater

C_{HEALTH}: Health Based Guideline

$C_{INTEGRATED}$: Integrated Human Health Based Guideline

CRS: Source Representative Concentration

CSC: Threshold Concentration For Contamination

CSR: Threshold Concentration For Risk

D. Lgs: Legislative Decree

DF: Dilution Factor

ED: Exposure Duration

$E_{off\ site}$: Soil Concentration For An Acceptable Level Of Chemical In Surface Water

E_{onsite}: Guideline For Protection Of Soil Environment

f_{oc}: Fraction Of Organic Matter In Soil

H: The Henry’s constant

HC<12: Hydrocarbons C<12

HC>12: Hydrocarbons C>12

HI: Hazard Index

HI_{mix}: Cumulative Hazard Index

ISPESL: Istituto Superiore per la Prevenzione E la Sicurezza Sul Lavoro

ISPRA: Istituto Superiore per la Protezione e la Ricerca Ambientale

ISS: Istituto Superiore della Sanità

K_d: Soil-Liquid Partition Coefficient

KM: Land with sensitive use

K_{oc}: Organic Carbon-Water Partitioning Coefficient

K_{ow}: Octanol-Water Partitioning Coefficient

L/S ratio: Liquid To Solid Ratio

LCL95%: Lower Confidential Limit at 95%

LOI: Loss on Ignition

MADEP: Massachusetts Department of Environmental Protection

MIFO: Methods for Inventories of Contaminated Sites

MKM: Land with less sensitive use without groundwater extraction

NOEC: No Observed Effect Concentration

PAH H: High Weight Polycyclic Aromatic Hydrocarbons

PAH L: Low Weight Polycyclic Aromatic Hydrocarbons

PAH M: Medium Weight Polycyclic Aromatic Hydrocarbons

PAHs: Polycyclic Aromatic Hydrocarbons

PBT: Persistent Bioaccumulative Toxic

PCBs: Polychlorinated Biphenyls

PdC: Plan of Characterization

PdI: Plan of the Investigations

POC: Point Of Conformity

POE: Point Of Exposure

R: Risk

RfD: Reference Dose

$R_{GW:}$ Risk Associated To The Hydric Resource R_{gw}

R_{mix}: Cumulative Risk

SEPA: Swedish Environmental Protection Agency

SOC: Soil Organic Carbon

SOM: Soil Organic Matter

TDAE: Tolerable Dose For Acute Effects

TDI: Tolerable Daily Intake

TPHWG: Total Petroleum Hydrocarbons Working Group

TRV: Toxicological Reference Value

UCL95%: Upper Confidential Limit at 95%

USEPA: Unites States Environmental Protection Agency

vPvB: very Persistent and very Bioaccumulative

WHO: World Health Organization

1 Introduction

Risk assessment is the formal process of evaluating the consequences of a hazard(s), i.e. a situation or a chemical, biological, physical agent that can cause adverse effects or harm, and their related probabilities (Gormley at al., 2011; Phillips et al., 2008). In the environmental contest, risk assessment is used in order to assess the risk associated to a polluted site and the consequent remediation required as well as a possible future hazard that has not occurred yet (Saponaro, 2015; NATURVÅRDSVERKET, 2009; Gormley at al., 2011). When dealing with an existing polluted site, the risk assessment methodology, as part of the remediation procedure, is based on the use of models that can connect the hazard due to the contamination with the exposure and migration pathways and the receptors (Saponaro, 2015).

Different countries have consequent different approaches to assess the risk, therefore the outcomes of the risk assessment and the practical actions adopted might differ significantly. Because of this heterogeneity, a comparison between different methodologies can be useful to highlight their positive and negative aspects and it can help further develop a more efficient procedure to assess the risk.

The polluted area Bollnäs Bro 4:4, in the Swedish city of Bollnäs, where train coaches were stored and maintenance work has been constantly performed for one century, is an example of a site that requires a risk assessment to evaluate the possible harm posed by the existing pollution. Previous reports and analysis performed at the site, reported contamination both in soil and groundwater and a risk assessment with the consequent possible actions to manage the risk was performed by Swedish Consultants (SWECO) in 2015, without considering the buildings present at the site.

1.1 Aim of the study

The aim of this thesis is to compare the Italian and Swedish risk assessment procedure, both considering the methodology itself and the software used, and performing a risk assessment for the site Bollnäs Bro 4:4 with the two different approaches. Even if analysis were executed in the previous years and a risk assessment was performed by the Swedish company SWECO in 2015, it is interesting to perform a risk assessment using different inputs after collecting samples at the site to check if the contamination is as heterogeneous as it appears from the previous reports. Moreover, due to the importance in evaluating the risk posed by toxic metals, it is of interest the actual mobility of these species in the site of study to properly determine the risk.

The questions that have to be answered in this study are:

1. What are the major differences between the Italian and Swedish risk assessment procedure?
2. Which conclusions can be drawn from the analysis on toxic metals in the samples collected at the site of study?
3. Which conclusions can be drawn from the outcomes of the two risk assessments?
4. Which are the differences in the results of the two risk assessments and how can they be explained?
5. Which are the strengths and the weaknesses of the two approaches and, how, if possible, could they be merged?

2 Background

2.1 Risk assessment

Risk assessment methods can be broadly divided in two types: qualitative and quantitative. The qualitative approach is usually simple and cost-effective, but it results as significantly subjective (Gormley at al., 2011; Linkov et al., 2009). Consequently, it is possible to obtain different outcomes if the performer of the assessment changes, due to the individual interpretation of the inputs and the outputs of the problem. Quantitative methods, on the other hand, are more complicated than the qualitative ones, but more reliable since based on a large amount of data and on the judgment of experts in the topic. However, quantitative methods can be simplified if the model is provided in the form of a software. In this case, it is possible to modify the inputs and the consequent outcomes of the assessment with the manipulation of a reasonable number of parameters. A possible issue of the quantitative methods can be identified in the strong dependence on the selection of the data to perform the assessment (Gormley at al., 2011; Linkov et al., 2009).

Environmental risk assessments consider three possible classes of hazards: sanitary risk related to human health, ecological risk for an ecosystem, and the risk for water resources (Saponaro, 2015). The ecological risk is the farthest from standardization of the procedure (Saponaro, 2015) and due to the ecosystem complexity the modelling results difficult.

It is possible to identify three different types of risk assessments, depending on the complexity of the approach and the instruments used to reach the aim of the study (APAT, 2008; Saponaro, 2015):

- Level 1: Tables with non-site-specific values;
- Level 2: Analytic model for transport and/or site-specific parameters;
- Level 3: Numerical model or direct measurement with probabilistic methods to estimate the risk.

A level 2 risk assessment, is an acceptable compromise between the other two levels but usually requires simplifications when drawing the conceptual model of the site of study, in particular about (Saponaro, 2015):

- Geology and hydrogeology of the site (isotropy etc.);
- Geometry and chemical features of the pollution sources;
- Lack of change of input parameters in time;
- Pollutant fate and transport mechanisms.

2.2 Problem formulation

A clear definition and description of the problem and its boundaries is of fundamental importance when performing a risk assessment, because it affects the outcomes and the consequent future actions at the site (Gormley at al., 2011; Nickson, 2008). When the schedule for a risk assessment is strict and the time is lacking, overlooking details and saving time collecting less information could appear easier, but this approach might lead to issues in the revision phase of the procedure (Gormley at al., 2011). It is important to assess the uncertainty of the problem formulation so that the outcomes can be clearly contextualized in the frame of assumptions adopted by the performer of the risk assessment without ambiguity.

Uncertainty is a critical aspect in the risk assessment (Unites States Environmental Protection Agency-USEPA; Gormley at al., 2011) and is usually caused by the lack of complete data. This factor can be decisive both in the formulation of the problem and it is the reason why fully gathering information is a crucial part of the process.

During the formulation of the problem, it is recommended to include in the discussion the stakeholders or the public bodies that could be directly or indirectly affected by the assessed risk (Gormley at al., 2011). The early participation of the interested parties can make the decisions taken during and after the risk assessment more efficient and punctual (Gormley at al., 2011). If doing so, it is also possible to avoid future bureaucratic issues between the different involved parties, which would cause delays both in the phase of risk assessment and in the remediation actions.

Basic general information about the risk must be collected considering the “four w”: what, to whom (or which part of the environment), where and when. The problem formulation phase can be divided in sub-stages: problem framing, conceptual model development, risk assessment planning, risk screening and prioritizing (Gormley at al., 2011; Nickson, 2008).

2.2.1 Conceptual model development

In order to formalize all the aspects cited above, a conceptual model, i.e. a schematic representation, of the site is necessary to represent the features and the boundaries of the environmental problem under evaluation (Gormley at al., 2011; Nickson, 2008). The complexity and the details of the model to be defined usually vary case by case, but the more detailed the model is, the closer the assessment is to the real situation. However, it must not be forgotten that a conceptual model will never be able to represent perfectly the site and imprecision will always affect the outcomes. Hence, an increased effort in the conceptual model development can only increase the reliability of the results of the risk assessment but will never remove the intrinsic imperfection of a schematic representation of a complex reality.

The development of a conceptual model is highly dependent on the quality of the data and information gathered about the site of study. Therefore, it is fundamental to collect the historical data available for the area in order to identify the proper methodology to follow when performing the investigations and the location of the sampling points. The investigations that can be executed must be divided in two classes: direct investigations, that give quantitative outcomes, and indirect investigations, that produce qualitative information (Nickson, 2008; Saponaro, 2015).

The complexity of the model is strictly connected to the one required for the risk assessment. A conceptual model is used to define the hypothetic connection and relationship between the source of the hazard (polluted site) and the pathways of exposure and migration to the receptors, i.e. humans and environment respectively (Gormley at al., 2011; Nickson, 2008; Saponaro, 2015). The source of the hazard, e.g., a polluted site, greatly bear on the results of the risk assessment, in the sense that a wrong or superficial description of the considered site can lead to misleading results and inefficient risk management actions. The distinction between migration and exposure pathways is based on the different receptor considered. When humans are considered, we talk about exposure because the quantity of the pollutant that reaches the receptor and its contact time, in addition to the chemical properties of the chemical itself, determine the consequences on human health. In the case of hazard to the environment, the term migration pathway is used because no exposure is calculated in the risk assessment (Saponaro, 2015).

When developing the conceptual model, it is important to be informed about all the factors that can affect the risk (Gormley at al., 2011; Nickson, 2008). All the natural and human processes that can influence the hazard must be taken into account. The activity in the nearby areas, the annual precipitations and the geochemical properties of the soil are examples of the information required. If any affecting factor is not considered from the very first stage, problems may arise during the assessment of the risk and the definition of the consequent practical actions (Gormley at al., 2011).

2.2.2 Planning the assessment

The stage of planning the assessment is focused on the definition of the required data and the methods to collect them (Gormley at al., 2011). In this context, the selection of which are the most important data in order to perform the risk assessment for the site provides opportunity to save time focusing the effort on the most critical aspects of the assessment and it leads to more punctual outcomes.

In the last years, the request for public participation in the risk assessment and for a procedure characterized by full transparency has become stronger along with the increase in the environmental awareness between citizens (Gormley at al., 2011, Petts and Brooks, 2005). Participatory risk assessment is an effective solution to the lack in the public participation (Gormley at al., 2011). This type of risk assessment involves people in the problem formulation, management options and final solutions communicating information in a comprehensible and non-specific language (Homan et al., 2001; Petts and Brooks, 2005).

2.2.3 Risk screening and prioritization

A first partial screening of the risk characterizes the stage of conceptual model definition (Gormley at al., 2011). The screening can be used to identify which are the most relevant risks that have to be analyzed and assessed, but also those aspects that can be overlooked when performing further investigations. In this way, it is possible to manage the efforts of the assessment in an efficient way saving time and resources. In this phase, the performer of the risk assessment can understand if a quantitative risk assessment is possible for the site, i.e. the available data and information are enough, or if more analysis is required. However, not all the risks need a quantitative risk assessment, since they might be considered negligible looking at the data already available (Gormley at al., 2011). Therefore, risk screening is useful to focus the assessment on those risks that are affected by an uncertainty that could greatly affect the outcomes of the study and the risk management.

Risk screening can be based on different factors (Gormley at al., 2011):

- The importance of a hazard, the susceptibility of the receptor or the accessibility of a pathway;
- The probability of an event, considering the historical occurrence and the changing in the circumstances;
- The reliability of the links identified between the hazard and the receptor.

Screening the risk, deciding with “filters” which are the hazards to be further analyzed, is only a first step that is followed by the prioritization of the risk. This process must be transparent due to the intrinsic subjectivity of the procedure, in order to clarify on which basis the outcomes of the assessment are founded (Gormley at al., 2011). Once transparency is ensured, it is also possible to compare results of different assessment in an effective way. Risk ranking can be performed in many ways: considering the relative strength of a dangerous chemical, the likelihood of a pathway to be relevant for a specific receptor, the necessary exposure to ensure critical hazard to a receptor and so on (Gormley at al., 2011). All these qualitative approaches use a conceptual model to identify the connections between sources of the hazard, pathways and receptors.

The process of screening and prioritizing the risk must be revised during the whole assessment. In fact, it is probable that some risks that are classified as not relevant, at the starting point of the study, gain more importance in the next steps with possible influence on the outcomes of the assessment.

2.3 Assessment of the risk

After a first stage of problem formulation in which planning and scoping are performed along with the collection of data to identify the dimensions and features of the site contamination and also all the information needed to predict the fate of the contaminants, the risk can be assessed (USEPA). Usually, the assessment can be divided in four stages (Gormley at al., 2011):

- Hazard(s) identification;
- Assessment of the potential consequences;
- Assessment of the probability of these consequences;
- Risk and uncertainty characterization.

Either performing a quantitative or qualitative risk assessment, the assessment of the risk follows the same steps as reported above.

2.3.1 Hazard(s) identification

When a chemical, physical or biological agent or a situation can cause, under specific conditions, harm, it can be identified as a hazard (Phillips et al., 2008). A hazard can be of different magnitude, spacing from a local context, e.g., highway traffic pollution, to a global one, e.g., ozone depletion. The identification of the hazards greatly affects the next steps of the risk assessment and, therefore, it is important to identify all the possible threats (Gormley at al., 2011).

Given a hazard, the consequences that can occur are intrinsic in the hazard itself and all the possible ones must be taken into account with the related probability to assess the risk. The magnitude of the consequences must be defined without neglecting not only the spatial but also the temporal scale of them (Critto et al., 2007; Gormley at al., 2011; Phillips et al., 2008).

2.3.2 Assessment of consequences probability

Given all the consequences that are likely to occur due to a hazard, it is important to associate to each of them a probability or frequency (Gormley at al., 2011). For example, in the case of a polluted site, the actual odds that an individual comes in contact with the polluted soil must be considered. Models are used to reproduce the migration of pollutants in the environment and estimate the off-site exposure of humans to these dangerous compounds. When estimating the exposure on site, the frequency at which the receptor is in contact with the hazardous chemical is considered. The carcinogenic risk, expressed as a probability, is itself an example of this concept and is direct consequence of the probability that the pollutant reaches the receptor (Phillips et al., 2008; Saponaro, 2015).

Once it is established the probability of exposure to harmful chemicals occurs, it is important to calculate the odds of adverse effect due to the exposure. Obviously, the occurrence's likelihood of consequences to exposure to hazardous compounds can be different due to the variety of factors involved. In fact, the probability of harm depends on the properties of the chemical itself, on the vulnerability of the receptor and on the extent of the exposure. As an example, it is unrealistic that the exposure to the same pollutant concentration would lead to the same consequences in the case of an adult and an infant. Usually the likelihood of harm is represented in a simplified way using a dose-response relationship that relates the magnitude of harm to a certain exposure for a given type of receptor (Gormley at al., 2011). These relationship is obtained using ecotoxicological tests that use as receptor small mammalians and extrapolate the results for humans using factors, e.g., safety factor, to adapt the outcomes to the different receptor (Norrström, 2015; Saponaro, 2015).

2.3.3 Risk and uncertainty characterization

At this step, the information and the results obtained from the previous stages are gathered to determine the definitive likelihood of harm that an activity or a compound could cause to a specific receptor in defined exposure conditions and with the related assumptions and uncertainties.

A common way to characterize the risk is to compare the contaminant concentration in an environmental matrix with a guideline value and then define what this would mean in terms of how likely adverse effect could occur (Critto et al., 2007; Gormley at al., 2011). Further considerations can be made about the validity of the guideline for the studied site and consequent actions to properly characterize risk, e.g., site specific guidelines (Elert, 2016; NATURVÅRDSVERKET (2), 2009).

In order to characterize the risk posed by dangerous chemicals, ecotoxicological tests, as mentioned before, can be performed using for example the predicted no-effect concentration (PNEC), determined using laboratory animals or gathering data from similar cases affecting population (Critto et al., 2007; Gormley at al., 2011; Phillips et al., 2008). In the case of hazardous chemicals, an important distinction must be highlighted between toxic and carcinogenic compounds, due to the different dose-response effect on humans and animals (Phillips et al., 2008; Saponaro, 2015).

Considering a dose-response relationship, in the case of a toxic agent, a threshold value is defined as that dose at which response, i.e. adverse effects, on the target occurs. When the acceptable dose has to be modified with respect to humans, a reference dose (RfD) is determined, that is always smaller than the threshold dose. In fact, the RfD is usually derived from the no adverse effect level (NOAEL) using uncertainty factors (UFs) that are based on the data and the procedure performed to determine the RfD (Phillips et al., 2008). For example, if animals are used, a normal UF is 100, but it can vary according to the number of studies and the type of animal (Saponaro, 2015). Then another modifying factor (MF) can be used which is based on the professional judgment of the chemical’s data (USEPA, 1993).

$$RfD = \frac{NOAEL}{UF * MF} \; [\frac{mg}{kg_{body} * d}]$$

The dose-response correlation for carcinogenic and mutagenic chemicals is considered as a no threshold one, i.e. adverse effects on human health are likely to occur also at very low exposure values (Critto et al., 2007; Phillips et al., 2008; USEPA, 1992). Since response at low doses of carcinogenic compounds cannot be directly determined either by epidemiologic studies or laboratory tests with animals, it must be derived from the correlation found at higher doses. A common way to extrapolate this relationship is the linearization of the dose-response curve, which is considered a valuable solution as long as other information suggest a different correlation. The slope of the linearized part of the curve is called slope factor (SF), with (mg/kg/day)$^{-1}$ as unit (Phillips et al., 2008; Saponaro, 2015; USEPA, 1992).

The dose-response correlation for carcinogenic and non-carcinogenic substances is reported in Figure 1.

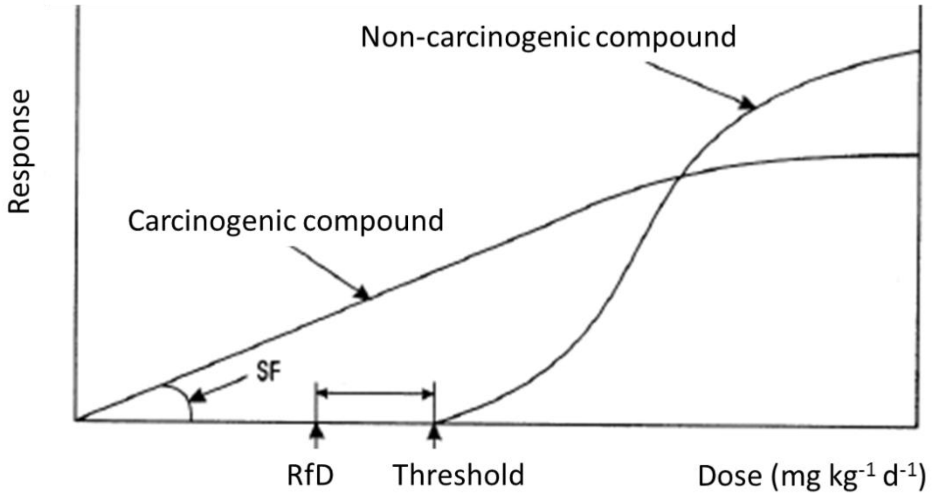

Figure 1: Carcinogenic and non-carcinogenic compounds dose-response correlation (Saponaro, 2015).

Uncertainty is present in all the stages of a risk assessment and in the case of environmental issues its precise quantification is an actual problem. Distinction must be made between epistemic uncertainty, due to lack of information, and aleatory one, consequence of the inherent variability of natural systems. The first step when dealing with uncertainty is its own identification. Even if it is clearly possible to reduce only the epistemic uncertainties collecting more data or performing further analysis, the identification of uncertainties can improve the quality of the whole study and insert the outcomes is a well-defined background. Uncertainty factors, as those reported before for human health risk, can be adopted to express the uncertainty and to provide a margin of safety (Critto et al., 2007; Gormley at al., 2011).

2.4 Risk management

The risk management is not a part of the risk assessment but it is briefly discussed here as the following step of the remediation process, when the risk is assessed as not acceptable.

Once risk is estimated as relevant and not tolerable, the decision-maker must choose one of the risk management options to terminate, mitigate, transfer, tolerate or exploit the risk, keeping in mind that the total neutralization of the risk is usually impossible. In order to select the best strategy to adopt, all the positive and negative aspects in an economic, environmental, technical and social contest must be taken into account. As a consequence, the following decision-making can result complex due to the trade-offs between these aspects. Also because of this, the involvement of public and stakeholders in the selection of the best option, can lead to positive effects in the efficiency of this stage (Gormley at al., 2011; Phillips et al., 2008; Saponaro, 2015).

After the appraisal of the options, the risk must be practically addressed in order to meet the objectives defined in the risk management strategy. All the actions put into practice must be clearly and unambiguously motivated. When this stage is completed, surveillance covers a fundamental role in monitoring possible variable circumstances at the site (Gormley at al., 2011).

The risk assessment procedure described and the considerations reported above are general. The approach to the risk can vary in different ways in different countries, as it will be observed in the following chapters where the procedures performed in Italy and in Sweden when dealing with polluted sites will be analyzed.

3 Risk assessment in Italy

The Italian risk assessment procedure for polluted sites is regulated, as part of the remediation process, by two official documents (Saponaro, 2016):

- Legislative decree (D. Lgs.) 152/06 – Part IV
- Legislative decree (D. Lgs.) 4/2008

Important definitions are present in these documents (D. Lgs. 152/06; Saponaro, 2016):

- CSC (threshold concentration for contamination): these concentrations are those above which a site-specific risk assessment must be performed. It must be specified that they are different for soil (and the associated land use) and groundwater and that are not risk-based;
- CSR (threshold concentration for risk): these concentrations are calculated as result of the risk assessment and represent the acceptable level of pollution for the site. If they are exceeded, remediation or securing actions must be adopted;
- Potentially polluted site: a site where one or more concentrations are found above the CSC;
- Polluted site: a site where one or more concentrations are found above the calculated CSR;
- Remediation: reduction of the pollutants concentration to a value below or equal to the CSR in soil and groundwater;

Usually, the CSRs are higher than the CSCs, so less strict, but in the case of the (Polycyclic Aromatic Hydrocarbons) PAHs and As, it is the opposite. Therefore, even if the CSRs for PAHs and As are calculated through a risk assessment, the remediation targets are usually replaced by the CSCs (Saponaro, 2015).

A schematic representation of the whole Italian methodology, from site characterization to soil remediation, is schematically represented in Figure 2.

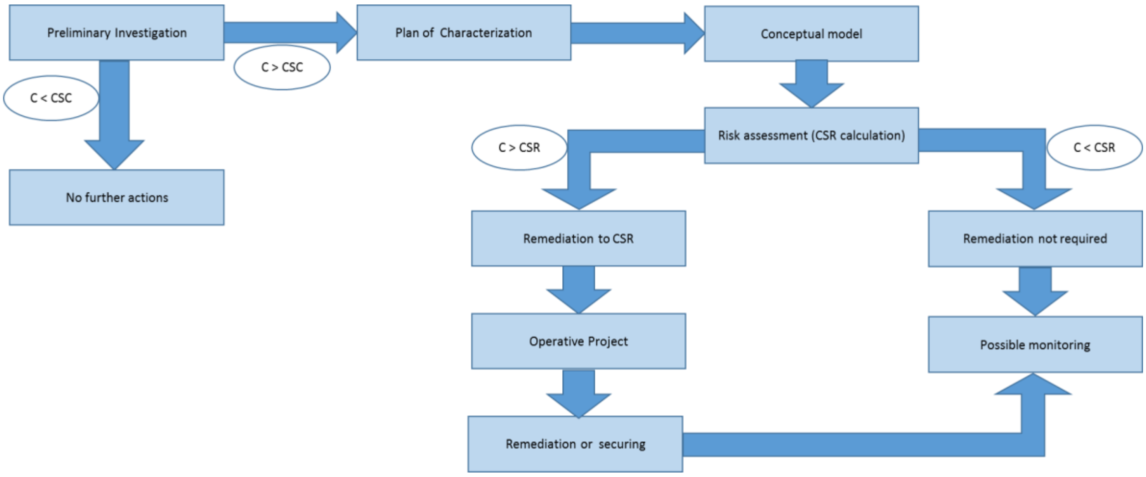

Figure 2: Schematic representation of the risk assessment methodology in Italy (Saponaro, 2015).

As explained before, in order to perform the risk assessment, a characterization of the site is necessary. In the following paragraph, the Italian procedure will be shortly described as fundamental preliminary step of the risk assessment.

3.1 Site characterization

The characterization of the site has the two following main aims: 1) the determination of the pollution of the site (concentration and spatial distribution of pollutants) and 2) the acquirement of the site-specific values for the physical-chemical parameters of soil and groundwater that affect the transport of pollutants.

When dealing with the definition of the features of the contamination the aspects that have to be addressed are:

- Identification of the primary sources of pollutions (that must be removed), e.g., leaching tanks, etc;
- Identification of the secondary sources of pollutions, i.e. the environmental matrices that are contaminated.

The secondary sources of pollution can be constituted by:

- surface soil (down to 1 m depth from ground surface);
- deep soil (from 1 m below ground surface to the groundwater level);
- groundwater.

The two first matrices form the unsaturated zone, the third one the saturated zone (APAT, 2008).

The dimension of the pollution, the potential pollutants and the concentrations are fundamental information that must be gathered to properly characterize the secondary sources of pollution (APAT, 2008; Saponaro, 2015).

The first step of the site characterization is constituted by the environmental investigations. These researches are different in the case of previously measured concentrations above the CSC and when there are no certainties about the level of pollution (APAT, 2008; Saponaro, 2015). When values above the CSC of soil and groundwater were already found at the site, the Plan of Characterization (PdC) is drafted, whereas preliminary investigations are performed if concentrations above the CSC were not detected yet. The soil CSCs to be considered are different depending on the land use that must be distinguished between residential/recreational and industrial/commercial.

The PdC must contain many information (APAT, 2008; Saponaro, 2015). The first fundamental part of the PdC is the historical reconstruction of the site which is constituted by all the data about the studied area, i.e. site evolution in the past (constructions, pavements etc.), incidents, analytic set (list of manufacturing processes, raw materials, by-products and leftovers) and works performed (substitutions of pipes etc.). Also the collection of environmental historical data about the site itself must be present in the drafted PdC (i.e. stratigraphy, depth of the aquifer, groundwater’s flow direction and chemical data about soil and groundwater). A preliminary conceptual model that defines the potential sources of contamination, based on the historical reconstruction, the features of the environmental matrices affected by the activity in the area, based on available historical data, and the possible migration pathways to receptors, must be included in the PdC as well. The last part of the PdC is constituted by the Plan of the Investigations (PdI). The PdI defines the environmental matrices to be analyzed, the typology, the depth and the points of the performed investigations, the sampling procedures and the parameters and/or compounds to be analyzed and the way the analysis must be performed.

The D. Lgs. 152/06 defines two main strategies to decide the location of the sampling points (APAT, 2008; Reteambiente, 2016; Saponaro, 2015):

- “reasoned location”: the sampling is performed on the base of the available historical data and the information gathered by the preliminary conceptual model. The aim of investigations is to verify the hypothesis of the model about extension, level and presence of pollution. This approach is suggested for complex sites where it is possible to identify the most vulnerable areas and the probable sources of contamination;
- “systematic location”: the sampling points are defined following statistic calculations or randomly, e.g., using a grid. This choice is recommended when the dimension of the site or the historical information about it are not sufficient to identify the most vulnerable areas and the probable sources of contamination.

According to the features of the site, both the two approaches can be adopted as represented in Figure 3. In particular, the presence of buildings and/or activities at the site affects the number and the location of the sampling points. Moreover, the use of indirect investigations, as soil gas sampling, can guarantee a better location of the sampling points. Samples can also be taken in the nearby of the site to determine the background level of contaminants in the soil matrices (Reteambiente, 2016; Saponaro, 2015)

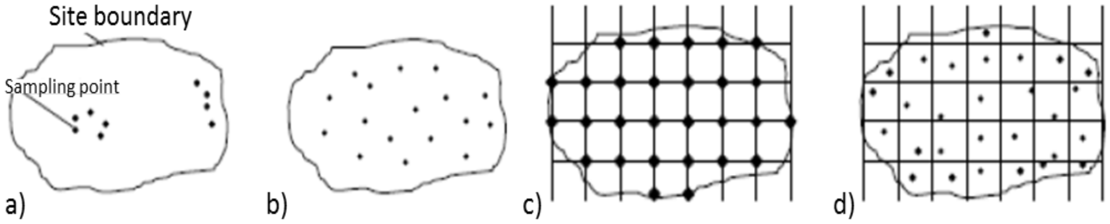

Figure 3: Possible criteria in the location of sampling points (Saponaro, 2015): a) reasoned location, b) random location, c) systematic location with grid, d) systematic random location.

When the characterization of the site is completed and a definitive conceptual model is developed, the risk assessment can be performed.

3.2 Conceptual model

In order to properly assess the risk associated to the pollution at the site of study, the values for the required input parameters must be fixed. The document “Criteri metodologici per l’applicazione dell’analisi assoluta di rischio ai siti contaminati” by APAT (2008), reports the procedure to develop the conceptual model for a polluted site.

In particular, it is of interest to determine the geometry of the polluted area and the source representative concentration (CRS). The secondary source of pollution, both in the saturated and unsaturated zone, is assumed to always have a minimal areal extension of 2500 m^2 (50 m x 50 m) with the exception of specific cases as gas stations (APAT, 2008).

The procedure to determine the geometry of one or more sources of pollution inside a contaminated site can be summarized as follows:

- Subdivision of the area of interest in polygons according to the sampling criteria adopted, i.e. Thiessen polygons for reasoned sampling and regular cells for systematic sampling;
- Determination of the spatial continuity of the source of pollution;
- Neighborhood analysis.

This procedure must be performed for each polluted matrix (APAT, 2008).

The source of pollution is identified as the area constituted by the contiguous cells or polygons where the CSC is exceeded at least for one contaminant. If more sources of pollution are identified, the risk assessment must be performed for each of them (APAT, 2008).

The cells or polygons where $C < CSC$ might have to be included to determine the polluted area and the CRS. In particular, a cell or polygon is included in the source of pollution if all or the majority of the cells or polygons surrounding it have a $C > CSC$. The cells/polygons that are included in the polluted area with this procedure have to be considered clean when doing the neighborhood analysis for a neighboring cell/polygon. The most ambiguous case is when the number of surrounding cells/polygons with $C < CSC$ and of those with $C > CSC$ is the same. The conservative solution contemplates the inclusion of the analyzed cell/polygon in the source of pollution (APAT 2008; Saponaro, 2015).

The concentration of each contaminant in each sampling point must be checked to distinguish the subareas of pollution. Usually the cells where an inorganic contaminant exceeds the guideline are all merged together. If it is possible to prove that the primary sources of pollution that caused the presence of the contaminants found on site are different, independent secondary sources must be identified for each pollutant (APAT, 2008; Saponaro, 2015).

Once the shape of the secondary source(s) of pollution is determined, the rectangle that better includes all the cells/polygons where C > CSC is used as input for the assessment of the risk. More specifically, two rectangles must be drawn (Saponaro, 2015):

- for the sanitary risk, with one side parallel and the other one perpendicular to the main wind direction;
- for the risk posed to groundwater, with one side parallel and the other one perpendicular to the main groundwater flow direction.

A unique secondary source is defined as (APAT, 2008):

- a continuous secondary source that might pose risk to the same receptor in the same area of exposure;
- a patch worked secondary source that it is impossible to divide in different polluted sources (Figure 4).

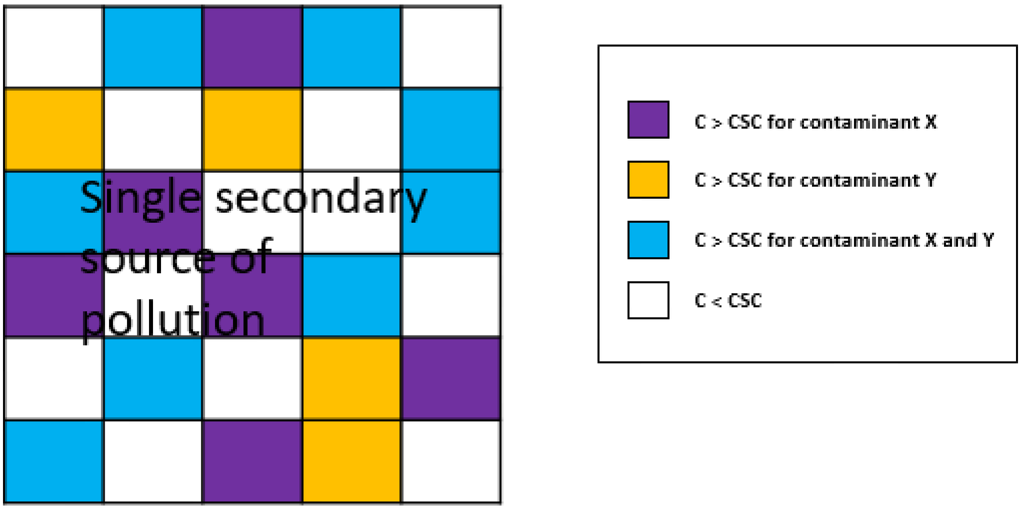

Figure 4: Example of single secondary source of pollution from patch worked contamination.

When dealing with the features of the polluted site, the representative value to be considered in the risk assessment is (APAT, 2008):

- the most conservative value, i.e. the lowest or the highest depending on the considered parameter, if less than 10 data are available;

- in the case of 10 or more data, the Lower Confidential Limit at 95% (LCL95%) if the lowest value is the most conservative, or the Upper Confidential Limit at 95% (UCL95%) if the highest values is the most conservative.

In the case of the CRS, for example, the concentration to be adopted will be either the greatest one or the UCL95% depending on the number of available data (APAT, 2008; Saponaro, 2015).

3.3 Risk assessment

A risk assessment can be performed before, during or after the remediation or securing of the site.

The aim of a risk assessment can be of two main types (Saponaro, 2015): to determine if the presence of pollution could pose harm to the receptors or to define the objectives of the remediation required for the site. In the former case, a "forward" approach is applied, in the latter a "backward" approach is adopted. An example of the second procedure is constituted by the CSR themselves that, fixed an acceptable level of risk, represent the remediation target in each environmental matrix. The two different approaches are schematically represented in Figure 5.

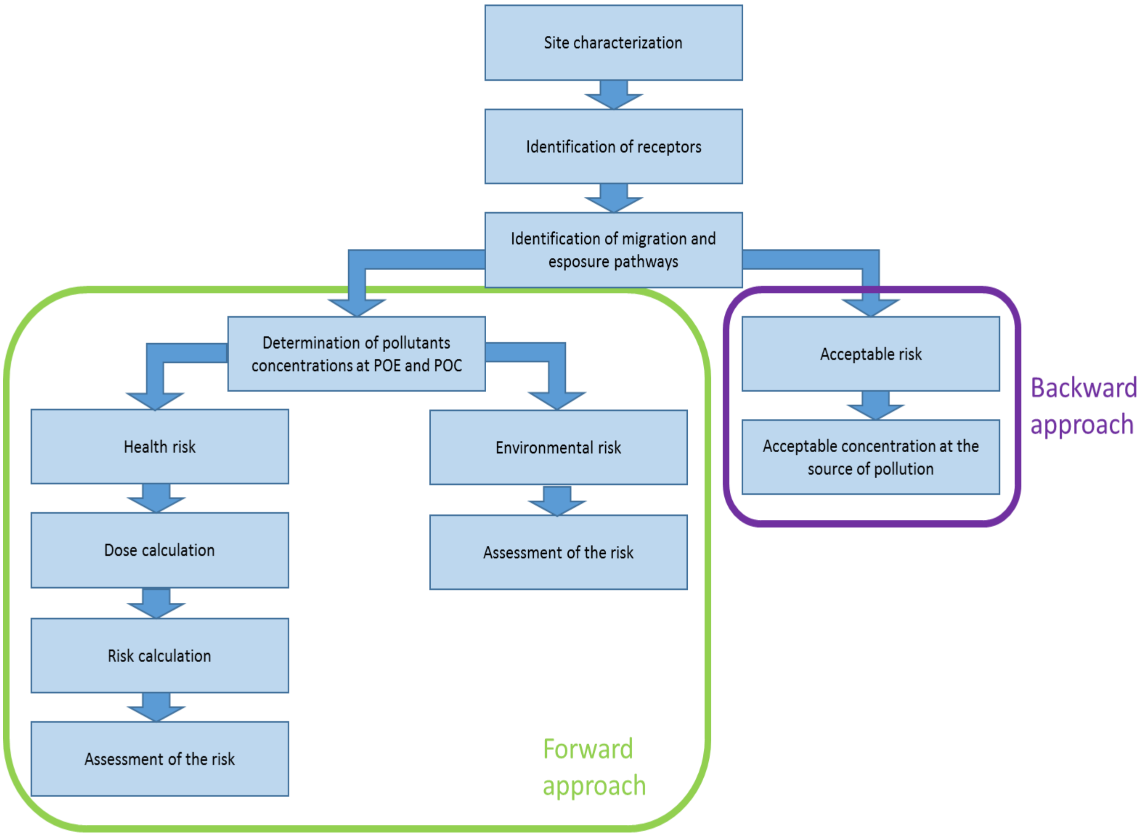

Figure 5: ”Forward” and “backward” risk assessment.

According to the adopted standards, the risk assessment is always performed only considering the secondary sources of pollution (APAT 2008).

3.3.1 Identification of receptors

In order to calculate the human health risk three classes of receptors must be distinguished: residents, workers and attenders for recreational purposes. The first and the third type of receptors are further divided in children and adults. While workers are usually considered as receptors only on site (an exception could be a polluted abandoned site surrounded by a mall or industrial areas to which might be associated a risk to the off-site workers), residents and attenders are taken into account as off-site receptors as well. These distinctions, summarized in Table 1, are important because different exposure scenarios take into account the different exposure frequencies of the classes (high for resident and low for attenders) and also the bodyweight of the receptor (greater for adults and lower for children) (APAT, 2008; Saponaro, 2015). The subdivision of human receptors in the different classes mentioned above, reflects the different susceptibility to the chemicals that they come in contact with (Figure 6). It must be specified, however, that the order of receptors proposed in Figure 6 can vary significantly depending on the site-specific parameters adopted (Saponaro, 2016). Therefore, when different receptors are found on or off-site the risk must be assessed for the most sensible one independently from the location. For example, if a worker is considered as a receptor but also residents off-site are likely exposed to the pollution, the risk must be assessed for a child resident off-site because more sensible than the worker.

Table 1: Classes of human receptors considered in the Italian risk assessment.

Receptor	**Sub-classes**	**Location of the receptor**
Resident	- Child - Adult	- On site - Off-site
Worker	- Adult	- On site
Attender for recreational purposes	- Child - Adult	- On site - Off-site

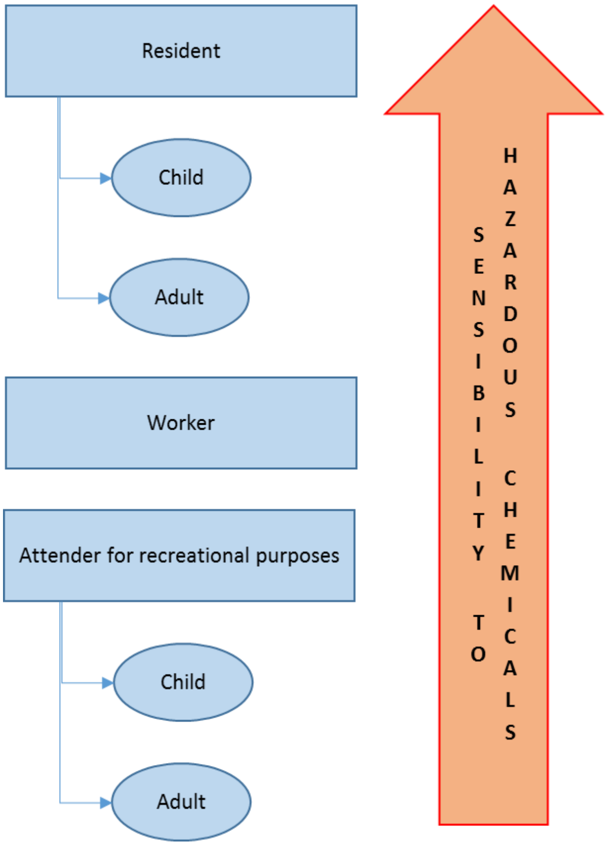

Figure 6: List of human receptors from the most to the less sensible to exposure to hazardous chemicals.

When water resources are considered, groundwater is the receptor usually considered (Saponaro, 2015).

3.3.2 Identification of migration and exposure pathways

As previously explained in the report, the distinction between migration and exposure pathways is due to the different receptors considered, i.e. water resources and humans.

Considering groundwater, the possible migration pathways are:

- Soil leaching, when the source of pollution is in the unsaturated soil;
- Transport of pollutants to the POC (Point Of Conformity), when the source of pollution is in the aquifer.

The exposure pathways of interest in the assessment of human health risk are named "direct", when the receptor comes in contact with the secondary source of pollution, and “indirect”, when the contact occurs after the migration of the contaminant to the receptor. The direct exposure pathways considered are accidental ingestion of soil and dermal contact with soil, while the indirect ones are inhalation of particulate matter and inhalation of vapors (indoor and outdoor). Moreover, the distinction between source of pollution in soil, deep soil, i.e. the unsaturated soil at a depth greater than 1 m, and groundwater affects the exposure pathways (Table 2). The indirect exposure pathways have to be considered when also off-site receptors are detected because the transport of pollutants through air or particulate matter can cover a long distance beyond the borders of the site.

Table 2: Exposure pathways.

Exposure pathway	**Type of pathway**	**Location of the source of pollution**	**Exposure**
Accidental ingestion of soil	Direct	Soil	On site
Dermal contact with soil	Direct	Soil	On site
Inhalation of particulate matter	Indirect	Soil	On site Off-site
Inhalation of vapors	Indirect	Soil Deep soil Groundwater	On site Off-site

The identification of the pathways that are relevant for the case of study is important because it bears on the calculation of the concentrations of pollutant at the POC and the Point Of Exposure (POE). The POC is the point where the original conditions (ecological and chemical) of the site must be guaranteed. Usually, the POC is located at the legal boundary of the site downstream the groundwater flow The POE is the point where a human receptor is exposed to a certain pollutant (Reteambiente, 2016).

The probability of the exposure to occur is assumed to be equal to 1, with a sure contact between receptor and pollutant (Saponaro, 2015).

The assessment of the risk requires site-specific values, when available, to perform a realistic simulation. The features of the case-scenario that can be modified by the performer of the risk assessment are reported in Table 3.

Table 3: Features of the polluted site that can be modified with site-specific values.

Risk object	**Site-specific features**
Humans	Exposure pathways (also off-site) Type of receptors Exposure parameters (bodyweight, exposure time, exposure frequency and exposure entity for each exposure pathway) Outdoor and Indoor environment parameters
Groundwater	Leaching from contaminated soil POC > or = 0
Humans and Groundwater	CRS Saturated and unsaturated zone hydrogeological properties

3.3.3 Pollutants concentrations at POE and POC

The concentration at the POE and POC can be directly determined but, when this is not feasible, models are used to simulate the migration of pollutants from the source of contamination to the POE and the POC (Saponaro, 2015). When a different exposure or migration pathway is considered, the calculation of the concentration at the POE or POC varies as well.

In the case of direct exposure pathways, the concentration at the POE is the same of the source of pollution and is previously determined during the characterization of the site. When indirect exposure is considered, the methodology to determine the concentration at the POE leans on the use of models. For inhalation of particulate matter and vapors outdoor, the box model is considered (Saponaro, 2015). In order to simulate the migration of particulate matter and vapors off-site, the gauss model is applied.

The simulation of the migration of pollutants must be as realistic as possible and in order to achieve a reliable approximation of the process all the environmental parameters that are affecting the transport of pollutants in the atmosphere and in the soil have to be quantified. For example, physical features and hydrogeology of the soil as well as climatic information must be analyzed. If a precautionary approach is adopted, the concentration at the POE and POC can be assumed equal to the one of the source of pollution (Saponaro, 2015).

3.3.4 Dose calculation for health risk

Once the pollutants concentration at the POE is determined, the chronic daily intake (CDI) for a generic pollutant *j* and an exposure pathway *i* can be estimated using the following general formula:

$$CDI_{j,i} = \frac{C_{POE_{j,i}} \times CR_i \times EF \times ED}{BW * AT} \quad [\frac{mg_{pollutant}}{kg_{bw} * d}]$$

where:

- $C_{POEj,i}$ = Concentration of the pollutant *j* at the POE in the environmental compartment associated to the exposure pathway *i*
- CR = contact rate, i.e. the daily volume of polluted environmental matrix taken [m^3/d]
- EF = exposure frequency, i.e. yearly contact frequency between the receptor and the polluted environmental matrix [d/year]
- ED = exposure duration, i.e. years of exposure [year]
- BW = bodyweight, with an average value of 70 kg for the adults and 15 kg for the children [kg_{bw}]
- AT = averaging time, i.e. time gap in which the negative effects of the contact with the pollutant occur [d]

The AT has a different value according to the toxicity of the chemical considered. If the pollutant has systemic negative effects, i.e. carcinogenic, mutagenic and teratogenic, the exposure is averaged using the average lifetime of an individual, i.e. 70 years. The AT for chemicals with local toxic effects, i.e. effects that are limited to the organ that absorb the compound, is instead stablished as equal to the actual exposition, i.e. posed equal to ED (Saponaro, 2015; APAT, 2008).

When the CDI of a pollutant which has both toxic and systemic effects, e.g., benzene, is estimated, the calculation has to be repeated twice, one for each property.

3.3.5 Health risk calculation and assessment

The estimated corresponding dose for each exposure pathway must then be integrated with the toxicological properties of the pollutant that are expressed by the dose-response correlation.

The information required when assessing the risk posed by a chemical with toxic properties is the RfD or the Acceptable Daily Intake (ADI) expressed as mg of pollutant per kg of bodyweight per day. The RfD is estimated considering the threshold value, beyond which negative effects are reported, and dividing it by a safety factor between 1 and 10000 which takes into consideration the approximations adopted. In fact, as explained before, the dose-response correlations are drawn with ecotoxicological experiments using laboratory animals or with historical data about disease in the population (Saponaro, 2015).

For a contaminant j with local toxic effects, the Hazard Index (HI) is defined as:

$$HI_j = \sum_i \frac{CDI_{j,i}}{RfD_{j,i}} \ [-]$$

Where:

- $CDI_{j,i}$ is the chronic daily intake of *j* through the exposure pathway *i*
- $RfD_{j,i}$ is the reference dose of *j* considering the exposure pathway *i*

In the case of more pollutants, the overall HI is called HI_{mix} and is expressed as the sum of the HIs for each single chemical:

$$HI_{mix} = \sum_j HI_j \ [-]$$

In the case of substances with systemic effects, the dose-response correlation is established considering the added probability, with respect to the one characterizing the "normal" conditions, that the chemical poses its negative effects as a consequence of a daily intake extended to the whole lifetime of the individual. In the practical uses, the dose-response curve is assumed as linear. The consequence of this simplification is the adoption of the SF (kg_{bw}*$d/mg_{pollutant}$), whose values are reported in Italy by the ISS-

ISPESL (Istituto Superiore della Sanità – Istituto Superiore per la Prevenzione E la Sicurezza Sul Lavoro) database (Saponaro, 2015).

For a contaminant j with systemic effects, the risk (R) is defined as:

$$R_j = \sum_i CDI_{j,i} * SF_j \ [-]$$

Where:

- $CDI_{j,i}$ is the chronic daily intake of *j* through the exposure pathway *i*
- SF_j is the carcinogenic potential of *j* associated to the exposure pathway *i*

In the case of more pollutants, the overall R is called R_{mix} with the assumption of an additive interaction between substances:

$$R_{mix} = \sum_j R_j \ [-]$$

All these parameters should be calculated for all the receptors but it is clear that, if the most sensible receptor is considered when assessing the risk, the ones left will be ensured as well.

According to the D. Lgs. 152/06 the conditions to be respected are:

$$HI_{mix} \leq 1$$

$$R_j \leq 10^{-6} \ for \ all \ the \ j$$

$$R_{mix} \leq 10^{-5}$$

For systemic effects, the acceptable incremental risk is 1 case out of one million people for one single substance while 1 out 100 000 people when the receptor is exposed to more contaminants. This variation takes into account that the exposure to multiple hazardous chemicals is more likely to cause adverse effects on human health.

Both the single and cumulative conditions on HI and R has to be respected. However, mathematically speaking, when the receptor is exposed to less than ten contaminants the respect of the condition on R_j ensures that the one on R_{mix} is satisfied (APAT, 2008; Saponaro, 2015).

3.3.6 Groundwater risk assessment

The environmental risk assessment is not defined in Italy. The risk posed by the pollutants to the environment is in fact assessed in an easier way than the health risk one and considering only groundwater. The risk is estimated comparing the concentration of the pollutant in groundwater at the POC with a value established as acceptable by the experts or the controlling authority. In Italy it is compulsory to have a concentration of the pollutant at the POC below the CSC value defined by the D. Lgs. 152/06 for groundwater. If a well for human use is present, the POC is located there.

3.3.7 After risk assessment

If the risk is assessed as not tolerable, risk management actions must be put into practice. At this point of the procedure, with the links between source of pollution, exposure/migration pathways and receptors that have been clearly defined, actions to reduce the risk at acceptable level can be aimed at (Saponaro, 2015):

- The removal or reduction of the concentration of pollutant at the source;
- The interruption of one (or more) exposure/migration pathway(s).

These two aims can be targeted using remediation techniques or securing the pollution. Once these procedures are concluded, a continuous monitoring of the site is usually performed to detect eventual variations in the current safe situation.

4 Risk assessment in Sweden

The Swedish Environmental Protection Agency (SEPA) indicates the risk assessment as a procedure constituted by several steps to determine if a site is contaminated and if remediation to reduce the associated risk is needed. SEPA defines a contaminated site as one in which the detected contaminant levels are above the background concentrations (NATURVÅRDSVERKET (2), 2009).

The main steps of the Swedish risk assessment are reported in Figure 7 (Norrström, 2015; Gustaffson, 2016).

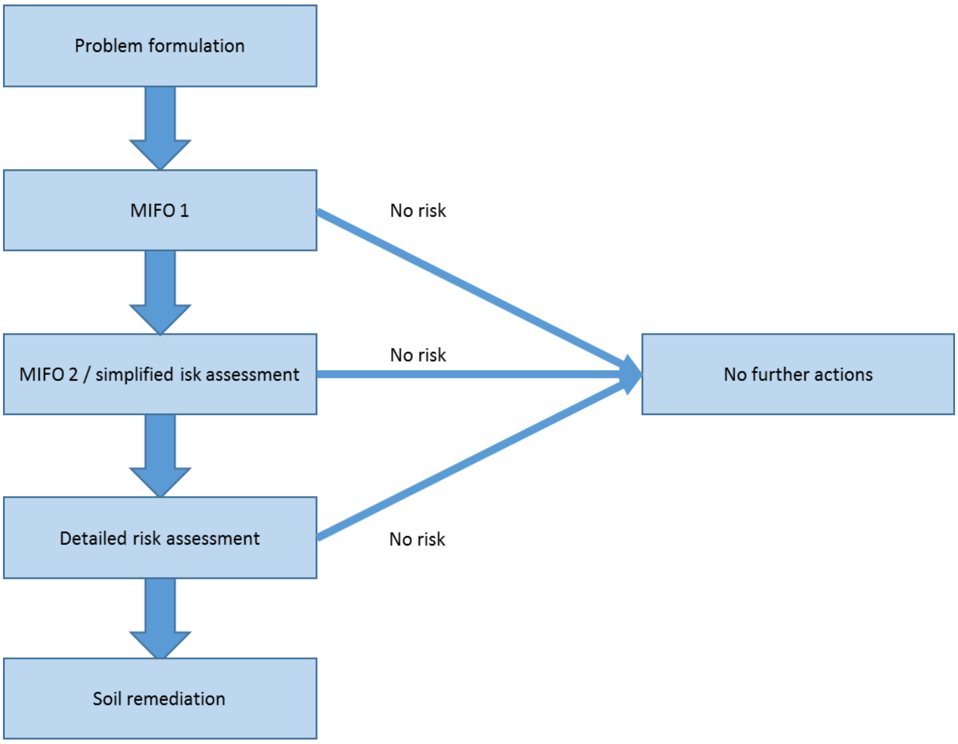

Figure 7: The risk assessment methodology in Sweden (Norrström, 2015; Gustaffson, 2016).

MIFO, in Swedish, stands for Methods for Inventories of Contaminated Sites and is the procedure to collect data and to define the requirements that the info of a contaminated site must meet. The MIFO is divided in two parts that together comprise the complete guidance for the inventory of contaminated sites (SEPA, 2002).

4.1 Problem formulation – MIFO phase 1

The problem formulation is the first step of the risk assessment that determines the scope of the study. The aim of this stage is to get a first impression of the contaminated area and if it can pose a possible risk considering the current and the planned land use. The phase one of the MIFO, i.e. a preliminary survey of the site without sampling, is included in the process of formulating the problem (Norrström, 2015; SEPA, 2002). The sources of pollution, the features of the contamination, the transport and the exposure pathways and the protected areas that might be affected by the pollution are qualitatively described. If new and relevant information becomes available during the risk assessment it might be necessary to revise the problem formulation and the conceptual model (NATURVÅRDSVERKET (2), 2009).

The problem formulation must include the following steps (NATURVÅRDSVERKET (2), 2009):

- Contextualization of risk assessment in time and space
- Description of the sources of pollution and pollution characteristics
- Description of the migration and exposure pathways
- Description of targets to be protected
- Description of future and possible scenarios
- Conceptual model formulation
- Identification of lack of information

4.1.1 Contextualization of the risk assessment

When contextualizing the risk assessment, the time horizon is fundamental, considering the present situation but also the impact associated to other important facilities and buildings nearby the site both in the medium (50 – 100 years) and long term (100 – 1000 years).

The spatial distribution, i.e. the boundaries of the site of study, and the pollution sources, that can be primary or secondary, has to be included (SEPA, 2002). The present and future land use must be evaluated as well, with the consequent level of protection required for health and environment. The environmental impact, with the individuation of the consequences of the polluted site on the current or future use of adjacent areas, has to be considered (NATURVÅRDSVERKET (2), 2009).

4.1.2 Description of the source(s) of pollution

The first aspect to be evaluated is which contaminants are present or suspected to be found at the site. The potential sources of pollution as well as the form in which chemicals are expected to be detected must be identified. The more the historical information about the previous activities at the site, the more detailed is the knowledge about the expected pollutants. Then, the chemical and physical properties of these contaminants are used to qualitatively assess:

- If pollutants have degraded and, if so, which are the properties of these chemicals;
- If pollutants can accumulate in the living organisms and, if possible, which would be the magnitude of the phenomenon;
- Which part of the environment would be impacted by the pollution, i.e. environmental compartment and level of the food chain, in the site of study and its surrounding;
- If toxic effects are expected to occur and if they are likely to occur directly, in the short term or after a long exposure.

Great effort must be aimed at those substances that are “prioritized” due to the dangerous environmental and/or health risk that they can pose. The chemicals that are present in the environment to an extent that the exposure to background levels might pose a risk, e.g., mercury, lead, cadmium, silver, PCBs (polychlorinated biphenyls) and dioxins, as well as PBT (Persistent Bioaccumulative Toxic) and vPvB (very Persistent and very Bioaccumulative) chemicals are examples of prioritized substances (NATURVÅRDSVERKET (2), 2009).

The form of the chemical can greatly affect its properties and toxicity might occur. An example is the inorganic arsenic which can be present in the pentavalent and trivalent forms, the former less toxic than the latter. Moreover, contaminants can be present in both inorganic and organic forms, as mercury which can be found as methyl mercury.

4.1.3 Description of exposure and migration pathways

The migration and exposure pathways are qualitatively described according to the available data. The chemical and physical properties of the pollution and the hydrogeological features of the site have to be determined in order to qualitatively assess the likelihood of a specific pathway to be relevant for the case of study (NATURVÅRDSVERKET (2), 2009).

The considered exposure pathways are different according to the use of the site. Two main types of land- use are defined (NATURVÅRDSVERKET, 1997):

- Land with sensitive use (KM), e.g., residential areas, land for agriculture or groundwater extraction etc.
- Land with less sensitive use without groundwater extraction (MKM).

Before, a third type of land use was included: less sensitive use with groundwater extraction (MKM GV), but was removed after revision (Norrström, 2015).

The exposure pathways for KM and MKM scenarios are reported in Table 4 (Elert, 2015).

Table 4: Exposure pathways according to the different land-use.

Exposure pathway	**KM**	**MKM**
Intake of soil	X	X
Dermal contact with soil/dust	X	X
Inhalation of dust	X	X
Inhalation of vapour (indoor and outdoor)	X	X
Intake of drinking water	X	X
Intake of plants	X	

The exposure probability is not considered in the Swedish procedure that assumes the phenomenon certain to occur, i.e. probability equal to 1 (SEPA, 1997).

The main migration pathways considered are:

- Leaching from soil to groundwater and surface water

- Transport in groundwater
- Transport in surface water
- Plant uptake.

4.1.4 Description of targets to be protected

The areas that might be affected by the pollution and that can be located both in the contaminated site or in the surroundings, have to be identified. The people that might be exposed to the pollution in the field or in the nearby areas must be identified and characterized. The present and future land use of the site is the factor that affects the most the groups of people to be considered. When dealing with the environment protection, it is necessary to gather information about ecosystem's structure connecting it with the features of the pollution in order to evaluate which are the environmental functions that have to be protected. The complexity of the ecosystem can make the assessment of which are the areas of protection difficult. The natural resources that are possible target of protection are groundwater, surface water and land ecosystem. As for the exposure pathways, the critical targets to be considered are different when the land-use changes, as reported in Table 5 (Elert, 2015).

Table 5: Critical targets to be taken into consideration according to the land-use of the polluted site.

Humans	**KM**	**MKM**
Residents	X	
Workers		X
Visitors		X
Neighbours		
Others		
Environment	**KM**	**MKM**
Soil ecosystem	X	X
Groundwater	X	X
Surface water	X	X
Animals	X	X

4.1.5 Description of future and possible scenarios

The knowledge of the different events that can be directly or indirectly caused by a contaminated area as consequences of short or long term variations is a useful resource in the assessment of the risk.

4.1.6 Conceptual model formulation

The problem description must be summarized in the conceptual model that describes the possible causal links between sources of pollution and receptors. At the beginning the level of detail of the model can be low and the more data are collected, the more precise the structure of the model becomes with the identification of the actual causal links. The complexity of the model can vary from the simple comparison with guidelines to more complex approaches. In Sweden, generic guidelines are used as first instrument to assess the potential risk posed by a polluted site (NATURVÅRDSVERKET (2), 2009).

4.1.7 Identification of lack of information

The development of a conceptual model is the best way to identify if some critical information is missing and which are the aspects the most affected by uncertainties. If present, the lack of data must be declared and explained, requesting further investigations (NATURVÅRDSVERKET (2), 2009).

4.2 MIFO phase 2

All the hypothesis about the contaminants expected on site and the exposition of humans and environment due to the supposed distribution of the pollution, are verified or refuted in the phase two of the MIFO. The phase two of the MIFO consists in a preliminary investigation of the site, and is performed in the case of sites for which supplementary inspections are required after phase one (Norrström, 2015; SEPA, 2002).

The first step of the MIFO 2 is constituted by the analysis or creation of a geological map that describes the features of the surface and that should be used as basis for planning the sampling criteria and to assess the migration of pollutants. Then, a sampling program is established which includes (SEPA, 2002):

- Media to be sampled and motivation of the choice;
- Location of samples and boreholes with motivation of the choice;
- Sampling method and motivation of the choice;
- Method for samples preparations and analysis to be carried out with motivation of the choice.

Then the sampling and the field investigations can be performed in order to gain more information about migration and actual contamination of the site. The number of samples can vary from case to case, with the principle that is better to have many instead of few. Those samples that are not selected for analysis are saved until the whole investigation is performed. Samples of soil, groundwater, surface water and sediments are taken to be further analyzed.

At the end of the MIFO 2, a comprehensive risk assessment can be performed, filling the form E, in order to preliminary establish the risk expected on the considered site. The graph reported in Figure 8 is used to evaluate the risk, with one to four horizontal lines for all the media at the site: groundwater, surface water, sediments and buildings and other constructions. On each line four points must be reported corresponding to hazard assessment (H), contamination level (C), sensitivity (S) and protection value (P).

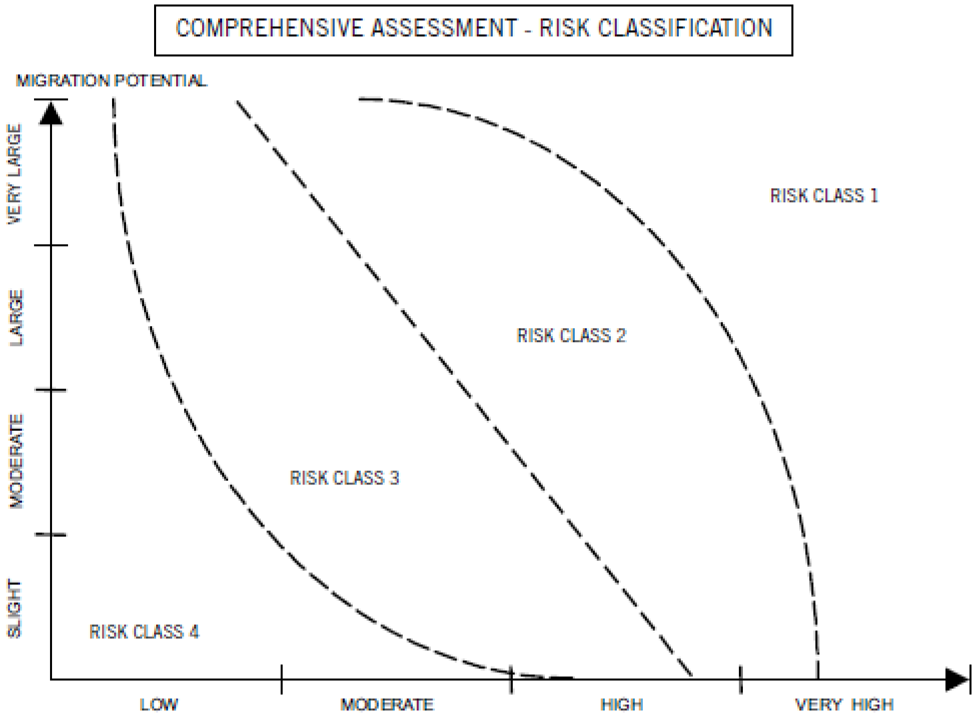

Figure 8: Diagram for schematic risk assessment (SEPA, 2002).

Hazard assessment consists in the evaluation of the potential harm that can be posed to human beings and environment by one or more substances. Contamination level is the amount of each pollutant in all the environmental compartments where it is present. Sensitivity is related to the risk that the pollution might pose to humans, while protection value is referred to the environment (SEPA, 2002).

On the vertical axis of the graph reported in Figure 8, the potential for migration determines the position of the horizontal lines for the considered compartments.

4.3 Simplified risk assessment

The simplified risk assessment is performed at the same stage of the MIFO 2 and consists in comparing the concentration levels of the contaminants found at the site with the corresponding generic guidelines or standards for environmental quality. If this is not sufficient, a more developed approach is adopted in the detailed risk assessment, where the level of contamination is compared to site-specific guidelines determined modifying the inputs to better represent the conditions at the polluted area (Norrström, 2015; Gustaffson, 2016; NATURVÅRDSVERKET (2), 2009).

The generic guidelines are established for all the two possible land-uses, i.e. KM and MKM. The basic principle to define the generic guideline values is to adopt the lowest concentration between the one based on human health and the one to protect the environment (NATURVÅRDSVERKET, 1997).

The procedure to determine the generic guidelines is schematically reported in Figure 9.

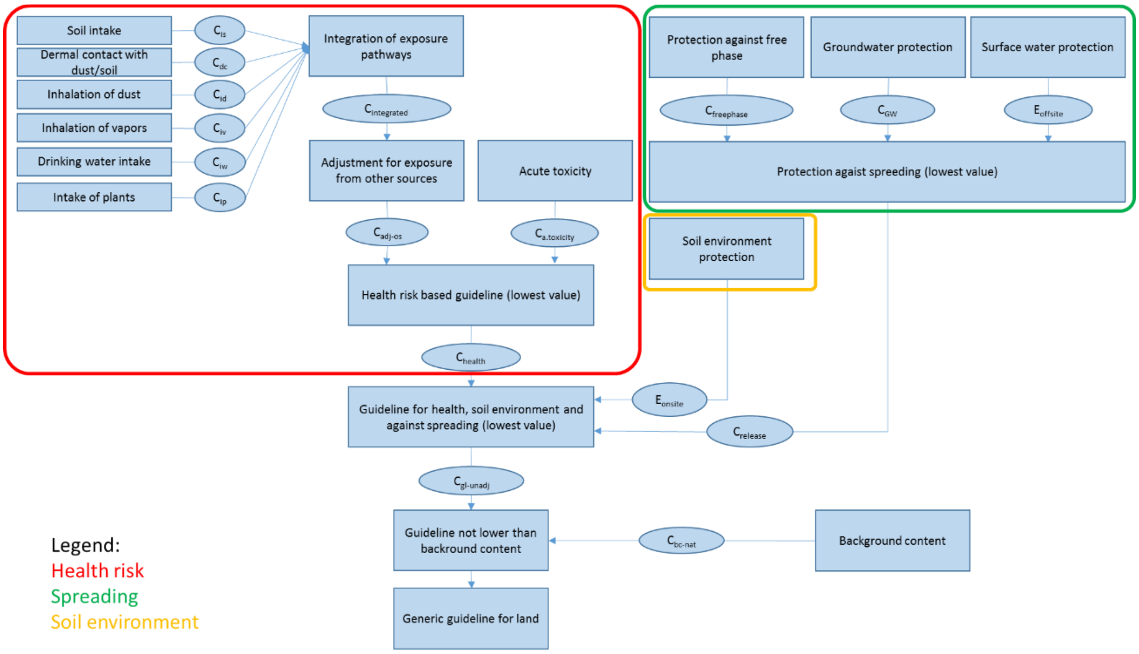

Figure 9: Schematic representation of the methodology to determine the generic guidelines for simplified risk assessment (NATURVÅRDSVERKET (3), 2009).

The Swedish generic guidelines for polluted land are used to indicate a level below which the risk is considered acceptable. Therefore, negative effects on humans, environment or natural resources are guaranteed to not occur. However, if the contamination level exceeds the guidelines, risk is not always implied, due to the possible case-specific variations from the scenario adopted to determine the guidelines. The generic guidelines represent a recommendation, i.e. not legally binding values, and are not the remediation goal (Elert, 2015; NATURVÅRDSVERKET (3), 2009).

4.3.1 Human health based guideline

When chronic exposure occurs, as in the case of a risk assessment, the average daily exposure is estimated per kg of body weight and the reference soil concentration (C) is calculated, i.e. the soil contamination resulting in an exposure that correspond to the Toxicological Reference Value (TRV). The TRV corresponds to the TDI (tolerable daily intake) for non-genotoxic substances whilst it is equal to the risk based daily intake for genotoxic compounds. The risk level used for genotoxic chemicals is a lifetime excess cancer risk of 1 in 100 000 (10^{-5}). The chronic exposure for non-genotoxic substances is based on the estimated exposure of a child with a body weight of 15 kg. In the case of genotoxic chemicals, for which the average daily exposure corresponds to the integrated lifetime exposure, a time-weighted average of the exposure of a child (0-6 years) and of an adult (7-64 years) is used, with the body weight of a grown up assumed to be 70 kg (NATURVÅRDSVERKET, 1997).

A reference soil concentration is calculated for each exposure pathway. Since this value represents the level of soil contamination that gives an exposure equal to the TDI or risk based daily intake considering only that specific pathway, an integrated value has to be estimated. The integrated human health based guideline for soil is calculated using the following formula:

$$C_{INTEGRATED} = \sum_{i} Ci \ [\frac{mg}{kg}]$$

Where C_i is the reference soil concentration for the I exposure pathway. As explained before, the exposure pathways to be included are different in the case of KM and MKM areas.

The integrated health based guideline calculated as shown, corresponds to an estimated total exposure equal to the TDI or the risk based daily intake, but humans are also exposed to other sources than the polluted area, i.e. background exposure. Therefore, since the background exposure is included in the acceptable daily intake, i.e. TDI or risk based daily intake, a downward modification of the integrated guideline must be performed. Through this procedure, the sum of the calculated exposure from the site of study and the background exposure do not exceed the acceptable daily intake. The assumed background exposure adopted for lead, cadmium and mercury is 80% of the acceptable daily intake, 90% for PCBs and dioxins and 50% for the other contaminants (Elert, 2016; NATURVÅRDSVERKET (3), 2009).

The acute toxicity of the contaminants, in the sense of acute adverse effect as a consequence of the ingestion of relatively small amount of polluted soil, must be considered as well, if characterizing the pollutant. Examples of these contaminants are arsenic and cyanide. The biggest risk is posed to children that can swallow relevant amount of soil and that have a low body weight. The guideline for acute toxicity is calculated to protect a small child with a body weight (m_{child}) of 10 kg that swallowed 5 g of soil (m_{soil}) with the formula reported below:

$$C_{A.TOXICITY} = \frac{TDAE * m_{child}}{m_{soil}} \; [\frac{mg}{kg}]$$

Where the TDAE (mg/kg) is the tolerable dose for acute effects for the considered contaminant (NATURVÅRDSVERKET (3), 2009).

The lowest between $C_{INTEGRATED}$ and $C_{A.TOXICITY}$ is adopted as health based guideline C_{HEALTH}.

4.3.2 Guideline for protection from diffusion

Three guidelines are determined considering three aspects that affect the spreading of the pollution: the presence of the contaminant in free phase, in groundwater and in surface water.

The impurities in free phase can lead to a fast spreading of the contaminant in the surrounding area and the concentration of contaminant in the soil ($C_{FREEPHASE}$) that can pose issues related to the presence in free phase is calculated as:

$$C_{FREEPHASE} = C_{sol}\left[K_d + \frac{(\theta_w + \theta_a H)}{\rho_b}\right] [\frac{mg}{kg}]$$

Where:

- C_{sol} is the solubility of the contaminant in water [mg/l]
- K_d is the soil/liquid partition coefficient [m^3/kg]
- θ_w and θ_a the volumetric water and air content respectively [-]
- ρ_b dry bulk density [kg/m^3]
- H is the Henry's constant [-]

It is important to protect groundwater downstream the polluted area, when it is considered a critical target for the considered site. The acceptable concentration of pollutant in soil (C_{GW}) in order to not pose risk to groundwater is calculated as:

$$C_{GW} = \frac{C_{crit-gw}}{DF_{gw-protect} * CF_{water-mob}} [\frac{mg}{kg}]$$

Where:

- $C_{crit-gw}$ is the criteria for the protection of groundwater [mg/l]
- $DF_{gw-pretect}$ is the dilution factor pore water-groundwater [-]
- $CF_{water-mob}$ the factor for pollution distribution between soil and water [kg/l]

The value for protection of groundwater is usually based on drinking water standards from WHO (World Health Organization). When a drinking water standard is missing, it can be calculated considering the TDI associated to the consumption of drinking water. In practice, the $C_{crit-gw}$ is determined as 50 percent of the drinking water standard. In the case of KM, an imaginary well at which groundwater must be protected is posed on site, while for MKM scenarios the groundwater protection is ensured at 200 m downstream from the site (Elert, 2015; Elert, 2016; NATURVÅRDSVERKET (3), 2009).

The protection of surface water must be considered as well, calculating the concentration of contaminant in soil ($E_{off\ site}$) to which correspond an acceptable presence of the same substance in the surface water using the following formula:

$$E_{off\ site} = \frac{C_{crit-sw}}{DF_{sw} * CF_{water-mob}} \left[\frac{mg}{kg}\right]$$

- $C_{crit\text{-}sw}$ is the criteria for the protection of surface water [mg/l]
- DF_{sw} is the dilution factor pore water-surface water [-]
- $CF_{water\text{-}mob}$ the factor for pollution distribution between soil and water [kg/l]

The $C_{crit\text{-}sw}$ value is set in order to not cause negative effects on plants and animals and it is usually below drinking water standards. Therefore, the protection of surface water environment will often ensure the human health to not be harmed by the consequences associated to the exposure to drinking water (NATURVÅRDSVERKET (3), 2009).

The strongest assumptions in the protection of surface water is the complete mixing. Therefore, the model results reliable only in the case of small basins or streams (Elert, 2015).

The lowest between $C_{FREEPHASE}$, C_{GW} and $E_{off\ site}$ is the guideline associated to the protection against the spreading of the contaminant ($C_{release}$).

4.3.3 Guideline for protection of soil environment

The guideline for protection of soil environment (E_{onsite}) is determined for KM and MKM, respectively E_{KM} and E_{MKM}. The objective of this benchmark for KM is to guarantee the preservation of the ecological processes naturally occurring in the soil matrix, e.g., metabolism of nutrients and soil respiration. In the case of MKM the aim of the guideline is to ensure that the land will support the ecological functions required in that specific land use, e.g., cultivation of ornamental plants, grass and other vegetation (Elert, 2016). The guideline values are based on dose-response ecotoxicological studies on soil species with the No Observed Effect Concentration (NOEC) as primary data, i.e. concentration of the chemical at which no adverse effects are observed. When enough data are not available, safety factors are used (NATURVÅRDSVERKET (3), 2009).

In the case of Sensitive Land Use, the guideline is established in order to protect the 75 percent of the terrestrial species. Due to the use of the NOEC to determine the guideline, it is possible to state that the preservation of the 75 percent of the species doesn’t mean that 25 percent of them will be negatively affected, hence, the resulting protection may be even greater than expected. If Less Sensitive Land Use is considered, the guideline is determined so that the 50 percent of the terrestrial species is protected from adverse effects (NATURVÅRDSVERKET (3), 2009).

4.3.4 *Final Guideline Value*

The lowest between C_{HEALTH}, E_{ONSITE} and $C_{RELEASE}$ is the generic guideline for protection of health, soil environment and against spreading ($C_{gl\text{-}unadj}$). This value is then compared to the background concentration of the contaminant ($C_{bc\text{-}nat}$) so that the guideline doesn't result lower than the level due to natural and diffuse anthropogenic sources (NATURVÅRDSVERKET (3), 2009). The final value is the actual generic guideline of a specific contaminant for polluted soil.

4.4 Detailed risk assessment

A detailed risk assessment can be performed in the case the evaluation of the risk in the simple risk assessment is not considered fulfilling the quality standard required for the case of study. This could be the case of an extensive and complex contamination that affects multiple media or the deviation from the generic conditions of KM and MKM scenarios. If the uncertainties about the risk are considered very relevant in the determination of the outcomes of the results of the risk assessment, it is necessary to perform a detailed one. A possible method to perform a detailed risk assessment is to determine site-specific guidelines to evaluate the level of pollution without using generic data as inputs. In fact, a major effort in modelling and measuring characterizes the detailed risk assessment (NATURVÅRDSVERKET (2), 2009).

When dealing, for example, with the spreading of the contaminant, studies on leaching, sorption, degradation, transformation and transport of the contaminant via groundwater, air and sediments must be performed. The risk posed to soil environment can be made more site-specific by biological and ecotoxicological tests. The interaction that might occur between chemicals when assumed must be taken in consideration as well using, for example, safety factors and it has to be analyzed with biological surveys and ecotoxicologial experiments (NATURVÅRDSVERKET (2), 2009).

Due to the amount of analysis required and to the lack of the instruments to perform a complete detailed risk assessment, the site-specific guidelines determined in this study will not be based on exotoxicological or biological test. For the same reason, degradation and transformation of contaminants, as well as interactions between them will not be considered.

4.4.1 Site-specific guidelines

The operation of comparing the levels of pollution with the generic guidelines can be quickly performed once all the necessary data about pollution are collected. However, it is possible that the assumptions in the model for the generic guidelines are not fitting the actual situation in the site of study. Therefore, site-specific guidelines can be calculated changing the inputs of the model. The features that can be made site-specific are reported in Table 6 (Elert, 2015).

Table 6: Features of the polluted site that can be modified with site-specific values (Elert, 2015).

Risk object	**Site-specific features**
Humans	Exposure pathways Exposure parameters (time on site, time indoor/outdoor, consumption) Transport parameters (leakage into houses, uptake in plants)
Soil environment	Not easy to be converted in site-specific due to KM & MKM
Groundwater	Leaching from contaminated soil Polluted area’s size Infiltration Distance to well Aquifer properties Gradient Water flow
Surface water	Leaching from contaminated soil Polluted area’s size Infiltration Distance to well Water discharge (for rivers) Water turn-over rate (for lakes)

In the determination of the health based guidelines, the inputs that can be modified to reproduce a specific situation are the exposure pathways considered and the exposure parameters. Depending on the land use, some exposure pathways can be in fact removed, but only after a detailed analysis of the circumstances. Exposure parameters as the time of exposure can be changed while usually others as ingestion of soil, water and plants are defined to protect critical targets and should not be modified

The most important parameter for the spreading of metals is the K_d. In order to calculate the site-specific guidelines for spreading protection, a site-specific K_d can be determined using soil samples from the site of study. For organic pollutants, the K_d can be estimated with the soil organic carbon-water partitioning coefficient (K_{oc}) and the fraction of organic matter in soil (f_{oc}). The Henry's constant (H) as well as the octanol-water partitioning coefficient (K_{ow}) are two other parameters of the pollutants that can be changed with site-specific values. If the transport to groundwater and its protection are considered, the dilution factor (DF) as well as hydrogeological properties of the soil, e.g., depth of the aquifer, porosity, groundwater flow, are relevant. For the protection of surface water, the discharge and turn-over rates in streams and lakes respectively can be modified to obtain more realistic guidelines. In the case of the guideline for the protection of soil environment, due to the ecotoxicological studies on which the model is based, it results difficult to fit it to site-specific conditions (NATURVÅRDSVERKET (3), 2009; Elert, 2015).

Once the site-specific guidelines are calculated, they are compared with the concentration of pollutants detected on site to estimate if risk might be posed to sensitive targets.

4.5 After risk assessment

Once risk is likely to occur due to the exceeding of the site-specific guidelines, the remediation actions have to be put into practice in order to prevent harm to people and environment. Since the guidelines are not legally binding, the remediation targets are discussed between the entity responsible for the site and the municipality, as well as the techniques to reach the acceptable levels of pollution (Elert, 2016).

5 Differences between Italian and Swedish procedure

As it appears from the previous chapters, there are many clear differences and some similarities between the Italian and the Swedish risk assessment's methodology, briefly summarized in Table 7.

A parallelism can be made, when considering the procedure to assess the risk in the two countries, between the CSCs and the generic soil guidelines and the CSRs and the site-specific soil guidelines respectively. In fact, the CSCs and the generic guidelines are not site-specific and are general "threshold" concentrations above which a further step is necessary. The CSRs and the site-specific guidelines, on the other hand, are calculated for the site and used to set the maximum level of acceptable pollution. However, the Italian CSCs are not risk-based, differently from the Swedish generic guidelines. Moreover, while the CSRs are the remediation goals for the site of study, the site-specific guidelines are not legally binding and are different from the remediation goals.

In both the procedures, these "threshold" pollution levels, i.e. CSCs and generic guidelines, are established considering two default land use scenarios, residential/recreational or commercial/industrial in Italy and KM or MKM in Sweden, that can be modified. In Italy is defined also a CSC for groundwater, that is valid for both the land uses.

Considering the exposure pathways and parameters, it has to be highlighted that the Italian procedure does not contemplate the intake of water and plants for health risk, that are instead included in the Swedish one. However, the groundwater CSCs, that correspond to the Italian drinking water standards, ensure the protection of human health from the intake of water. The exposure pathways, in the Swedish case, are established by default according to the land use of the site, as well as the targets to be protected, and the exclusion of one of them can be done only if site-specific guidelines are determined. In the Italian procedure, the exposure pathways as well as the targets are established case-by-case and they are included according to the secondary sources (soil, deep soil, groundwater) and type of the pollution. Moreover, in the Italian risk assessment, the inhalation of vapors and particulate matter off-site are taken into account as possible exposure pathways, while neglected in the Swedish procedure. The exposure time instead, is modified very rarely in the Italian methodology, while it is usually changed in the determination of the site-specific guidelines.

The possible receptors are different in the two procedures. In fact, five classes of human targets are identified in the Swedish approach whilst only three in Italy. The main difference is that the Swedish guidelines are calculated using the bodyweight of a child whilst the Italian procedure contemplates the protection of the most sensible human receptor. Therefore, if only workers are pointed as targets, only the adults and their average bodyweight are considered.

In the Italian risk assessment, the protection of groundwater must be ensured at the POC. The POC is usually located on the downgradient site's legal boundary. In the Swedish methodology the distance at which groundwater has to be protected is 0 m for sensitive land use and 200 m downstream the site for less sensitive land use. If a well for drinking water purposes is present, the groundwater must be protected at the well too. It is however possible to decide in which location the groundwater should be preserved from pollution giving satisfying motivations, e.g., protected groundwater area. In addition, the Swedish model identifies more environmental targets than the Italian one. In fact, not only surface water and groundwater, but also soil environment is taken into account as a critical entity. Moreover, the protection against the spreading of the contamination must be ensured. Biological surveys and ecotoxicological studies can be performed to assess the adverse effect of pollution on animal species and vegetation in the Swedish assessment, while in the Italian one they are not performed.

When considering the genotoxic risk, the two methodologies differ significantly one from the other. In the Italian approach the acceptable additional risk is equal to 10^{-6} for a single contaminant and 10^{-5} for the cumulative risk. As explained before, if there are no more than 10 pollutants on site the respect of the first condition satisfies the second as well. The Swedish procedure considers tolerable an additional risk equal to 10^{-5} for each contaminant, but the background exposure, as well as the acute ecotoxicity of the compound, if present, are considered to reduce the guideline for human health. For toxic chemicals, the Italian approach consists in ensuring the $HI_{mix} < 1$ while the Swedish guideline is determined through the concept of TDI.

In the Italian regulation, the PAHs are not divided in classes but each of them is independently analyzed as a single contaminant due to the dangerous effect that they can have on humans and environment. In Sweden instead, the PAHs are divided in three classes: high (PAH-H), medium (PAH-M) and low (PAH-L) molecular weight PAHs. The aromatic hydrocarbons are classified in three blocks, >C8-C10, >C10-C16 and >C16-C35, according to the Swedish regulation, whilst in Italy the subdivision in classes, either the TPHCWG or MADEP, is applied only if the CSC is exceeded for hydrocarbons C≤12 or C>12. The classes of aliphatic hydrocarbons differ as well in the two countries. The symbols ">" and "<" indicates the hydrocarbons with a number of carbon atoms greater or smaller than the following number.

Table 7: Differences between Italian and Swedish risk assessment procedures.

Aspect	**Risk assessment methodology**	
	ITA	**SWE**
"Threshold" pollution concentration	- CSC (generic) - CSR (site-specific)	- Soil generic guideline - Site-specific soil guideline
Risk-based "threshold" concentrations	Risk not considered in CSC	Risk considered in generic guidelines
Remediation goals	CSRs (legally binding) [1]	Different from generic and site-specific guidelines
Exposure pathways	Determined by the source location (pollution secondary source, site use)	Fixed for KM and MKM (can be excluded only for site-specific guidelines)
Intake of plants	No	If KM
Intake of drinking water	No	In KM
Exposure time	Usually not modified	Fixed for KM and MKM (can be modified only for site-specific guidelines)

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[1] In the case of PAHs, for which the CSR is lower than the CSC, the remediation goal becomes the CSC itself.

Table 7: Differences between Italian and Swedish risk assessment procedures.

Aspect	**Risk assessment methodology**	
	ITA	**SWE**
Human receptors off-site	Yes (inhalation of vapors and particulate matter)	No
Land use	Residential/Recreational Commercial/Industrial	KM MKM
Receptors	Residents Workers Visitors	Residents (KM) Workers (MKM) Visitors (MKM) Neighbors Others
Protection of groundwater	- At POC (site border) - At drinking water well if present inside the site	At: - 0 m (KM) - 200 m downstream (MKM) - drinking water well (if present)
Environmental targets	Groundwater	Groundwater Surface water Soil environment Animals
Biological surveys and ecotoxicological tests	No	Can be performed for site-specific guidelines

Table 7: Differences between Italian and Swedish risk assessment procedures.

Aspect	Risk assessment methodology	
	ITA	**SWE**
Genotoxic risk for humans	If number of contaminants < 10[2] - $R_j<10^{-6}$ for all the j-contaminants If number of contaminants > 10 - $R_j<10^{-6}$ for all the j-contaminants - $R_{mix}<10^{-5}$	Guideline for human health that considers: - $R<10^{-5}$ - Acute toxicity - Background exposure
Toxic effects on humans	$H_{mix}\leq1$	Guideline for human health based on TDI
PAHs and aromatic hydrocarbons	No categories: - Every single PAH - Sum of PAHs - Aromatic Hydrocarbons C9-C10 + Aromatic Hydrocarbons C11-C22 (in case of petroleum hydrocarbons exceeding of CSCs) [3]	3 categories: - High molecular weight (PAH-H) - Medium molecular weight (PAH-M) - Low molecular weight (PAH-L) - Aromatic Hydrocarbons >C8-C10 + Aromatic Hydrocarbons >C10-C16 + Aromatic Hydrocarbons >C16-C35
Interactions between contaminants	No	Not present but can be added

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[2] Once again, the Italian regulation for genotoxic risk does not change with the number of contaminants considered, but for less than 10 pollutants the respect of the R_j is mathematically sufficient to guarantee the R_{mix} as well.

[3] According to the MADEP classification.

All the differences here reported are significant in the sense that they surely affect the outcomes of the risk assessment procedures in both the Italian and Swedish methodology.

5.1 Comparison between Italian CSC and Swedish generic guidelines for soil

In addition to the different considerations and assumptions of the Italian and Swedish risk assessment methodology, it is reasonable to expect different limit values for the same pollutants in the two cases. In fact, if the CSCs are based on the international suggested values and are not risk-based, the generic guidelines, on the other hand, are determined using models that require assumptions which can be dissimilar from the international ones. Moreover, the contaminants for which a limit concentration is established and that can be included in a risk assessment can change in the two methodologies. The soil CSCs and the soil generic guidelines are reported, for those contaminants that are regulated both in Italy and Sweden, in Table 8. It must be specified that the Italian regulation includes more pollutants than the Swedish one that however considers some chemicals that are not regulated in Italy (e.g., Barium).

Table 8: Italian CSCs for soil and Swedish soil generic guidelines.

Compound	**Italian CSC (mg/kg$_{d.m.}$)**		**Swedish generic guideline (mg/kg$_{d.m.}$)**	
	Recreational/ residential	**Commercial/ industrial**	**KM**	**MKM**
Antimony	10	30	12	30
Arsenic	20	50	10	25
Lead	100	1000	50	400
Cadmium	2	15	0.5	15
Cobalt	20	250	15	35
Copper	120	600	80	200
Chromium total	150	800	80	150
Chromium (VI)	2	15	2	10
Mercury	1	5	0.25	2.5
Nickel	120	500	40	120
Vanadinium	90	250	100	200
Zinc	150	1500	250	500
Cyanide free	1	100	0.4	1.5
Trichlorobenzenes	1	50	1	10
Hexachlorobenzene	0.05	5	0.035	2
Dichloromethane	0.1	5	0.08	0.25
Dibromchloromethane	0.5	10	0.5	2
Bromdichloromethane	0.5	10	0.06	1
Trichloromethane	0.1	5	0.4	1.2
1,2-dichloroethane	0.2	5	0.02	0.06

Table 8: Italian CSCs for soil and Swedish soil generic guidelines.

Compound	**Italian CSC (mg/kg$_{d.m.}$)**		**Swedish generic guideline (mg/kg$_{d.m.}$)**	
	Recreational/ residential	**Commercial/ industrial**	**KM**	**MKM**
1,1,1-trichloroethane	0.5	50	5	30
Trichloroethene (TCE)	1	10	0.2	0.6
Tetrachloroethene (PCE)	0.5	20	0.4	1.2
PCB-7	0.06	5	0.008	0.2
Benzene	0.1	2	0.012	0.04
Toluen	0.5	50	10	40
Etylbenzene	0.5	50	10	50
Xylene	0.5	50	10	50

Looking at the values of the Italian and Swedish “threshold” concentrations for the two land uses, it is possible to notice that in the large majority of the cases the Swedish guidelines are lower than the Italian CSCs. The fact that the generic guidelines, as well as the site-specific ones, are not legally binding and neither the remediation goals, can be a possible explanation to this differences, allowing lower concentrations to be adopted as limit. In the case of the sensible land use, the smaller values adopted in the Swedish system, if compared to the Italian CSCs, might be a consequence of the fact that in the Italian regulation residential and recreational land use are put together whilst the KM scenario excludes the recreational purpose. Therefore, if the CSC for sensitive land use has to be respected, the acceptable pollution level is increased considering the possible lack of residents in a recreational area.

6 Software to assess the risk

Software are a very useful tool to easily-reproduce the conceptual model of a polluted site for which a risk assessment must be performed. In fact, the possibility to manipulate and to change the input parameters and to quickly evaluate the variation in the outcomes of the program, enable the user to simulate different scenarios and then choose the one that fits the most the features of the site.

The software used in a risk assessment, as well as its complexity, usually varies in different countries. However, it is common that the software is presented in the form of an excel file, as the ones used in Italy and Sweden.

6.1 Risk-net 2.0

Risk-net is a software, based on an Excel file, used to perform a risk assessment according to the Italian regulation (D.Lgs. 152/06 and D. Lgs. 04/08) and the indication by APAT-ISPRA guideline (Istituto Superiore per la Protezione e la Ricerca Ambientale) (2008).

The software allows the user to calculate both the risk using a "forward" approach, starting from the concentration of pollutants detected at the source of pollution, and the remediation targets, i.e. CSRs, with a "backward" approach, defining the acceptable R and HI.

The structure of the software consists in a main screen in which different boxes are present and clicking on the cells inside them, new windows are opened to insert inputs, show outputs etc.

6.1.1 Main screen

In Figure 10 is reported the main screen that is shown to the user after opening Risk-net. In this screen it is possible to have access to the input and output windows using the command buttons. The user can define the type of assessment, insert the general information on the project and the options of calculation. The button "Zoom" is used to modify the view of the main screen, while the "?" buttons open the rapid help guide.

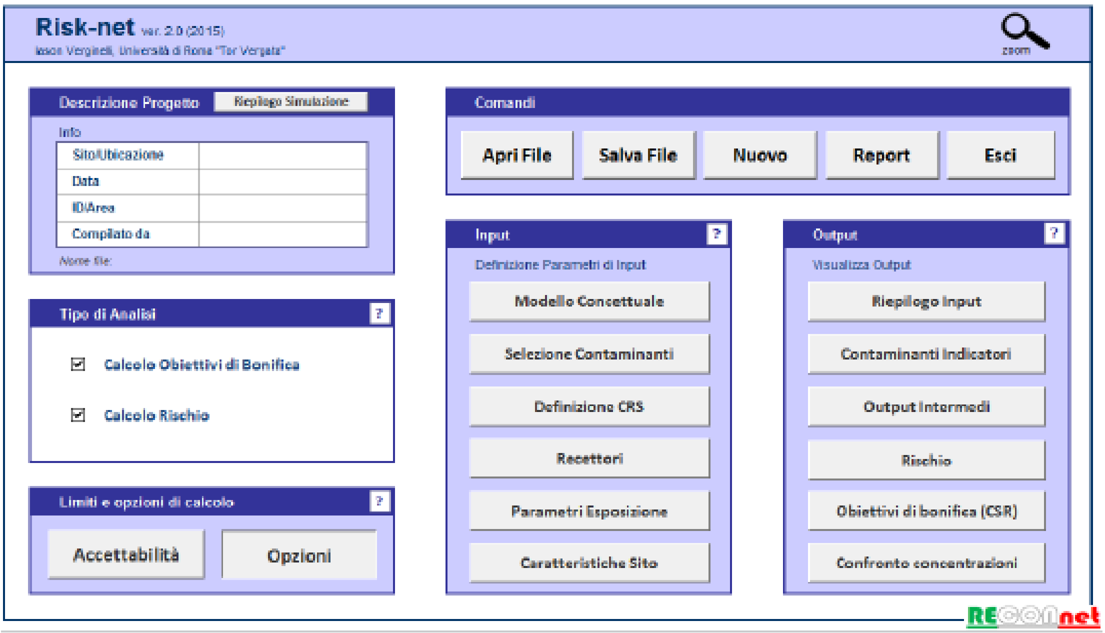


Figure 10: Main screen of Risk-net 2.0.

In the “Descrizione Progetto” dialog box, it is possible to insert general information about the project, i.e. site, data, ID/area and compiled by. Clicking on “Riepilogo simulazione” the settings and assumptions of the case of study are shown.

The “Tipo di Analisi” dialog box is where the user specifies which type of analysis has to be performed. If a “forward” approach is adopted, “Calcolo Rischio” is selected, whilst “Calcolo Obiettivi di Bonifica”, i.e. CSRs, is chosen if a “backward” approach is applied. The simulation can be run also if both the options are selected (RECONnet, 2015).

“Limiti e Opzioni di Calcolo” allows the user to define the acceptable limits, i.e. R and HI.

“Input” is used to insert the inputs necessary to perform the risk assessment. A ✓ is shown next to the command button if it was clicked, in order to remind the user which inputs have already been edited.

The “Output” dialog box shows the summary of the outputs, given the inputs inserted in the program.

“Comandi” contains the following command buttons:

- “Apri File”: to load a previously saved simulation;
- “Salva File”: to save the inputs and the outputs of the performed simulation;

- “Nuovo”: to reset the program to the starting point (not saved data will be lost);
- “Report”: to obtain an Excel file where the main inputs and outputs of the simulation are reported;
- “Esci”: to exit from the software (not saved data will be lost).

In the following paragraphs, the dialog boxes and their command buttons will be further described.

6.1.2 “Tipo di Analisi”

As already explained, Risk-net can be used to perform a risk assessment adopting a “forward” or a “backward” approach.

If “Calcolo Obiettivi di Bonifica” is selected, the maximum acceptable concentrations at the pollution source, according to the acceptable R and HI, are calculated in three steps (RECONnet, 2015):

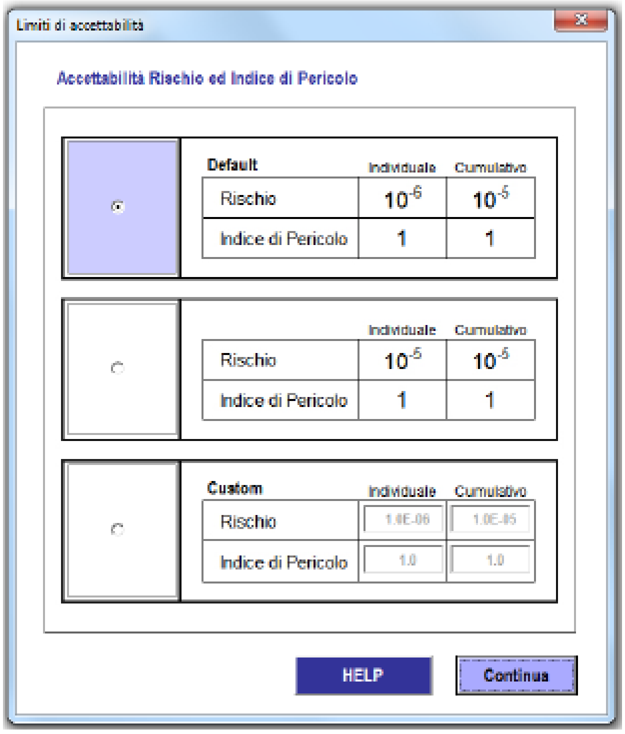
1. Calculation of the CSR for each substance (with a “backward” approach);
2. Check of the cumulative risk due to the presence of more contaminants (the program calculate the risk associated to the CSR of each contaminant and the total risk summing the individual ones);
3. Reduction of the individual CSR by the user in order to obtain a total risk equal or below the limit.

The CSRs that respect the acceptable limits of risk, both individual and cumulative, are the remediation goals for the site of study.

“Calcolo Rischio” is used to calculate the risk associated to the source representative concentration (CRS), defined by the user. As for “Calcolo Obiettivi di Bonifica”, the individual and cumulative risk are determined and the values obtained has to be compared to the acceptable levels for health risk (RECONnet, 2015).

6.1.3 *“Limiti e opzioni di calcolo”*

Clicking on the button “Accettabilità”, a window is open (Figure 11) to define the acceptable R and HI values. The standards determined by the Italian regulations are used by default, but the user can modify them for the simulation.



● **Default**

	Individuale	Cumulativo
Rischio	10^{-6}	10^{-5}
Indice di Pericolo	1	1

○

	Individuale	Cumulativo
Rischio	10^{-5}	10^{-5}
Indice di Pericolo	1	1

○ **Custom**

	Individuale	Cumulativo
Rischio	1.0E-06	1.0E-05
Indice di Pericolo	1.0	1.0

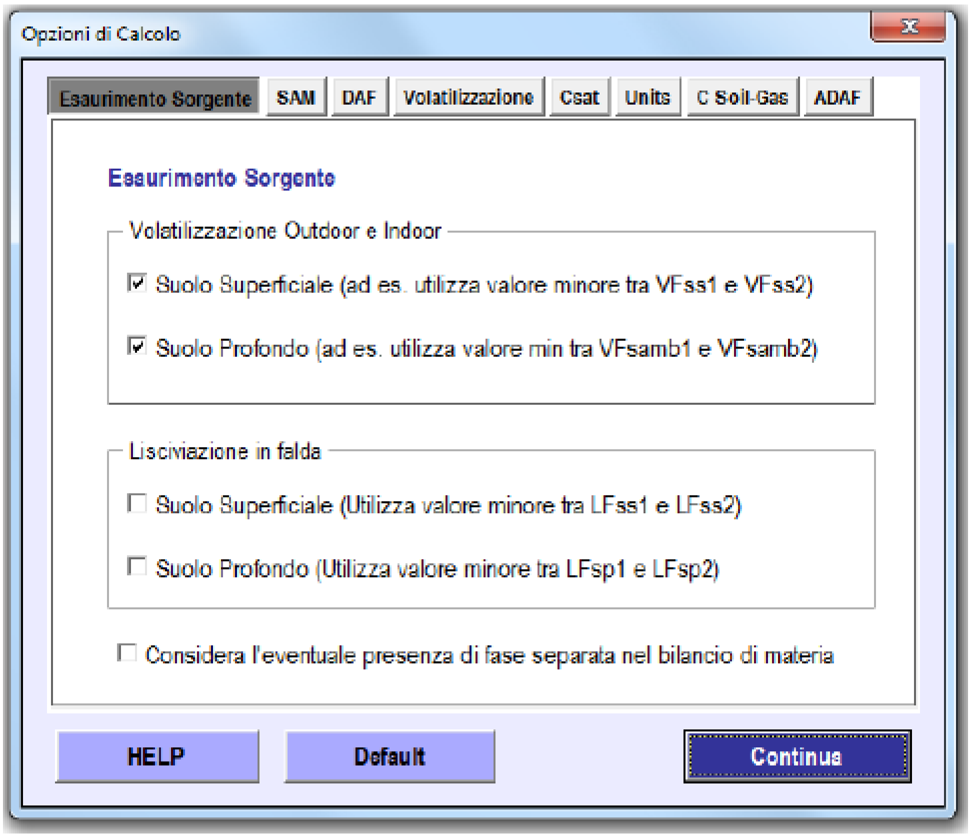
Figure 11: The window opening from the “Accettabilità” button, to modify the acceptable R and HI values.

6.1.4 *“Opzioni”*

The program considers by default the equations and the criteria defined by APAT-ISPRA (2008), but the user can activate and define other calculation options by clicking on the “Opzioni” button. The “Opzioni di calcolo” window that appears (Figure 12) presents different options as (RECONnet, 2015):

- “Esaurimento sorgente”: to consider the depletion of the source of pollution;
- “SAM” (Soil Attenuation Model): to take into account the attenuation of contamination during the leaching, due to the mass redistribution;
- “DAF”: to consider the dilution in the groundwater, selecting the direction of the dispersion;

- “Volatilizzazione”: to consider the volatilization of the contaminant if the pollution in the upper soil is not reaching the soil surface;
- “C_{sat}“: to consider the saturation concentration for indirect exposure pathways;
- “Units”: to specify if the dimensions of the source of pollution are expressed in cm or m.
- “C soil-gas”: to adopt the concentration of pollutant in soil gas for indoor and outdoor volatilization;
- ADAF”: to adjust the toxicological parameter for the child receptor.



Esaurimento Sorgente

Volatilizzazione Outdoor e Indoor

☑ Suolo Superficiale (ad es. utilizza valore minore tra VFss1 e VFss2)

☑ Suolo Profondo (ad es. utilizza valore min tra VFsamb1 e VFsamb2)

Lisciviazione in falda

☐ Suolo Superficiale (Utilizza valore minore tra LFss1 e LFss2)

☐ Suolo Profondo (Utilizza valore minore tra LFsp1 e LFsp2)

☐ Considera l'eventuale presenza di fase separata nel bilancio di materia

Figure 12: The window “Opzioni di calcolo” from “Opzioni”.

6.1.5 “Input”

In the “Input” dialog box it is possible to access the different windows for the definition of the conceptual model, the contaminants and the required input parameters.

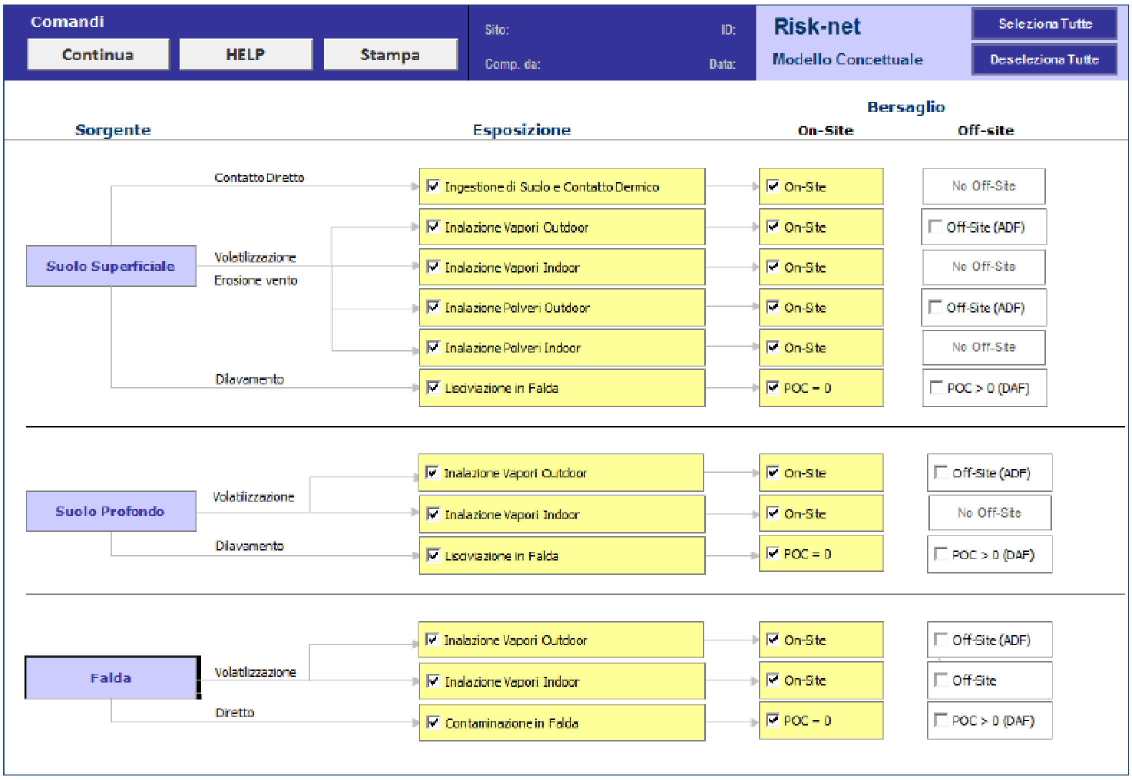
“Modello concettuale”

In the window appearing after clicking the button “Modello concettuale” (Figure 13), the user selects the migration and exposure pathways for each secondary source of pollution, i.e. surface soil (0-1 m from ground surface), deep soil and groundwater. For each matrix, the exposure pathways and the types of receptor (on site, off-site or both) to be taken into account are added with a ✓ and the cell is colored in yellow by the program. If the target for an exposure pathway is not selected, the cell is colored in red to highlight the incomplete information.

For the exposure pathways in which the receptors off-site are considered, the program allows the user to distinguish between transport through dispersion in air (ADF) and in groundwater (DAF). In the case of “Liscivazione in falda” (leaching towards groundwater) and “Contaminazione in falda” (contamination in groundwater), if the cell “POC=0” is selected, the concentration estimated by the software due to the leaching from soil and the concentration in groundwater defined by the user respectively is compared to the CSC (on the vertical of the pollution source un the first case and at the source of pollution in the second one). This calculation is performed only if groundwater is considered as a receptor in the window “Recettori”. Even if it is possible to select both “POC=0” and “POC>0”, in that case only “POC=0” is considered by the program for the risk assessment (RECONnet, 2015).

There are other command buttons present in the window:

- “Continua”: to go back to the main screen;
- “Help”: to open the manual;
- “Stampa”: to print the screen;
- “Seleziona tutte”: to select all the migration and exposure pathways;
- “Deseleziona tutte”: to unselect all the migration and exposure pathways.



Sorgente		Esposizione	On-Site	Off-site
Suolo Superficiale	Contatto Diretto	☑ Ingestione di Suolo e Contatto Dermico	☑ On-Site	No Off-Site
	Volatilizzazione Erosione vento	☑ Inalazione Vapori Outdoor	☑ On-Site	☐ Off-Site (ADF)
		☑ Inalazione Vapori Indoor	☑ On-Site	No Off-Site
		☑ Inalazione Polveri Outdoor	☑ On-Site	☐ Off-Site (ADF)
		☑ Inalazione Polveri Indoor	☑ On-Site	No Off-Site
	Dilavamento	☑ Lisciviazione in Falda	☑ POC = 0	☐ POC > 0 (DAF)
Suolo Profondo	Volatilizzazione	☑ Inalazione Vapori Outdoor	☑ On-Site	☐ Off-Site (ADF)
		☑ Inalazione Vapori Indoor	☑ On-Site	No Off-Site
	Dilavamento	☑ Lisciviazione in Falda	☑ POC = 0	☐ POC > 0 (DAF)
Falda	Volatilizzazione	☑ Inalazione Vapori Outdoor	☑ On-Site	☐ Off-Site (ADF)
		☑ Inalazione Vapori Indoor	☑ On-Site	☐ Off-Site
	Diretto	☑ Contaminazione in Falda	☑ POC = 0	☐ POC > 0 (DAF)

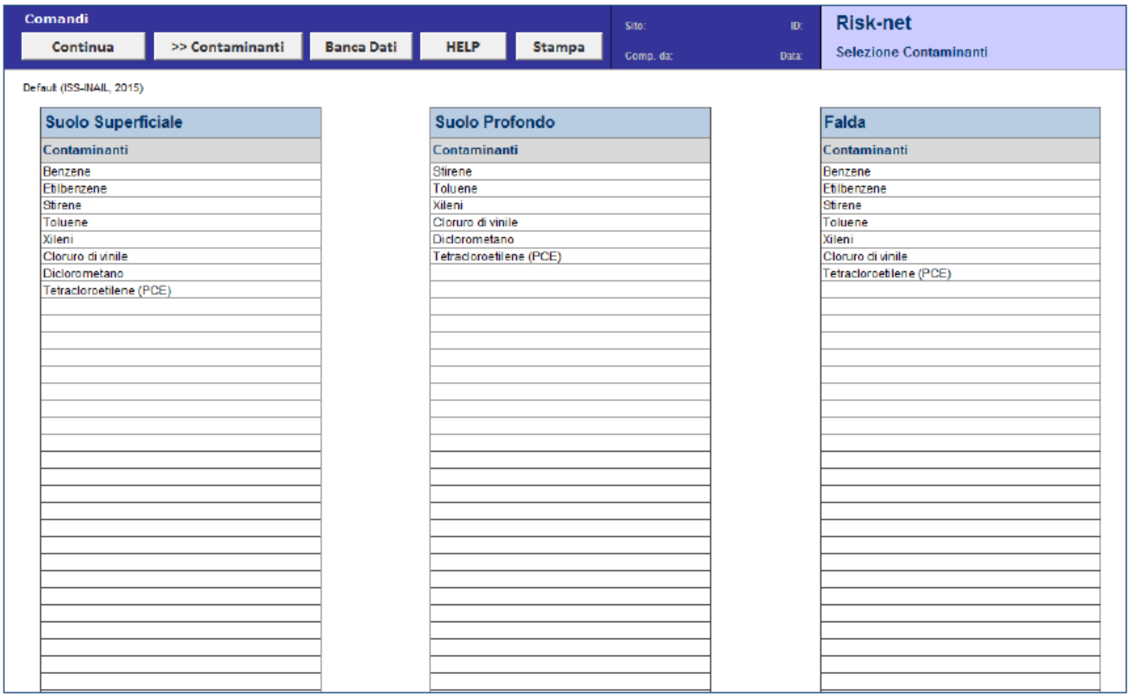
Figure 13: The window showed after clicking on the "Modello concettuale" command button.

Since some of the command buttons are the same for many windows, they are not described in the following paragraphs.

"<u>Selezione contaminanti</u>"

In this window (Figure 14) the user has to add the contaminants that must be considered in the risk assessment. There are some command buttons showed on the screen:

- ">> Contaminanti": to open the window for the insertion of the contaminants;
- "Banca dati": to access the database and to check, modify or insert new contaminants.



Sito:

ID:

Comp. da:

Data:

Default (ISS-INAIL, 2015)

Suolo Superficiale

Contaminanti
Benzene
Etilbenzene
Stirene
Toluene
Xileni
Cloruro di vinile
Diclorometano
Tetracloroetilene (PCE)

Suolo Profondo

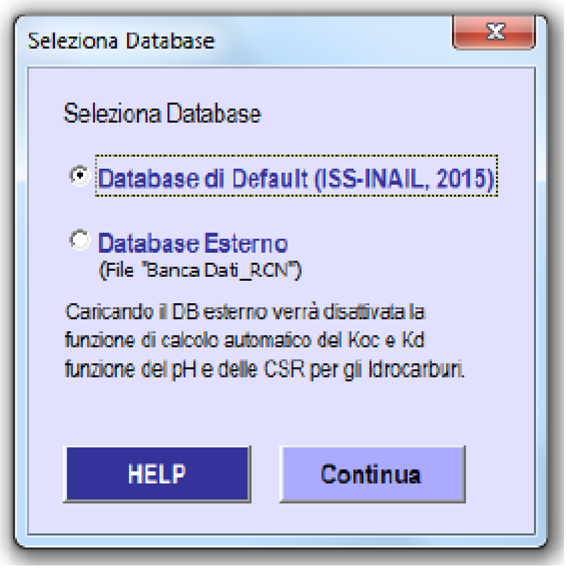
Contaminanti
Stirene
Toluene
Xileni
Cloruro di vinile
Diclorometano
Tetracloroetilene (PCE)

Falda

Contaminanti
Benzene
Etilbenzene
Stirene
Toluene
Xileni
Cloruro di vinile
Tetracloroetilene (PCE)

Figure 14: “Selezione contaminanti” window.

When accessing the window to insert the contaminants for the first time, the user has to specify which database will be used in the window reported in Figure 15. It is possible to select the database of the software (“Database di Default”), by ISS (Istituto Superiore Sanità)-INAIL (Istituto Nazionale Assicurazione Infortuni sul Lavoro) (2015) or an external one (“Database Esterno”), in the form of a modifiable excel file. If the external database is used, the K_{oc} and K_d, that depend on the pH of the soil, and the CSRs for hydrocarbons are no longer automatically calculated. The choice can be changed later clicking on “Banca Dati”. If the database changes, the added contaminants are deleted (RECONnet, 2015).



Seleziona Database

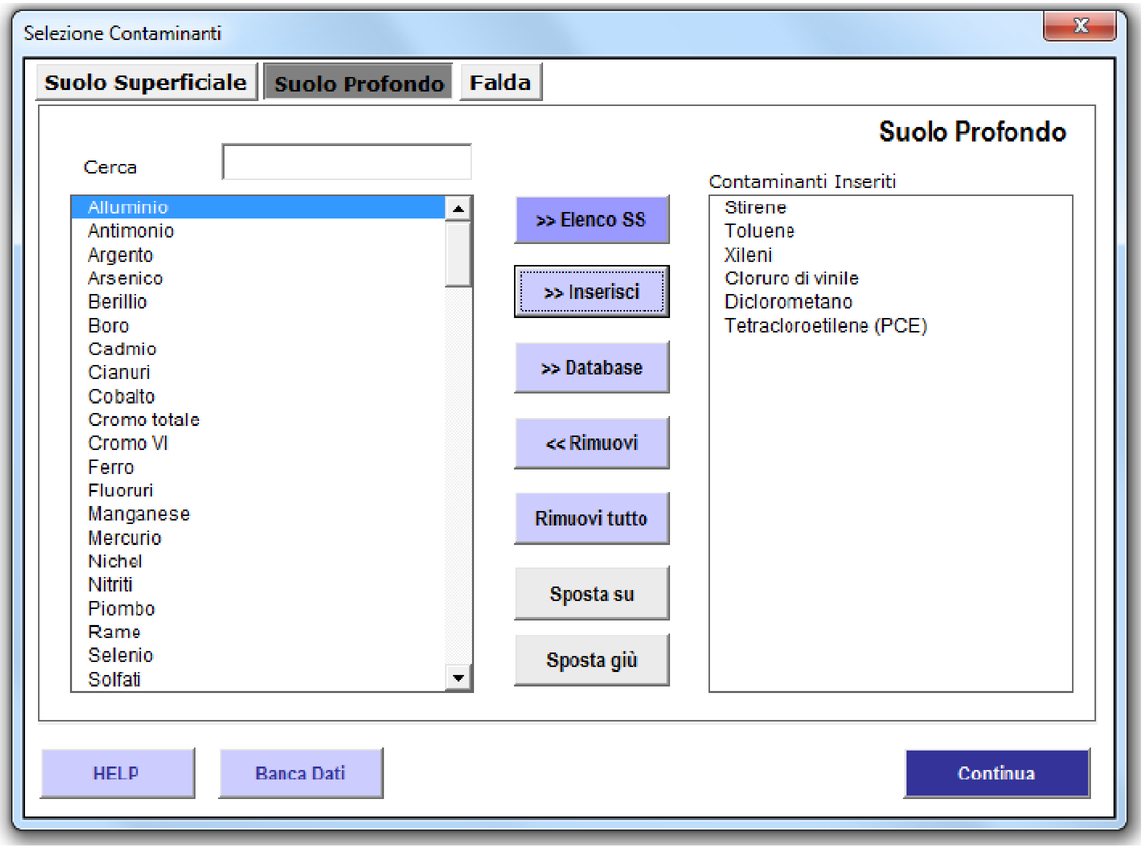
● Database di Default (ISS-INAIL, 2015)

○ Database Esterno
(File "Banca Dati_RCN")

Caricando il DB esterno verrà disattivata la funzione di calcolo automatico del Koc e Kd funzione del pH e delle CSR per gli Idrocarburi.

Figure 15: Window for database selection.

Once the database is chosen clicking on the cell “Continua”, the window to insert the contaminants automatically appears (Figure 16). It is possible to select different contaminants for surface soil, deep soil and groundwater clicking on “Suolo Superficiale”, “Suolo Profondo” and “Falda” respectively. The column on the left of the window contains all the chemicals present in the database, whilst the one on the right reports those that have been considered so far. The user has to click on “>> Inserisci” to add a contaminant selected in the left column. To remove a pollutant, it must be first selected in the right column and then the cell “<< Rimuovi” has to be clicked. In the cell “Cerca”, it is possible to insert some letters of the name of the contaminant to search it in the database. The button “>> Database” allows the user to consider all the contaminants present in the database, while “Rimuovi tutto” deletes all the inserted contaminants. With the buttons “Sposta su” and “Sposta giù”, the contaminant selected in the right column can be moved upwards and downwards respectively.



Suolo Profondo

Cerca

Alluminio
Antimonio
Argento
Arsenico
Berillio
Boro
Cadmio
Cianuri
Cobalto
Cromo totale
Cromo VI
Ferro
Fluoruri
Manganese
Mercurio
Nichel
Nitriti
Piombo
Rame
Selenio
Solfati

Contaminanti Inseriti

Stirene
Toluene
Xileni
Cloruro di vinile
Diclorometano
Tetracloroetilene (PCE)

Figure 16: Window for insertion of contaminants.

The other command buttons are:

- ">> Elenco SS": to insert for the deep soil the same contaminants considered for surface soil;
- ">> Elenco SP": to insert for the groundwater the same contaminants considered for deep soil;
- "Continua": to complete the procedure of inserting the contaminants and go back to the main screen;
- "Banca Dati": to access the database to check, modify or insert new compounds.

In particular, when clicking on the "Banca Dati" button, a new window appears that shows the database of loaded in the software (Figure 17). Here it is possible to check the chemical, physical and toxicological properties of the contaminants present in the selected database.

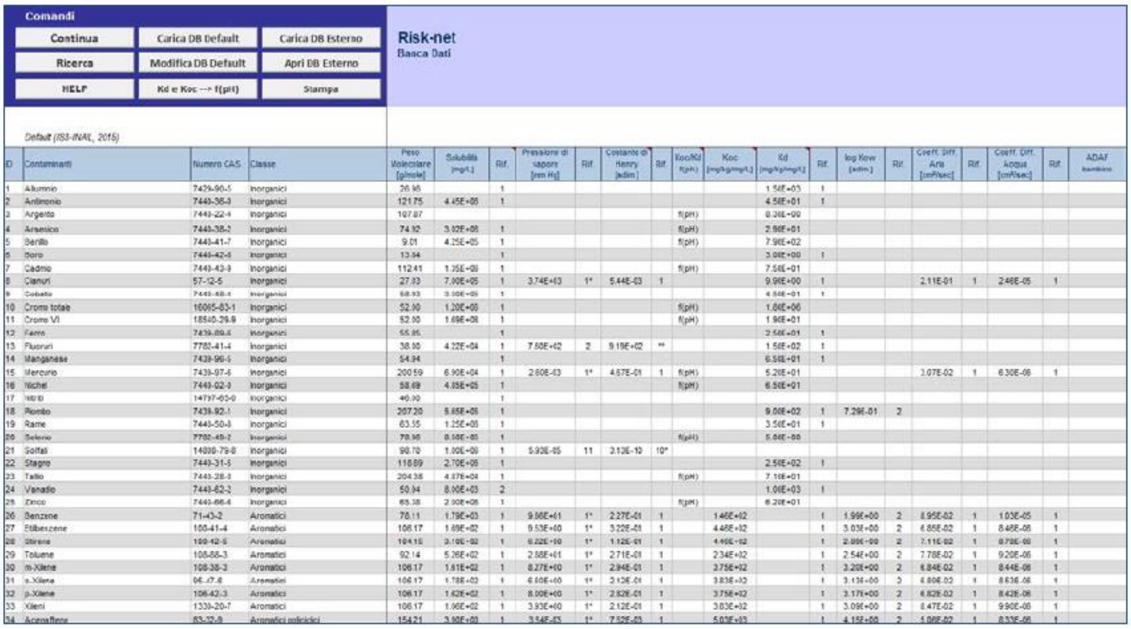
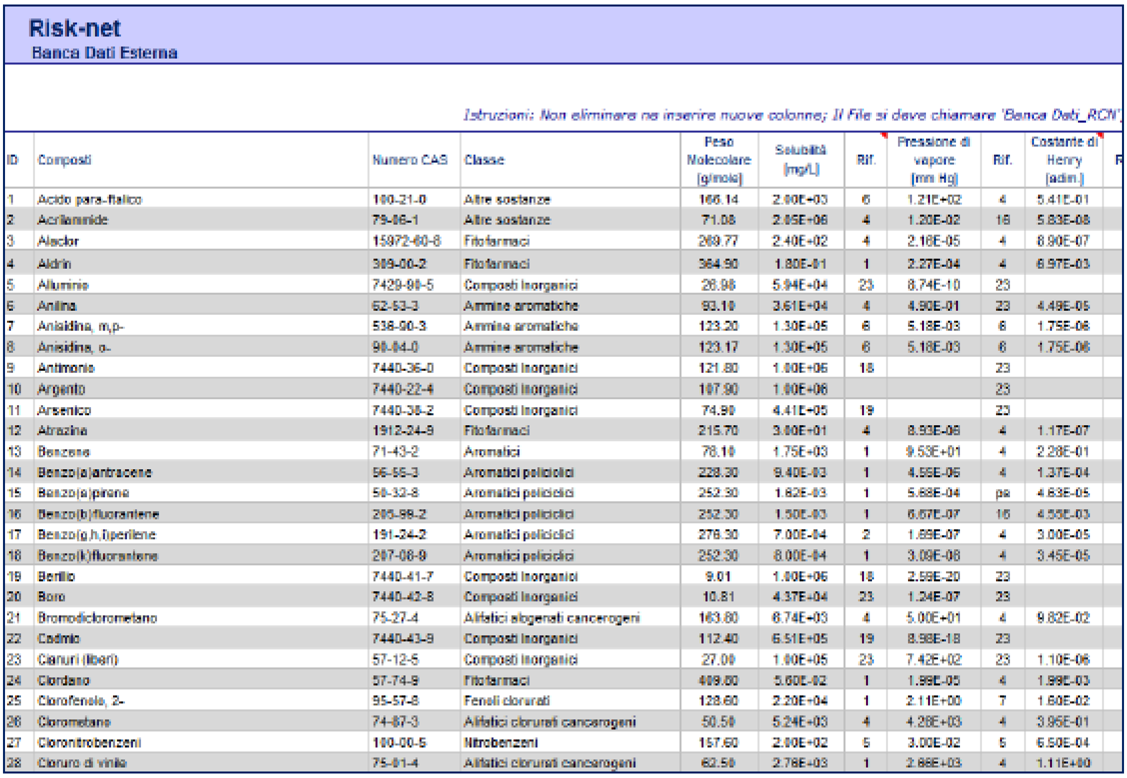


Figure 17: Window with the Risk-net's database.

The command buttons present in the window are:

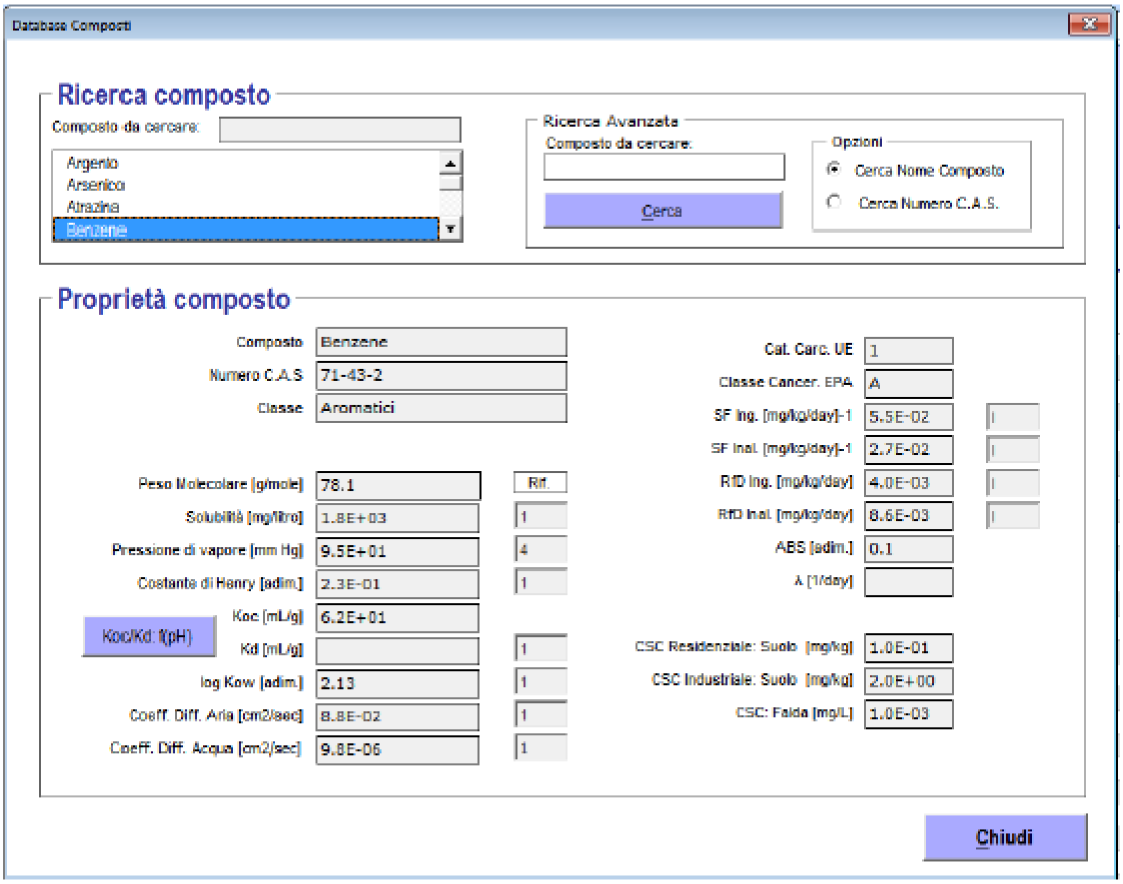
- "Modifica DB Default": to modify the parameters of the database ISS-INAIL (these variations are valid only for the current simulation);
- "Apri DB esterno": to open the external database (Figure 18) and then modify or add compounds (no empty rows must be left because the program stops at the first empty row). Once the user has completed the modifications, the database must be saved without changing its name ("Banca Dati_RCN").
- "Carica DB esterno": to load the external database;
- "K_d e K_{oc} --> f(pH)": to show the K_d and K_{oc} that are pH-dependent;
- "Ricerca": to open the window in Figure 19 and search a contaminant with its name ("Cerca Nome Composto") or with the Chemical Abstracts Service (CAS) number ("Cerca Numero C.A.S.") and show its chemical, physical and toxicological properties. Clicking on "Chiudi" it is possible to go back to the database window.


Risk-net
Banca Dati Esterna

Istruzioni: Non eliminare ne inserire nuove colonne; Il File si deve chiamare 'Banca Dati_RCN'

ID	Composti	Numero CAS	Classe	Peso Molecolare [g/mole]	Solubilità [mg/L]	Rif.	Pressione di vapore [mm Hg]	Rif.	Costante di Henry [adim.]	R
1	Acido para-ftalico	100-21-0	Altre sostanze	166.14	2.00E+03	6	1.21E+02	4	5.41E-01	
2	Acrilammide	79-06-1	Altre sostanze	71.08	2.05E+06	4	1.20E-02	16	5.83E-08	
3	Alaclor	15972-60-8	Fitofarmaci	269.77	2.40E+02	4	2.16E-05	4	8.90E-07	
4	Aldrin	309-00-2	Fitofarmaci	364.90	1.80E-01	1	2.27E-04	4	6.97E-03	
5	Alluminio	7429-90-5	Composti Inorganici	26.98	5.94E+04	23	8.74E-10	23		
6	Anilina	62-53-3	Ammine aromatiche	93.10	3.61E+04	4	4.90E-01	23	4.49E-05	
7	Anisidina, m,p-	536-90-3	Ammine aromatiche	123.20	1.30E+05	6	5.18E-03	6	1.75E-06	
8	Anisidina, o-	90-04-0	Ammine aromatiche	123.17	1.30E+05	6	5.18E-03	6	1.75E-06	
9	Antimonio	7440-36-0	Composti Inorganici	121.80	1.00E+06	18		23		
10	Argento	7440-22-4	Composti Inorganici	107.90	1.00E+06			23		
11	Arsenico	7440-38-2	Composti Inorganici	74.90	4.41E+05	19		23		
12	Atrazina	1912-24-9	Fitofarmaci	215.70	3.00E+01	4	8.93E-08	4	1.17E-07	
13	Benzene	71-43-2	Aromatici	78.10	1.75E+03	1	9.53E+01	4	2.28E-01	
14	Benzo(a)antracene	56-55-3	Aromatici policiclici	228.30	9.40E-03	1	4.55E-06	4	1.37E-04	
15	Benzo(a)pirene	50-32-8	Aromatici policiclici	252.30	1.62E-03	1	5.68E-04	pa	4.63E-05	
16	Benzo(b)fluorantene	205-99-2	Aromatici policiclici	252.30	1.50E-03	1	6.67E-07	16	4.55E-03	
17	Benzo(g,h,i)perilene	191-24-2	Aromatici policiclici	276.30	7.00E-04	2	1.69E-07	4	3.00E-05	
18	Benzo(k)fluorantene	207-08-9	Aromatici policiclici	252.30	8.00E-04	1	3.09E-08	4	3.45E-05	
19	Berillio	7440-41-7	Composti Inorganici	9.01	1.00E+06	18	2.59E-20	23		
20	Boro	7440-42-8	Composti Inorganici	10.81	4.37E+04	23	1.24E-07	23		
21	Bromodiclorometano	75-27-4	Alifatici alogenati cancerogeni	163.80	6.74E+03	4	5.00E+01	4	9.82E-02	
22	Cadmio	7440-43-9	Composti Inorganici	112.40	6.51E+05	19	8.98E-18	23		
23	Cianuri (liberi)	57-12-5	Composti Inorganici	27.00	1.00E+05	23	7.42E+02	23	1.10E-06	
24	Clordano	57-74-9	Fitofarmaci	409.80	5.60E-02	1	1.99E-05	4	1.99E-03	
25	Clorofenolo, 2-	95-57-8	Fenoli clorurati	128.60	2.20E+04	1	2.11E+00	7	1.60E-02	
26	Clorometano	74-87-3	Alifatici clorurati cancerogeni	50.50	5.24E+03	4	4.28E+03	4	3.95E-01	
27	Cloronitrobenzeni	100-00-5	Nitrobenzeni	157.60	2.00E+02	5	3.00E-02	5	6.50E-04	
28	Cloruro di vinile	75-01-4	Alifatici clorurati cancerogeni	62.50	2.76E+03	1	2.66E+03	4	1.11E+00	

Figure 18: Window with the external database.

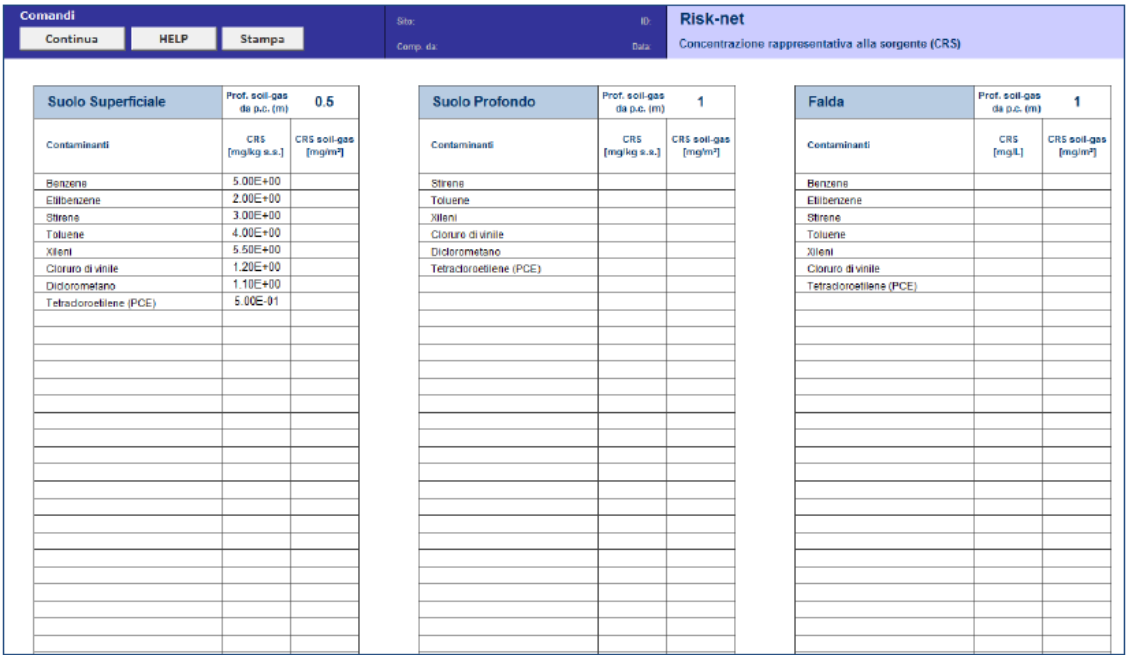


Composto: Benzene
Numero C.A.S: 71-43-2
Classe: Aromatici
Peso Molecolare [g/mole]: 78.1
Solubilità [mg/litro]: 1.8E+03 (Rif. 1)
Pressione di vapore [mm Hg]: 9.5E+01 (Rif. 4)
Costante di Henry [adim.]: 2.3E-01 (Rif. 1)
Koc [mL/g]: 6.2E+01
Kd [mL/g]: (Rif. 1)
log Kow [adim.]: 2.13 (Rif. 1)
Coeff. Diff. Aria [cm2/sec]: 8.8E-02 (Rif. 1)
Coeff. Diff. Acqua [cm2/sec]: 9.8E-06 (Rif. 1)
Cat. Carc. UE: 1
Classe Cancer. EPA: A
SF Ing. [mg/kg/day]-1: 5.5E-02 (I)
SF Inal. [mg/kg/day]-1: 2.7E-02 (I)
RfD Ing. [mg/kg/day]: 4.0E-03 (I)
RfD Inal. [mg/kg/day]: 8.6E-03 (I)
ABS [adim.]: 0.1
λ [1/day]:
CSC Residenziale: Suolo [mg/kg]: 1.0E-01
CSC Industriale: Suolo [mg/kg]: 2.0E+00
CSC: Falda [mg/L]: 1.0E-03

Figure 19: The window for the search of the contaminant.

“<u>Definizione CRS</u>”

If the user decides to apply a “forward” approach to perform the risk assessment, the CRS has to be defined for each contaminant considered. Clicking on the button “Definizione CRS” the window in Figure 20 appears and the CRS are inserted as mg/kg of dry substance and mg/l for soil and groundwater respectively. It is also possible to insert the soil gas CRS (mg/m^3) in the homonymous column, if available, for the volatilization indoor and outdoor (RECONnet, 2015).



Suolo Superficiale	Prof. soil-gas da p.c. (m)	0.5
Contaminanti	CRS [mg/kg s.s.]	CRS soil-gas [mg/m^3]
Benzene	5.00E+00	
Etilbenzene	2.00E+00	
Stirene	3.00E+00	
Toluene	4.00E+00	
Xileni	5.50E+00	
Cloruro di vinile	1.20E+00	
Diclorometano	1.10E+00	
Tetracloroetilene (PCE)	5.00E-01	

Suolo Profondo	Prof. soil-gas da p.c. (m)	1
Contaminanti	CRS [mg/kg s.s.]	CRS soil-gas [mg/m^3]
Stirene		
Toluene		
Xileni		
Cloruro di vinile		
Diclorometano		
Tetracloroetilene (PCE)		

Falda	Prof. soil-gas da p.c. (m)	1
Contaminanti	CRS [mg/L]	CRS soil-gas [mg/m^3]
Benzene		
Etilbenzene		
Stirene		
Toluene		
Xileni		
Cloruro di vinile		
Tetracloroetilene (PCE)		

Figure 20: Window for the definition of the CRS.

“<u>Recettori</u>”

Clicking on the “Recettori” command button, the widow reported in Figure 21 is opened and it allows the user to select the receptors on site or next to it.

It is possible to choose receptors between “Residenziale Ricreativo” (Residential Recreational) and “Industriale Commerciale” (Industrial Commercial):

- “Adulto” (Adult): for recreational or residential conditions (the difference is determined by the exposure parameters);
- “Bambino” (Child): for recreational or residential conditions (the difference is determined by the exposure parameters);
- “Adjusted”: for recreational or residential conditions (the difference is determined by the exposure parameters). Selecting this option, the exposure for genotoxic compound is averaged on the 6 years of the child and the 24 of the adult, whilst for non-genotoxic chemicals the exposure of a child is cautiously considered;
- “Lavoratore Adulto” (Adult Worker): for industrial or commercial conditions.

If the leaching to or the transport in groundwater are considered, the user has to select from the box “Protezione Risorsa Idrica” between (RECONnet, 2015):

- “Limiti Tabellari” to assess the risk to the water resource as indicated by the D.Lgs. 04/08;
- “Ingestione di Acqua” to assess the health risk associated to the ingestion of drinking water (option not contemplated by the actual regulation).

This procedure must be done also for the receptors off-site, from the button on the upper right corner of the window. If the exposure pathways are not taken into account for on site or off-site receptors, it is not possible to visualize the corresponding window.

The command button “Default” sets the options for calculation according to the guidelines by APAT-ISPRA (i.e. “Adjusted” and “Limiti Tabellari”).

Figure 21: The window “Recettori”.

”<u>Parametri Esposizione</u>”

The following step consists in the definition of the exposure parameters for the site of study that can be modified in the window that appears after clicking on the “Parametri Esposizione” command button in the main screen (Figure 22). The user has to insert the parameters for the exposure pathways considered, both on site and off-site.

The definition of the exposure parameters affects the consequences for the individual targets. The parameters to be inserted and that vary for adults, children and workers, are: frequency and exposure duration, daily contact rate (for inhalation, ingestion or dermal contact), bodyweight and the time used to average the exposure (RECONnet, 2015).

Only the parameters for the considered exposure pathways have to be inserted, with gray cells in correspondence of unnecessary data. Clicking on the button "Imposta valori default ISPRA", the default values are implemented in the software. The user has then to choose between recreational and residential values.

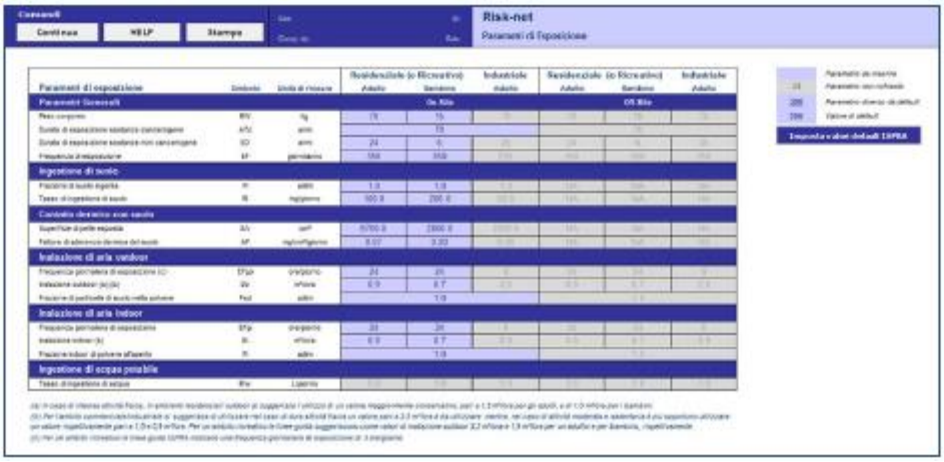


Figure 22: The window for exposure parameters.

"Caratteristiche Sito"

The parameters about the geometry and the features of the site must be defined in order to determine the transport factors. This is possible clicking on the command button "Caratteristiche Sito" and compiling the window that appears (Figure 23). The value of each parameter can be site-specific or the default one defined by APAT-ISPRA. All the parameters are divided in four tables: "Zona Insatura" (Unsaturated zone), "Zona Satura" (Saturated zone), "Ambiente Outdoor" and "Ambiente Indoor".

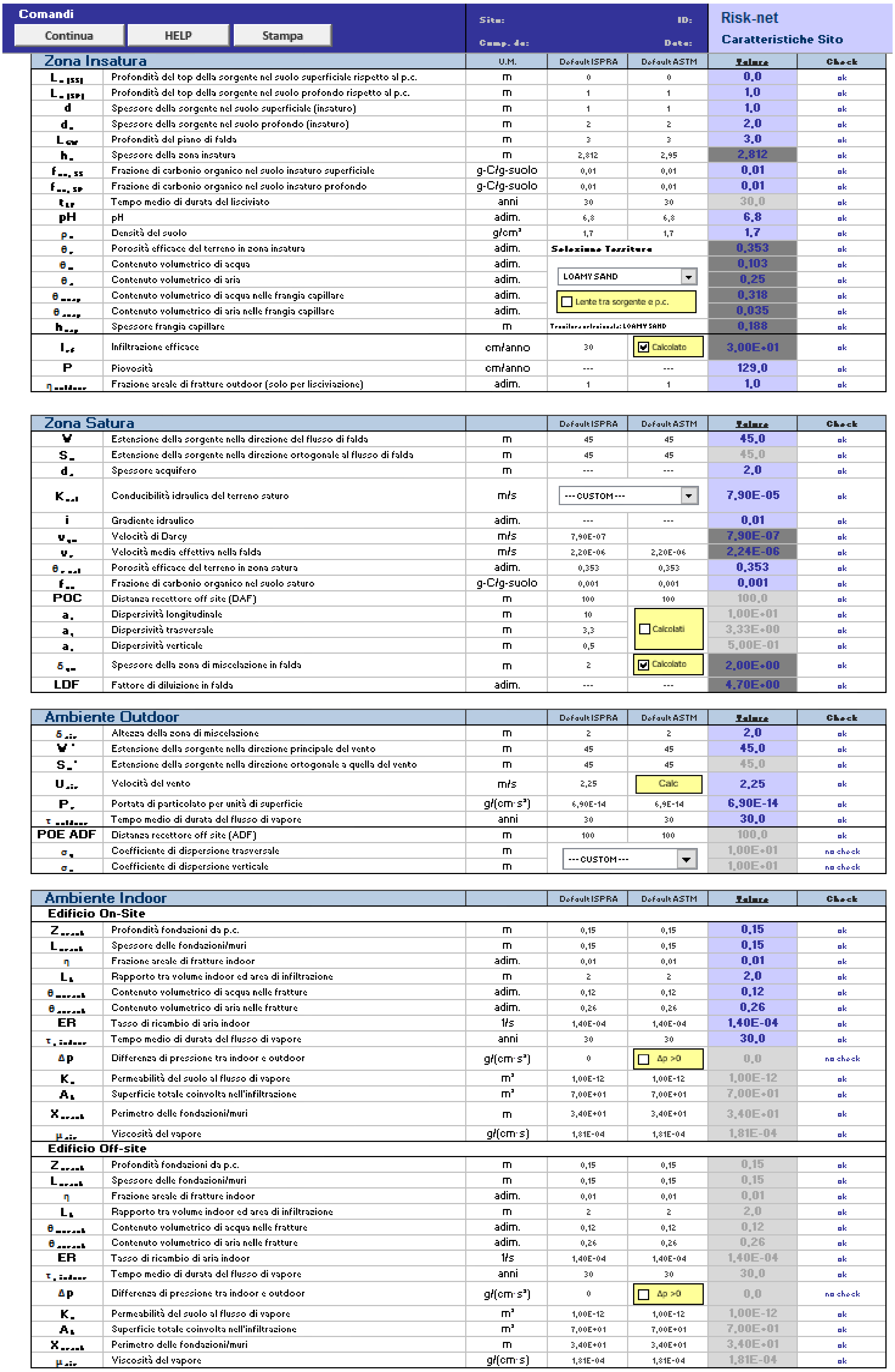
The parameters required to perform the calculations, for the matrices and exposure pathways considered, are highlighted in the violet cells, whilst those not necessary are located in the light gray cells. The dark gray cells contain the data already calculated or determined by literature. If the values in the violet cells is modified by the user, it is underlined, otherwise the default one by APAT-ISPRA is adopted (RECONnet, 2015).

The box “Selezione tessitura” is used to insert the parameters of the soil texture at the site of study. If the “Lente tra sorgente e p.c.” option is activated, the program consider the presence of a lens of soil with high water content and a pop-up window appears to insert information about the lens. For the parameter “Infiltrazione Efficace” (Effective Infiltration) the user can select the option “Calcolato”, to make the program calculate the value, otherwise the value can be manually inserted. The value for the dispersivity in groundwater (“Dispersività”) can be manually inserted or calculated by the software at the POC. The thickness of the mixing zone (“Spessore della zona di miscelazione”) can be a user-value or the default one, calculated from the features of the soil and the aquifer. The default wind speed (“Velocità del vento”) corresponds to 2 m above soil surface, therefore, if data at a different height are available, the corresponding value at 2 m can be calculated clicking on the button “Calc”. The dispersion factors in the atmosphere and the difference between indoor and outdoor pressure can be manually inserted by the user as well (RECONnet, 2015).

The command button “Default ISPRA” is used to insert the default values as defined by APAT-ISPRA.

In the case of unrealistic parameter values a warning is shown in the column “Check”. For the parameters that are not checked by the software, “no check” is reported.

A different error message is shown if the format of the value is not correct or the value itself is not present, when closing a window.



Site:

ID:

Comp. da:

Data:

Risk-net

Caratteristiche Sito

Zona Insatura		U.M.	Default ISPRA	Default ASTM	Valore	Check
$L_{s(SS)}$	Profondità del top della sorgente nel suolo superficiale rispetto al p.c.	m	0	0	0,0	ok
$L_{s(SP)}$	Profondità del top della sorgente nel suolo profondo rispetto al p.c.	m	1	1	1,0	ok
d	Spessore della sorgente nel suolo superficiale (insaturo)	m	1	1	1,0	ok
d_s	Spessore della sorgente nel suolo profondo (insaturo)	m	2	2	2,0	ok
L_{GW}	Profondità del piano di falda	m	3	3	3,0	ok
h_v	Spessore della zona insatura	m	2,812	2,95	2,812	ok
$f_{oc,SS}$	Frazione di carbonio organico nel suolo insaturo superficiale	g-C/g-suolo	0,01	0,01	0,01	ok
$f_{oc,SP}$	Frazione di carbonio organico nel suolo insaturo profondo	g-C/g-suolo	0,01	0,01	0,01	ok
t_{LF}	Tempo medio di durata del lisciviato	anni	30	30	30,0	ok
pH	pH	adim.	6,8	6,8	6,8	ok
ρ_s	Densità del suolo	g/cm³	1,7	1,7	1,7	ok
θ_e	Porosità efficace del terreno in zona insatura	adim.	Selezione Tessitura		0,353	ok
θ_w	Contenuto volumetrico di acqua	adim.			0,103	ok
θ_a	Contenuto volumetrico di aria	adim.	LOAMY SAND ▾		0,25	ok
θ_{wcap}	Contenuto volumetrico di acqua nelle frangia capillare	adim.	☐ Lente tra sorgente e p.c.		0,318	ok
θ_{acap}	Contenuto volumetrico di aria nelle frangia capillare	adim.			0,035	ok
h_{cap}	Spessore frangia capillare	m	Tessitura selezionata: LOAMY SAND		0,188	ok
I_{ef}	Infiltrazione efficace	cm/anno	30	☑ Calcolato	3,00E+01	ok
P	Piovosità	cm/anno	---	---	129,0	ok
$\eta_{outdoor}$	Frazione areale di fratture outdoor (solo per lisciviazione)	adim.	1	1	1,0	ok

Zona Satura			Default ISPRA	Default ASTM	Valore	Check
W	Estensione della sorgente nella direzione del flusso di falda	m	45	45	45,0	ok
S_w	Estensione della sorgente nella direzione ortogonale al flusso di falda	m	45	45	45,0	ok
d_a	Spessore acquifero	m	---	---	2,0	ok
K_{sat}	Conducibilità idraulica del terreno saturo	m/s	--- CUSTOM --- ▾		7,90E-05	ok
i	Gradiente idraulico	adim.	---	---	0,01	ok
v_{gw}	Velocità di Darcy	m/s	7,90E-07		7,90E-07	ok
v_e	Velocità media effettiva nella falda	m/s	2,20E-06	2,20E-06	2,24E-06	ok
$\theta_{e,sat}$	Porosità efficace del terreno in zona satura	adim.	0,353	0,353	0,353	ok
f_{oc}	Frazione di carbonio organico nel suolo saturo	g-C/g-suolo	0,001	0,001	0,001	ok
POC	Distanza recettore off site (DAF)	m	100	100	100,0	ok
a_x	Dispersività longitudinale	m	10	☐ Calcolati	1,00E+01	ok
a_y	Dispersività trasversale	m	3,3		3,33E+00	ok
a_z	Dispersività verticale	m	0,5		5,00E-01	ok
δ_{gw}	Spessore della zona di miscelazione in falda	m	2	☑ Calcolato	2,00E+00	ok
LDF	Fattore di diluizione in falda	adim.	---	---	4,70E+00	ok

Ambiente Outdoor			Default ISPRA	Default ASTM	Valore	Check
δ_{air}	Altezza della zona di miscelazione	m	2	2	2,0	ok
W'	Estensione della sorgente nella direzione principale del vento	m	45	45	45,0	ok
S_w'	Estensione della sorgente nella direzione ortogonale a quella del vento	m	45	45	45,0	ok
U_{air}	Velocità del vento	m/s	2,25	Calc	2,25	ok
P_e	Portata di particolato per unità di superficie	g/(cm·s²)	6,90E-14	6,9E-14	6,90E-14	ok
$\tau_{outdoor}$	Tempo medio di durata del flusso di vapore	anni	30	30	30,0	ok
POE ADF	Distanza recettore off site (ADF)	m	100	100	100,0	ok
σ_y	Coefficiente di dispersione trasversale	m	--- CUSTOM --- ▾		1,00E+01	no check
σ_z	Coefficiente di dispersione verticale	m			1,00E+01	no check

Ambiente Indoor			Default ISPRA	Default ASTM	Valore	Check
Edificio On-Site						
Z_{crack}	Profondità fondazioni da p.c.	m	0,15	0,15	0,15	ok
L_{crack}	Spessore delle fondazioni/muri	m	0,15	0,15	0,15	ok
η	Frazione areale di fratture indoor	adim.	0,01	0,01	0,01	ok
L_b	Rapporto tra volume indoor ed area di infiltrazione	m	2	2	2,0	ok
θ_{wcrack}	Contenuto volumetrico di acqua nelle fratture	adim.	0,12	0,12	0,12	ok
θ_{acrack}	Contenuto volumetrico di aria nelle fratture	adim.	0,26	0,26	0,26	ok
ER	Tasso di ricambio di aria indoor	1/s	1,40E-04	1,40E-04	1,40E-04	ok
τ_{indoor}	Tempo medio di durata del flusso di vapore	anni	30	30	30,0	ok
Δp	Differenza di pressione tra indoor e outdoor	g/(cm·s²)	0	☐ Δp >0	0,0	no check
K_v	Permeabilità del suolo al flusso di vapore	m²	1,00E-12	1,00E-12	1,00E-12	ok
A_b	Superficie totale coinvolta nell'infiltrazione	m²	7,00E+01	7,00E+01	7,00E+01	ok
X_{crack}	Perimetro delle fondazioni/muri	m	3,40E+01	3,40E+01	3,40E+01	ok
μ_{air}	Viscosità del vapore	g/(cm·s)	1,81E-04	1,81E-04	1,81E-04	ok
Edificio Off-site						
Z_{crack}	Profondità fondazioni da p.c.	m	0,15	0,15	0,15	ok
L_{crack}	Spessore delle fondazioni/muri	m	0,15	0,15	0,15	ok
η	Frazione areale di fratture indoor	adim.	0,01	0,01	0,01	ok
L_b	Rapporto tra volume indoor ed area di infiltrazione	m	2	2	2,0	ok
θ_{wcrack}	Contenuto volumetrico di acqua nelle fratture	adim.	0,12	0,12	0,12	ok
θ_{acrack}	Contenuto volumetrico di aria nelle fratture	adim.	0,26	0,26	0,26	ok
ER	Tasso di ricambio di aria indoor	1/s	1,40E-04	1,40E-04	1,40E-04	ok
τ_{indoor}	Tempo medio di durata del flusso di vapore	anni	30	30	30,0	ok
Δp	Differenza di pressione tra indoor e outdoor	g/(cm·s²)	0	☐ Δp >0	0,0	no check
K_v	Permeabilità del suolo al flusso di vapore	m²	1,00E-12	1,00E-12	1,00E-12	ok
A_b	Superficie totale coinvolta nell'infiltrazione	m²	7,00E+01	7,00E+01	7,00E+01	ok
X_{crack}	Perimetro delle fondazioni/muri	m	3,40E+01	3,40E+01	3,40E+01	ok
μ_{air}	Viscosità del vapore	g/(cm·s)	1,81E-04	1,81E-04	1,81E-04	ok

Figure 23: Window "Caretteristiche Sito" used to insert the infro about the site of study.

6.1.6 *“Output”*

The “Output” box in the main screen is used to open the windows with a summary of the input and those reporting the outputs, both final and not.

“Riepilogo Input”

Clicking on the button “Riepilogo Input”, the window reported in Figure 24 appears, showing exposure and migration pathways, receptors, limits for risk, features of the site and exposure parameters that will be used in the simulation to determine the CSRs and the Risk.

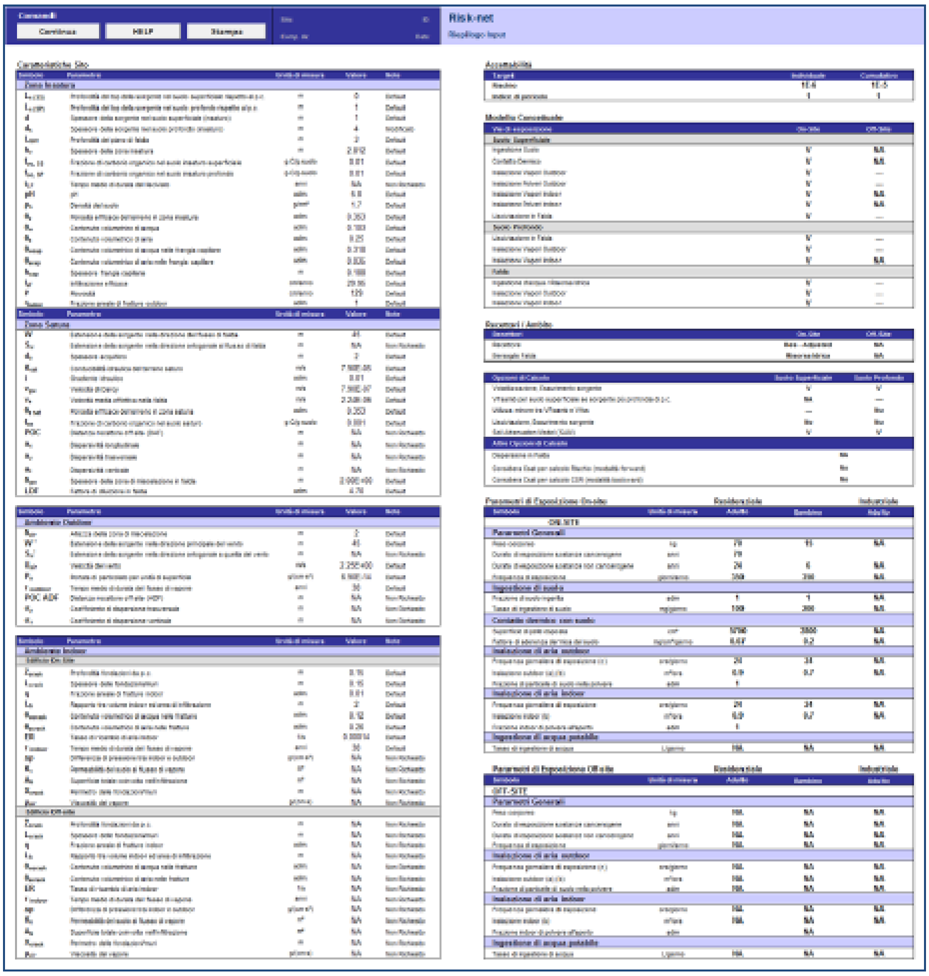


Figure 24: “Riepilogo Input” window.

“Contaminanti Indicatori”

After the user has clicked on the button “Contaminanti indicatori”, the window that appears is used to select the matrix to be considered: surface soil (“Suolo Superficiale”), deep soil (“Suolo Profondo”) and groundwater (“Falda”) (Figure 25). Clicking on one of the three buttons, a window, with all the chemicals considered for that matrix and their related properties, is shown (Figure 26).

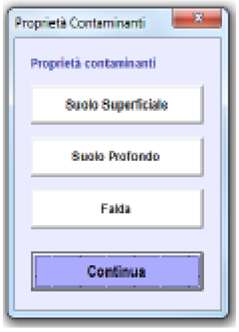


Figure 25: Window for selection of the matrix for which the contaminants must be shown.

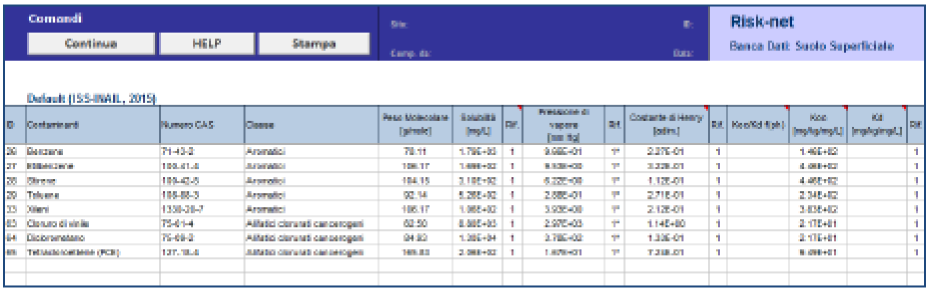


Figure 26: Window with the contaminants and the related properties considered in the selected matrix.

“Output Intermedi”

The window reported in Figure 27 is shown on the screen after clicking the button “Output Intermedi” and it allows to show the exposure pathways and parameters, the transport factors and the sheet for the assessment of the level of pollution in groundwater for each matrix (RECONnet, 2015).

Figure 27: Windows with the command buttons for the intermediate results.

The button “Vie Attive” shows the summary of the conceptual model of the simulation, as reported in Figure 28. In this window it is possible to check the receptors and the pathways affecting each matrix (soil, air, groundwater). Arrows connect the secondary sources of pollution (surface soil, deep soil and groundwater) with the mechanism of transport and the exposure pathway corresponding to each of the environmental matrices (soil, air, groundwater). A green arrow indicates the pathways related to volatilization, the violet ones the transport and leaching that impact the groundwater and the red ones the direct contacts (soil ingestion and dermal contact) that affect the soil. On the right side of the window, the receptors on site and off-site are listed with the corresponding scenario (residential or industrial) (RECONnet, 2015).

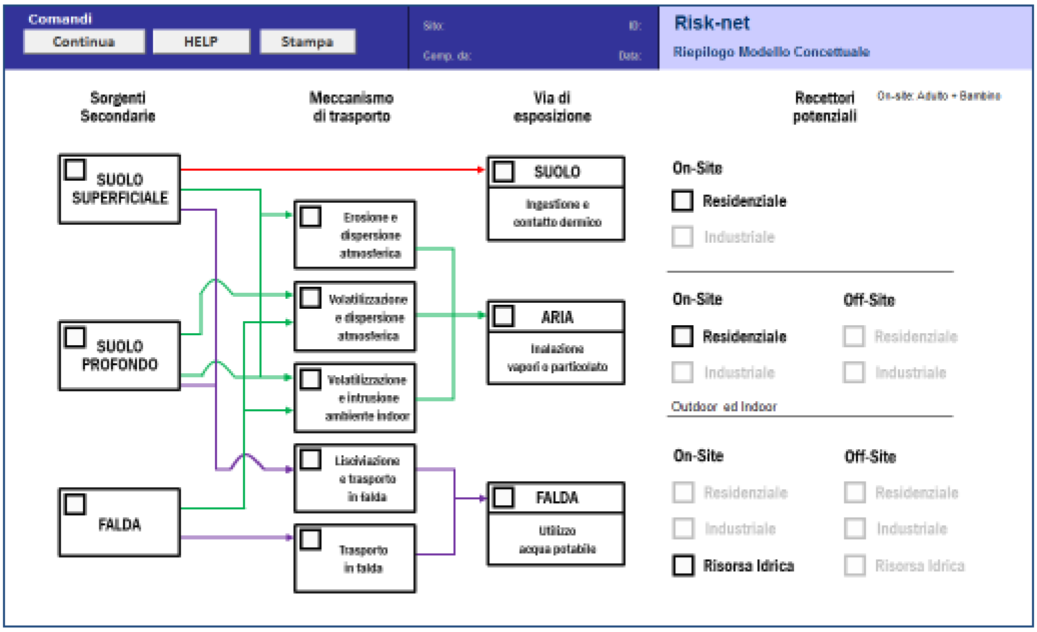
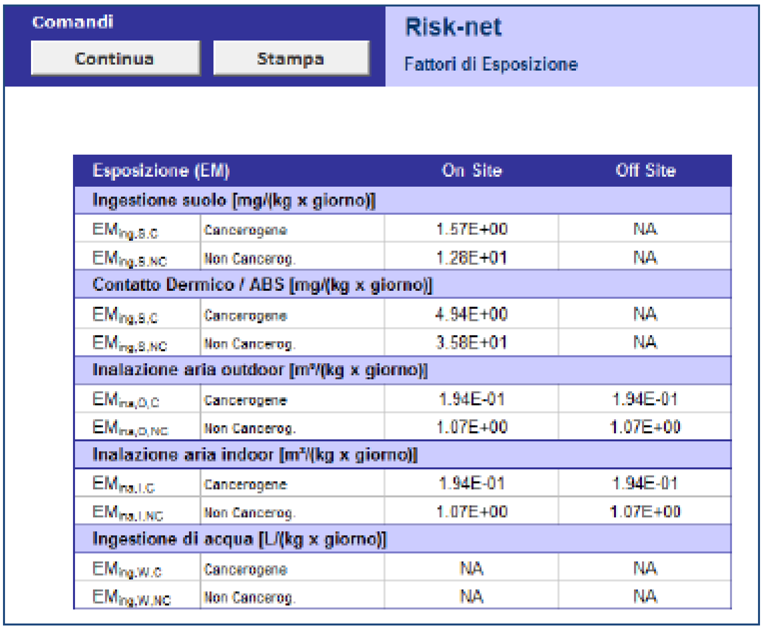


Figure 28: Schematic representation of the conceptual model of the simulation.

With the button "EM", it is possible to check the exposure pathways considered and the calculated exposure factors for both genotoxic and no-genotoxic substances in the opened window (Figure 29). "NA" indicates that the specific exposure pathway was not taken into account.



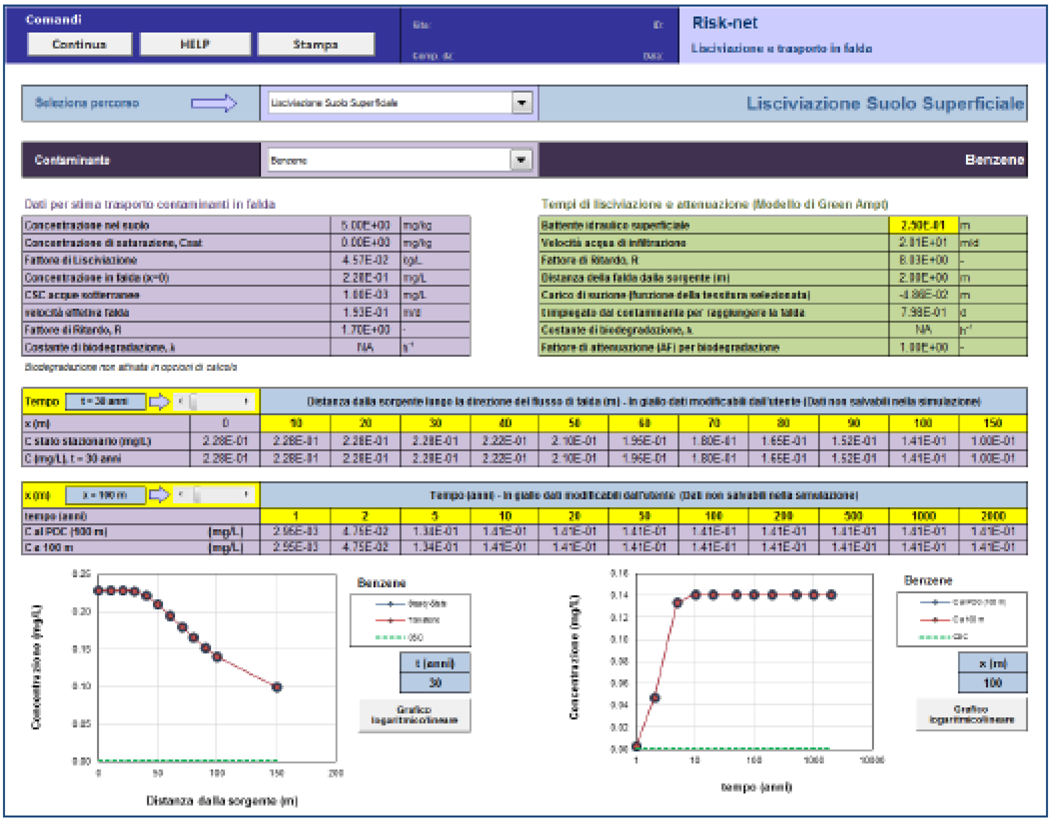
Esposizione (EM)		On Site	Off Site
Ingestione suolo [mg/(kg x giorno)]			
$EM_{ing,S,C}$	Cancerogene	1.57E+00	NA
$EM_{ing,S,NC}$	Non Cancerog.	1.28E+01	NA
Contatto Dermico / ABS [mg/(kg x giorno)]			
$EM_{ing,S,C}$	Cancerogene	4.94E+00	NA
$EM_{ing,S,NC}$	Non Cancerog.	3.58E+01	NA
Inalazione aria outdoor [m³/(kg x giorno)]			
$EM_{ina,O,C}$	Cancerogene	1.94E-01	1.94E-01
$EM_{ina,O,NC}$	Non Cancerog.	1.07E+00	1.07E+00
Inalazione aria indoor [m³/(kg x giorno)]			
$EM_{ina,I,C}$	Cancerogene	1.94E-01	1.94E-01
$EM_{ina,I,NC}$	Non Cancerog.	1.07E+00	1.07E+00
Ingestione di acqua [L/(kg x giorno)]			
$EM_{ing,W,C}$	Cancerogene	NA	NA
$EM_{ing,W,NC}$	Non Cancerog.	NA	NA

Figure 29: Exposure factors calculated in the simulation.

Clicking on one of the three command buttons under “Fattori di Trasporto”, the calculated transport factors are shown for the selected matrix (Figure 30). The excluded migration pathways are identified with “NA”. If the option for the depletion of the source of pollution is activated, the factors for which the transport is limited are reported in red.

Figure 30: Transport factors calculated in the simulation.

The window that appears after clicking on the button “Steady State vs Transitorio” (Figure 31), shows the variation in space and time of the pollution in groundwater according to the Domenico equation. The user has to select from the scrollbar “Seleziona percorso” the migration pathway (leaching from deep or surface soil, or transport in groundwater) and the contaminant considered. In the two tables in the lower part of the window, the variation of the concentration of the pollutant in groundwater with respect to space and time can be observed. The concentration is calculated both for unsteady (red points) and steady conditions (blue points). The button “Grafico logaritmico/lineare” is used to convert the linear scale to the logarithmic one and vice versa (RECONnet, 2015).



Dati per stima trasporto contaminanti in falda

Concentrazione nel suolo	5.00E+00	mg/kg
Concentrazione di saturazione, Csat	0.00E+00	mg/kg
Fattore di Lisciviazione	4.57E-02	kg/L
Concentrazione in falda (x=0)	2.28E-01	mg/L
CSC acque sotterranee	1.00E-03	mg/L
velocità effettiva falda	1.53E-01	m/d
Fattore di Ritardo, R	1.70E+00	-
Costante di biodegradazione, λ	NA	s⁻¹

Biodegradazione non attivata in opzioni di calcolo

Tempi di lisciviazione e attenuazione (Modello di Green Ampt)

Battente idraulico superficiale	2.50E-01	m
Velocità acqua di infiltrazione	2.01E+01	m/d
Fattore di Ritardo, R	8.03E+00	-
Distanza della falda dalla sorgente (m)	2.00E+00	m
Carico di suzione (funzione della tessitura selezionata)	-4.88E-02	m
t impiegato dal contaminante per raggiungere la falda	7.98E-01	d
Costante di biodegradazione, λ	NA	h⁻¹
Fattore di attenuazione (AF) per biodegradazione	1.00E+00	-

Tempo t = 30 anni

Distanza dalla sorgente lungo la direzione del flusso di falda (m) - In giallo dati modificabili dall'utente (Dati non salvabili nella simulazione)

x (m)	0	10	20	30	40	50	60	70	80	90	100	150
C stato stazionario (mg/L)	2.28E-01	2.28E-01	2.28E-01	2.28E-01	2.22E-01	2.10E-01	1.96E-01	1.80E-01	1.65E-01	1.52E-01	1.41E-01	1.00E-01
C (mg/L), t = 30 anni	2.28E-01	2.28E-01	2.28E-01	2.28E-01	2.22E-01	2.10E-01	1.96E-01	1.80E-01	1.65E-01	1.52E-01	1.41E-01	1.00E-01

x (m) x = 100 m

Tempo (anni) - In giallo dati modificabili dall'utente (Dati non salvabili nella simulazione)

tempo (anni)		1	2	5	10	20	50	100	200	500	1000	2000
C al POC (100 m)	(mg/L)	2.95E-03	4.75E-02	1.33E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01
C a 100 m	(mg/L)	2.95E-03	4.75E-02	1.34E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01	1.41E-01

Figure 31: Variation of contamination in groundwater.

“<u>Calcolo C_{poe}</u>”

If the risk assessment is performed with a “forward” approach, clicking on the “<u>Calcolo C_{poe}</u>” button a window appears on which are reported the concentration at the POE for each polluted matrix (Figure 32). Moreover, the CRS (as total and soil gas concentration), the saturation concentration (C_{sat}) and the concentration outdoor ($C_{outdoor}$), indoor (C_{indoor}), in groundwater (C_{falda}) both on site and off-site are reported. “NA” indicates that the migration pathway is not activated.

Figure 32: Concentrations at the POE.

6.1.7 “Rischio”

In the case of a “forward” risk assessment, clicking on the “Rischio” button the user accesses the window reported in Figure 33 that is used to visualize the calculated risk for each of the three matrices (“Suolo Superficiale”, “Suolo Profondo” and “Falda”) and the summary of the outputs.

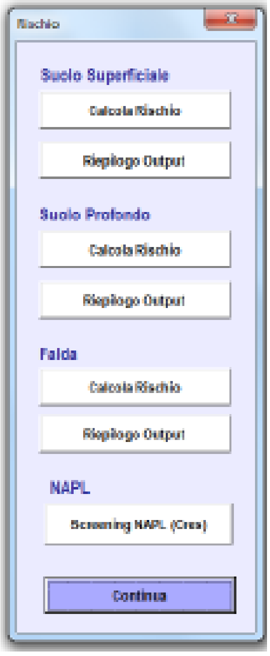


Figure 33: “Rischio” window.

“Calcolo Rischio”

Clicking on one of the three “Calcolo Rischio” buttons, the user opens the window reported in Figure 34 in which the R and the HI are reported. The CRS established by the user is reported in the second column of the table. The shown R and HI are determined after calculating the R and HI for each exposure pathway and then considering the most conservative value, i.e. the highest, between exposure outdoor, indoor and the intake of water (if this option was activated). If the respect of the CSC at the POC was selected, the risk associated to the hydric resource (R_{GW}) is reported as a ratio between C_{POC} and the CSC. In order to take into account the presence of many pollutants, the cumulative R and HI are reported at the bottom of the window and if hydrocarbons classified according to MADEP (Massachusetts Department of Environmental Protection) or TPH WG (Total Petroleum Hydrocarbons Working Group) speciation where inserted, the cumulative risk for the hydric resource related to the total hydrocarbons, is reported as well. When the condition of acceptability is not satisfied, the cell is colored in orange. If the user wants to determine the maximum acceptable CRS, a corrective factor (f) can be applied inserting a value in the fourth column of the table to obtain cumulative R and HI below the limits. The button “Ricalcola con fattore di correzione” is used to perform the latter operation (RECONnet, 2015).

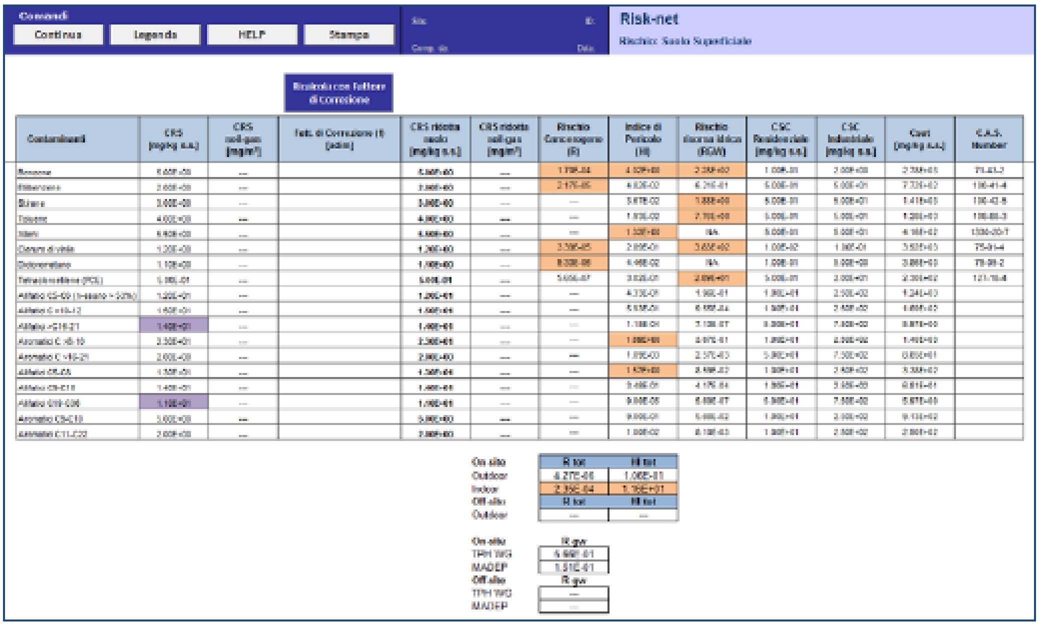
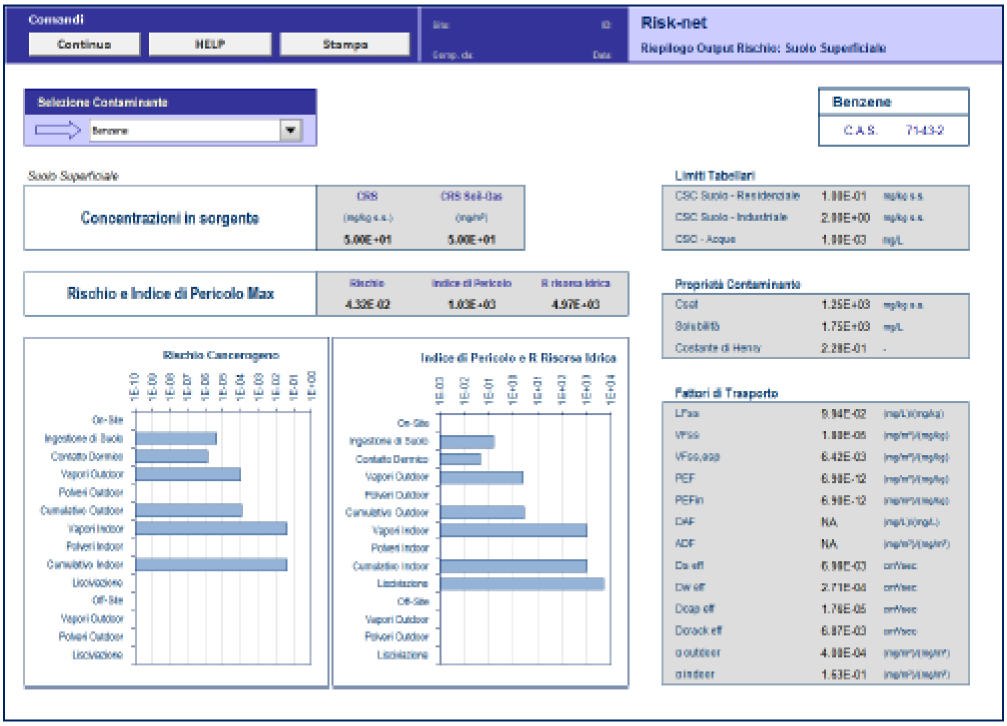


Figure 34: “Calcolo Rischio” window with the values of R and HI for surface soil matrix.

“<u>Riepilogo Output</u>”

This button is clicked by the user to show the summary of the calculated outputs (Figure 35). Once the contaminant to be considered is selected from the scroll bar in the upper left corner of the window, the R and HI is reported for each exposure pathway. All the transport factors used in the current simulation to determine the results are listed in the box “Fattori di Trasporto”.



Risk-net

Riepilogo Output Rischio: Suolo Superficiale

Benzene

C.A.S. 71-43-2

Suolo Superficiale

Concentrazioni in sorgente	CRS (mg/kg s.s.)	CRS Soil-Gas (mg/m³)
	5.00E+01	5.00E+01

Rischio e Indice di Pericolo Max	Rischio	Indice di Pericolo	R risorsa idrica
	4.32E-02	1.03E+03	4.97E+03

Limiti Tabellari

CSC Suolo - Residenziale	1.00E-01	mg/kg s.s.
CSC Suolo - Industriale	2.00E+00	mg/kg s.s.
CSC - Acque	1.00E-03	mg/L

Proprietà Contaminante

Csat	1.25E+03	mg/kg s.s.
Solubilità	1.75E+03	mg/L
Costante di Henry	2.28E-01	-

Fattori di Trasporto

LFss	9.94E-02	(mg/L)/(mg/kg)
VFss	1.80E-05	(mg/m³)/(mg/kg)
VFss,esp	6.42E-03	(mg/m³)/(mg/kg)
PEF	6.90E-12	(mg/m³)/(mg/kg)
PEFin	6.90E-12	(mg/m³)/(mg/kg)
DAF	NA	(mg/L)/(mg/L)
ADF	NA	(mg/m³)/(mg/m³)
Ds eff	6.90E-03	cm²/sec
Dw eff	2.71E-04	cm²/sec
Dcap eff	1.76E-05	cm²/sec
Dcrack eff	6.87E-03	cm²/sec
α outdoor	4.00E-04	(mg/m³)/(mg/m³)
α indoor	1.63E-01	(mg/m³)/(mg/m³)

Figure 35: "Riepilogo Output" window with the summary of the outputs for a "forward" risk assessment, for surface soil matrix.

"<u>Screening NAPL (C_{res})</u>"

This command is described in the "Obiettivi di Bonifica (CSR)" paragraph.

6.1.8 "Obiettivi di Bonifica (CSR)"

If a "backward" risk assessment is performed, clicking on the button "Obiettivi di Bonifica (CSR)" it is possible to open the window reported in Figure 36. From here, the user can check the remediation targets (CSRs) calculated for each of the three matrices (surface soil, deep soil and groundwater) and access the summary of the outputs.

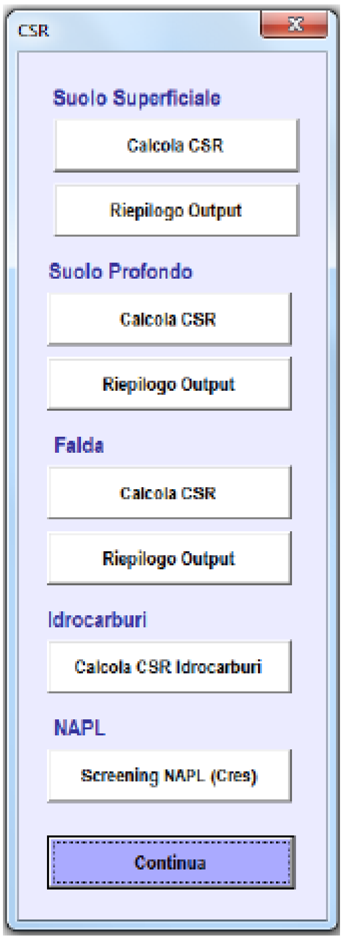
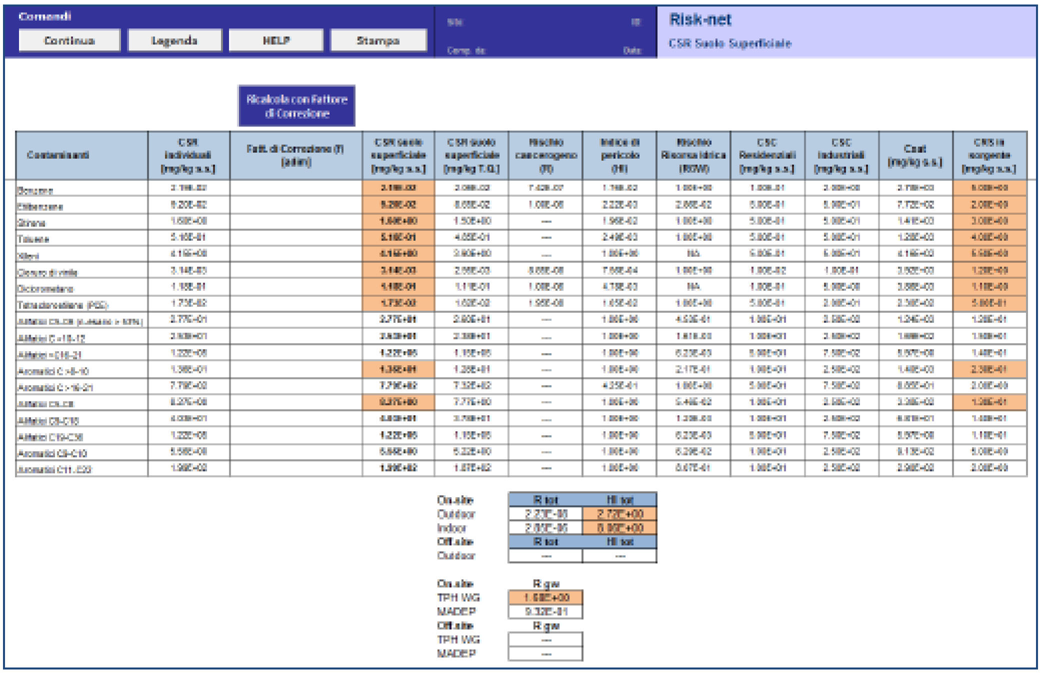


Figure 36: The window "CSR" to access at the calculated CSR and the output of a "backward" risk assessment.

"Calcola CSR"

Clicking on the "Calcola CSR" button, the user accesses the window reported in Figure 37 where the CSRs for the selected matrix are shown. The individual CSR of each contaminant, calculated from the maximum acceptable R and HI, i.e. with "backward" approach, are listed in the second column of the table. The reported CSR is chosen as the most conservative value, i.e. the lowest, between the CSRs determined for each exposure pathway. However, the individual CSRs are not the remediation goals because they may not satisfy the limits for cumulative R and HI. If this is the case, the user has to insert a corrective factor (f) to reduce the CSR and the associated risk, calculated clicking on the button "Ricalcola con fattore di correzione". This value can be the same for all the chemicals or different for each of them. The CSRs that respect the individual and cumulative limits are the remediation values for the site of study. If the hydrocarbons classified as MADEP o TPH WG where inserted, the cumulative risk for the hydric resource related to the total hydrocarbons, is reported as well (RECONnet, 2015).

If the CRS defined by the user is bigger than the CSR the contaminant cell is colored in orange.



Contaminanti	CSR individuali [mg/kg s.s.]	Fatt. di Correzione (f) [adim]	CSR suolo superficiale [mg/kg s.s.]	CSR suolo superficiale [mg/kg T.Q.]	Rischio cancerogeno (R)	Indice di pericolo (HI)	Rischio Risorsa idrica (RGW)	CSC Residenziali [mg/kg s.s.]	CSC Industriali [mg/kg s.s.]	Csat [mg/kg s.s.]	CRS in sorgente [mg/kg s.s.]
Benzene	2.19E-02		2.19E-02	2.08E-02	7.42E-07	1.76E-02	1.00E+00	1.00E-01	2.00E+00	2.79E+03	5.00E+00
Etilbenzene	5.20E-02		5.20E-02	4.95E-02	1.00E-06	2.22E-03	2.66E-02	5.00E-01	5.00E+01	7.72E+02	2.00E+00
Stirene	1.60E+00		1.60E+00	1.50E+00	—	1.96E-02	1.00E+00	5.00E-01	5.00E+01	1.41E+03	3.00E+00
Toluene	5.16E-01		5.16E-01	4.05E-01	—	2.49E-03	1.00E+00	5.00E-01	5.00E+01	1.28E+03	4.00E+00
Xileni	4.15E+00		4.15E+00	3.90E+00	—	1.00E+00	NA	5.00E-01	5.00E+01	4.16E+03	5.50E+00
Cloruro di vinile	3.14E-03		3.14E-03	2.95E-03	5.65E-08	7.56E-04	1.00E+00	1.00E-02	1.00E-01	3.92E+03	1.20E+00
Diclorometano	1.18E-01		1.18E-01	1.11E-01	1.00E-06	4.78E-03	NA	1.00E-01	5.00E+00	3.88E+03	1.10E+00
Tetracloroetilene (PCE)	1.73E-02		1.73E-02	1.62E-02	1.95E-06	1.65E-02	1.00E+00	5.00E-01	2.00E+01	2.30E+02	5.00E-01
Alifatici C5-C8 (n-esano > 53%)	2.77E+01		2.77E+01	2.60E+01	—	1.00E+00	4.53E-01	1.00E+01	2.50E+02	1.24E+03	1.20E+01
Alifatici C >10-12	3.93E+01		3.93E+01	2.39E+01	—	1.00E+00	1.81E-03	1.00E+01	2.50E+02	1.69E+02	1.50E+01
Alifatici >C16-21	1.22E+05		1.22E+05	1.15E+05	—	1.00E+00	6.23E-03	5.00E+01	7.50E+02	5.97E+08	1.40E+01
Aromatici C >8-10	1.36E+01		1.36E+01	1.28E+01	—	1.00E+00	2.17E-01	1.00E+01	2.50E+02	1.40E+03	2.30E+01
Aromatici C >16-21	7.79E+02		7.79E+02	7.32E+02	—	4.25E-01	1.00E+00	5.00E+01	7.50E+02	8.65E+01	2.00E+00
Alifatici C5-C8	8.27E+00		8.27E+00	7.77E+00	—	1.00E+00	5.46E-02	1.00E+01	2.50E+02	3.28E+02	1.20E+01
Alifatici C9-C18	4.03E+01		4.03E+01	3.79E+01	—	1.00E+00	1.23E-03	1.00E+01	2.50E+02	6.81E+01	1.40E+01
Alifatici C19-C36	1.22E+05		1.22E+05	1.15E+05	—	1.00E+00	6.23E-03	5.00E+01	7.50E+02	5.97E+08	1.10E+01
Aromatici C9-C10	5.56E+00		5.56E+00	5.22E+00	—	1.00E+00	6.29E-02	1.00E+01	2.50E+02	9.13E+02	5.00E+00
Aromatici C11-C22	1.99E+02		1.99E+02	1.87E+02	—	1.00E+00	6.67E-01	1.00E+01	2.50E+02	2.98E+02	2.00E+00

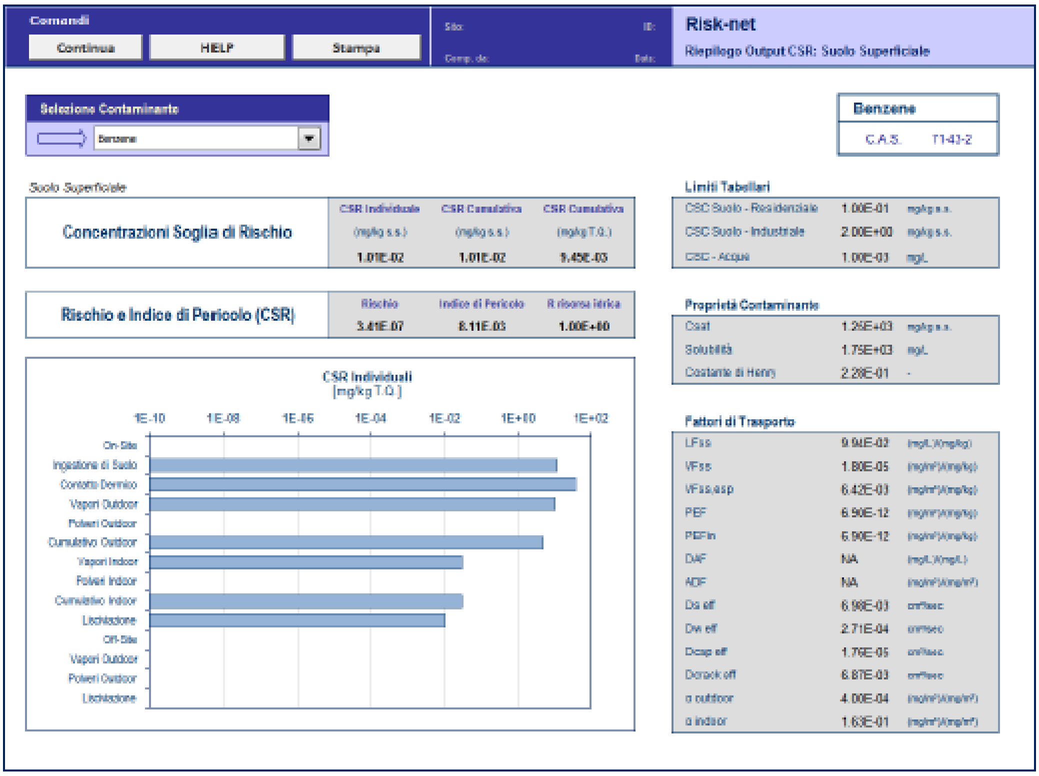
On-site	R tot	HI tot
Outdoor	2.23E-06	2.72E+00
Indoor	2.00E-06	6.86E+00
Off-site	**R tot**	**HI tot**
Outdoor	—	—

On-site	R gw
TPH WG	1.68E+00
MADEP	9.32E-01
Off-site	**R gw**
TPH WG	—
MADEP	—

Figure 37: "Calcola CSR" window with reported the calculated CSRs and the cumulative HI and R for surface soil.

"<u>Riepilogo Output</u>"

Once the remediation targets are determined, clicking on the "Riepilogo Output" button the user can visualize the summary of the outputs (Figure 38). The contaminant that is considered is selected from the scroll bar on the top-left of the window and the CSR for each exposure pathway is reported below. The box "Fattori di Trasporto" contains all the transport factors that were used to obtain the outputs of the simulation.



Benzene

C.A.S. 71-43-2

Suolo Superficiale

	CSR Individuale (mg/kg s.s.)	CSR Cumulativa (mg/kg s.s.)	CSR Cumulativa (mg/kg T.Q.)
Concentrazioni Soglia di Rischio	1.01E-02	1.01E-02	9.45E-03

	Rischio	Indice di Pericolo	R risorsa idrica
Rischio e Indice di Pericolo (CSR)	3.41E-07	8.11E-03	1.00E+00

Limiti Tabellari

CSC Suolo - Residenziale	1.00E-01	mg/kg s.s.
CSC Suolo - Industriale	2.00E+00	mg/kg s.s.
CSC - Acque	1.00E-03	mg/L

Proprietà Contaminante

Csat	1.26E+03	mg/kg s.s.
Solubilità	1.75E+03	mg/L
Costante di Henry	2.28E-01	-

Fattori di Trasporto

LFss	9.94E-02	(mg/L)/(mg/kg)
VFss	1.80E-05	$(mg/m^3)/(mg/kg)$
VFss,esp	6.42E-03	$(mg/m^3)/(mg/kg)$
PEF	6.90E-12	$(mg/m^3)/(mg/kg)$
PEFin	6.90E-12	$(mg/m^3)/(mg/kg)$
DAF	NA	(mg/L)/(mg/L)
ADF	NA	$(mg/m^3)/(mg/m^3)$
Ds eff	6.98E-03	cm^2/sec
Dw eff	2.71E-04	cm^2/sec
Dcap eff	1.76E-05	cm^2/sec
Dcrack eff	6.87E-03	cm^2/sec
α outdoor	4.00E-04	$(mg/m^3)/(mg/m^3)$
α indoor	1.63E-01	$(mg/m^3)/(mg/m^3)$

Figure 38: The window that summarizes the outputs for the surface soil matrix.

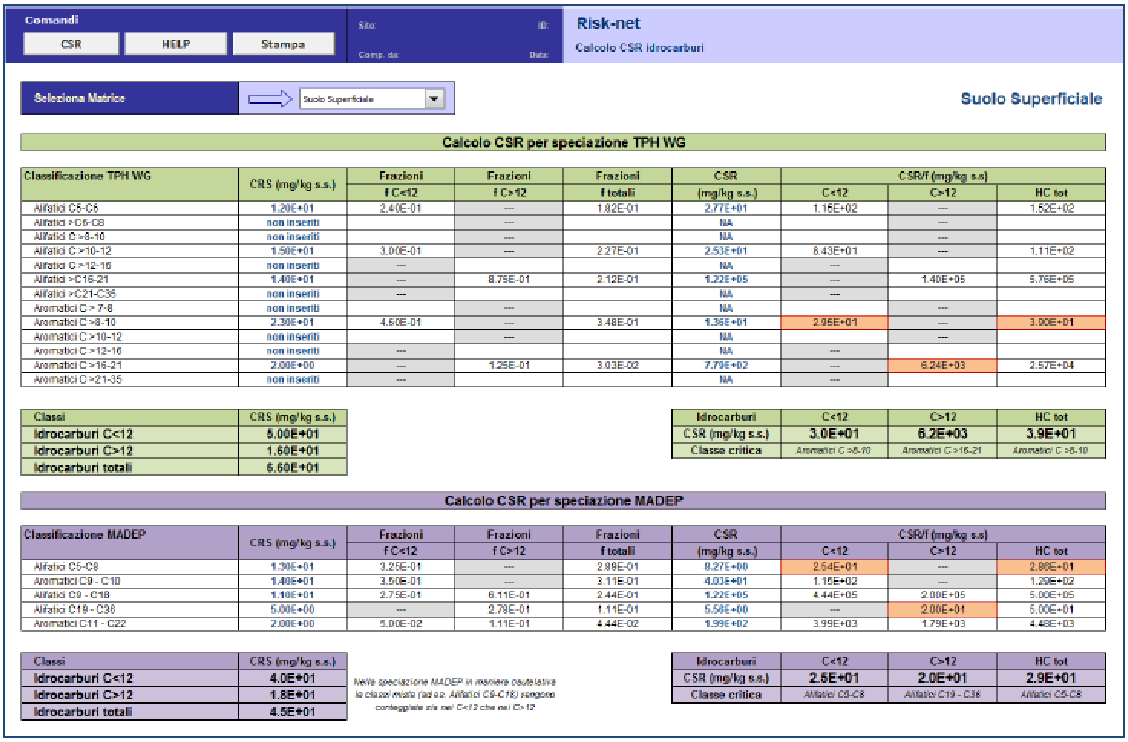
“<u>Calcola CSR idrocarburi</u>”

If the user has inserted hydrocarbons according to the MADEP or TPH WG classification, clicking on the button “Calcola CSR Idrocarburi” it is possible to determine the CSR for the classes:

- “Idrocarburi C>12” (hydrocarbons with more than 12 C atoms) and “Idrocarburi C<12” (hydrocarbons with less than 12 C atoms) in soil;
- “Idrocarburi totali” (total hydrocarbons) in groundwater.

The CSR is defined selecting the class MADEP or TPH WG that poses the greatest risk. In order to do so, the software determines, based on the CRS inserted by the user, the fraction (f) of each sub-class, e.g., “Alifatici C5-C6” etc., present in the macro-classes “Idrocarburi C>12”, “Idrocarburi C<12” and “Idrocarburi totali”, as shown in Figure 39, where the window for hydrocarbons CSR is reported. The calculated fractions are applied to each sub-class to identify which is the one with the lowest CSR. The CSR for the three main classes is calculated as CSR/f. In the two small tables (green for TPH WG and violet for MADEP) where the CSR are reported, the most critical sub-class is specified for each of the three main classes in the row “Classe critica”. The lowest CSR value is highlighted in orange (RECONnet, 2015).

From the scrollbar on the top left of the screen, it is possible to select which matrix has to be considered.



Seleziona Matrice: Suolo Superficiale

Suolo Superficiale

Calcolo CSR per speciazione TPH WG

Classificazione TPH WG	CRS (mg/kg s.s.)	Frazioni	Frazioni	Frazioni	CSR	CSR/f (mg/kg s.s)		
		f C<12	f C>12	f totali	(mg/kg s.s.)	C<12	C>12	HC tot
Alifatici C5-C6	1.20E+01	2.40E-01	---	1.82E-01	2.77E+01	1.16E+02	---	1.52E+02
Alifatici >C6-C8	non inseriti		---		NA		---	
Alifatici C >8-10	non inseriti		---		NA		---	
Alifatici C >10-12	1.50E+01	3.00E-01	---	2.27E-01	2.53E+01	8.43E+01	---	1.11E+02
Alifatici C >12-16	non inseriti	---			NA	---		
Alifatici >C16-21	1.40E+01	---	8.75E-01	2.12E-01	1.22E+05	---	1.40E+05	5.76E+05
Alifatici >C21-C35	non inseriti	---			NA	---		
Aromatici C > 7-8	non inseriti		---		NA		---	
Aromatici C >8-10	2.30E+01	4.60E-01	---	3.48E-01	1.36E+01	2.95E+01	---	3.90E+01
Aromatici C >10-12	non inseriti		---		NA		---	
Aromatici C >12-16	non inseriti	---			NA	---		
Aromatici C >16-21	2.00E+00	---	1.25E-01	3.03E-02	7.79E+02	---	6.24E+03	2.57E+04
Aromatici C >21-35	non inseriti	---			NA	---		

Classi	CRS (mg/kg s.s.)
Idrocarburi C<12	**5.00E+01**
Idrocarburi C>12	**1.60E+01**
Idrocarburi totali	**6.60E+01**

Idrocarburi	C<12	C>12	HC tot
CSR (mg/kg s.s.)	**3.0E+01**	**6.2E+03**	**3.9E+01**
Classe critica	Aromatici C >8-10	Aromatici C >16-21	Aromatici C >8-10

Calcolo CSR per speciazione MADEP

Classificazione MADEP	CRS (mg/kg s.s.)	Frazioni	Frazioni	Frazioni	CSR	CSR/f (mg/kg s.s)		
		f C<12	f C>12	f totali	(mg/kg s.s.)	C<12	C>12	HC tot
Alifatici C5-C8	1.30E+01	3.25E-01	---	2.89E-01	8.27E+00	2.54E+01	---	2.86E+01
Aromatici C9 - C10	1.40E+01	3.50E-01	---	3.11E-01	4.03E+01	1.15E+02	---	1.29E+02
Alifatici C9 - C18	1.10E+01	2.75E-01	6.11E-01	2.44E-01	1.22E+05	4.44E+05	2.00E+05	5.00E+05
Alifatici C19 - C36	5.00E+00	---	2.78E-01	1.11E-01	5.56E+00	---	2.00E+01	5.00E+01
Aromatici C11 - C22	2.00E+00	5.00E-02	1.11E-01	4.44E-02	1.99E+02	3.99E+03	1.79E+03	4.48E+03

Classi	CRS (mg/kg s.s.)
Idrocarburi C<12	**4.0E+01**
Idrocarburi C>12	**1.8E+01**
Idrocarburi totali	**4.5E+01**

Nelle speciazione MADEP in maniera cautelativa le classi miste (ad es. Alifatici C9-C18) vengono conteggiate sia nei C<12 che nei C>12

Idrocarburi	C<12	C>12	HC tot
CSR (mg/kg s.s.)	**2.5E+01**	**2.0E+01**	**2.9E+01**
Classe critica	*Alifatici C5-C8*	*Alifatici C19 - C36*	*Alifatici C5-C8*

Figure 39: Window with the CSRs for the hydrocarbons for surface soil.

“<u>Screening NAPL (C_{res})</u>”

The button “Screening NAPL (C_{res})” is used to check the mobility of Non-Aqueous Phase Liquid (NAPL) in the saturated and unsaturated soil (Figure 40). For each contaminant the screening value, according to the standard ASTM E2081, is calculated and allows the user to determine the residual concentration of pollutants in soil[4] (RECONnet, 2015). Different information is present for each contaminant in this window:

---

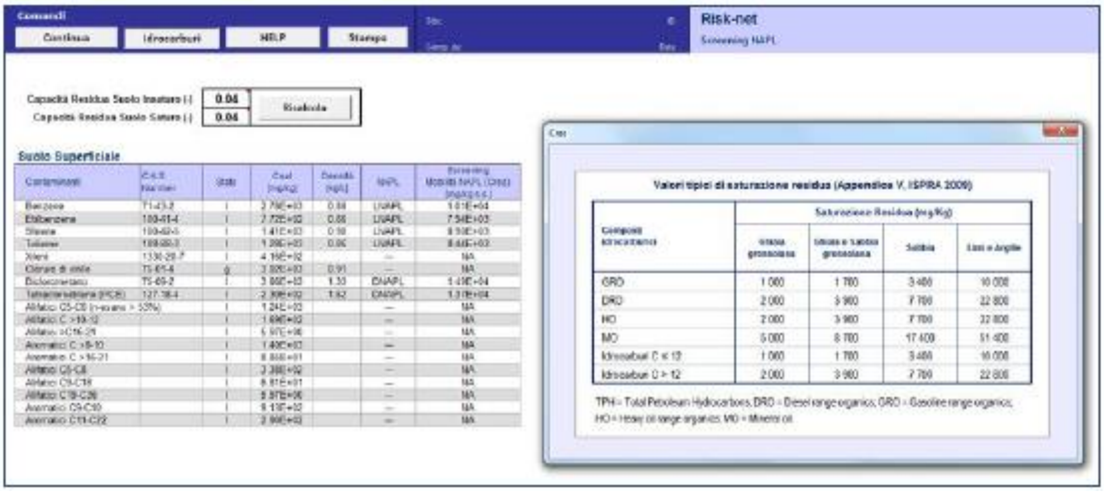
[4] The standard ASTM E2081 assumes that, in the case of a contaminant that is in the liquid phase at room temperature, the separated phase that is present when the C_{sat} is exceeded, is immobilized until the mechanical adsorbent capacity of the soil is reached (residual saturation) and the leaching can occur. In Risk-net, the residual capacity of soil is fixed by default at 0.04 according to the standard ASTM E2081-00.

- Physical phase at room temperature (L=liquid, S=solid, G=gaseous);
- C_{sat};
- Density;
- Type of NAPL, i.e. LNAPL (Light NAPL) and DNAPL (Dense NAPL);
- Screening concentration for mobilization of NAPL (only for liquid contaminants).

The contaminants for which the physical state or the density are not present in the database are indicated with "NA".

The command button "Idrocarburi" shows the typical residual concentration for the classes of hydrocarbons.

The button "Ricalcola" performs the calculation of the screening values according to the residual capacity of soil defined by the user in the cells on the top-left of the window.



Capacità Residua Suolo Insaturo (-) 0.04
Capacità Residua Suolo Saturo (-) 0.04

Valori tipici di saturazione residua (Appendice V, ISPRA 2009)

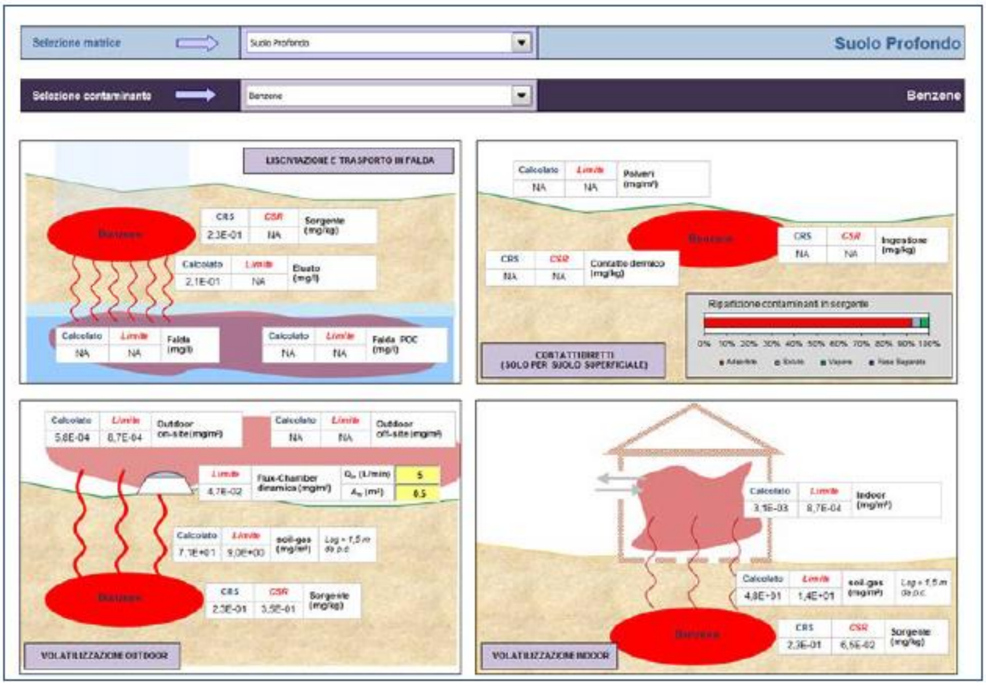
Composti idrocarburici	Saturazione Residua (mg/Kg)			
	Ghiaia grossolana	Ghiaia e sabbia grossolana	Sabbia	Limi e Argille
GRO	1 000	1 700	3 400	10 000
DRO	2 000	3 900	7 700	22 800
HO	2 000	3 900	7 700	22 800
MO	5 000	8 700	17 400	51 400
Idrocarburi C < 12	1 000	1 700	3 400	10 000
Idrocarburi C > 12	2 000	3 900	7 700	22 800

TPH = Total Petroleum Hydrocarbons, DRO = Diesel range organics, GRO = Gasoline range organics, HO = Heavy oil range organics, MO = Mineral oil

Figure 40: Window for the screening of NAPL.

6.1.9 *"Confronto concentrazioni"*

In the case of a "forward" risk assessment, the window reported in Figure 41 appears to the user after clicking on the button "Confronto concentrazioni". The user has to specify, in the two scrollbars, the matrix and the contaminant that have to be considered. Then the software reports the expected concentration for each matrix, based on the CRS defined before, and the corresponding CSR for the three polluted matrices, i.e. secondary sources (surface soil, deep soil and groundwater). Moreover, the weight distribution of the contaminant in the soil phases is shown. The cells with "NA" inside, indicate the exposure or migration pathways that were not considered or the cases where the CSR exceed the C_{sat}. In the latter case, it is necessary to remove the consideration of the Csat for the determination of the CSRs from the options for calculation in order to show the limits for the compartments.



Selezione matrice: Suolo Profondo

Selezione contaminante: Benzene

Calcolato	Limite	
NA	NA	Polveri (mg/m³)
2,1E-01	NA	Eluato (mg/l)
NA	NA	Falda (mg/l)
NA	NA	Falda POC (mg/l)
5,8E-04	8,7E-04	Outdoor on-site (mg/m³)
NA	NA	Outdoor off-site (mg/m³)
7,1E+01	9,0E+00	soil-gas (mg/m³)
3,1E-03	8,7E-04	Indoor (mg/m³)
4,8E+01	1,4E+01	soil-gas (mg/m³)

CRS	CSR	
2,3E-01	NA	Sorgente (mg/kg)
NA	NA	Ingestione (mg/kg)
NA	NA	Contatto dermico (mg/kg)
2,3E-01	3,5E-01	Sorgente (mg/kg)
2,3E-01	6,5E-02	Sorgente (mg/kg)

Limite			
4,7E-02	Flux-Chamber dinamica (mg/m³)	Q_{in} (L/min)	5
		A_{in} (m²)	0.5

Figure 41: "Confronto concentrazioni" window.

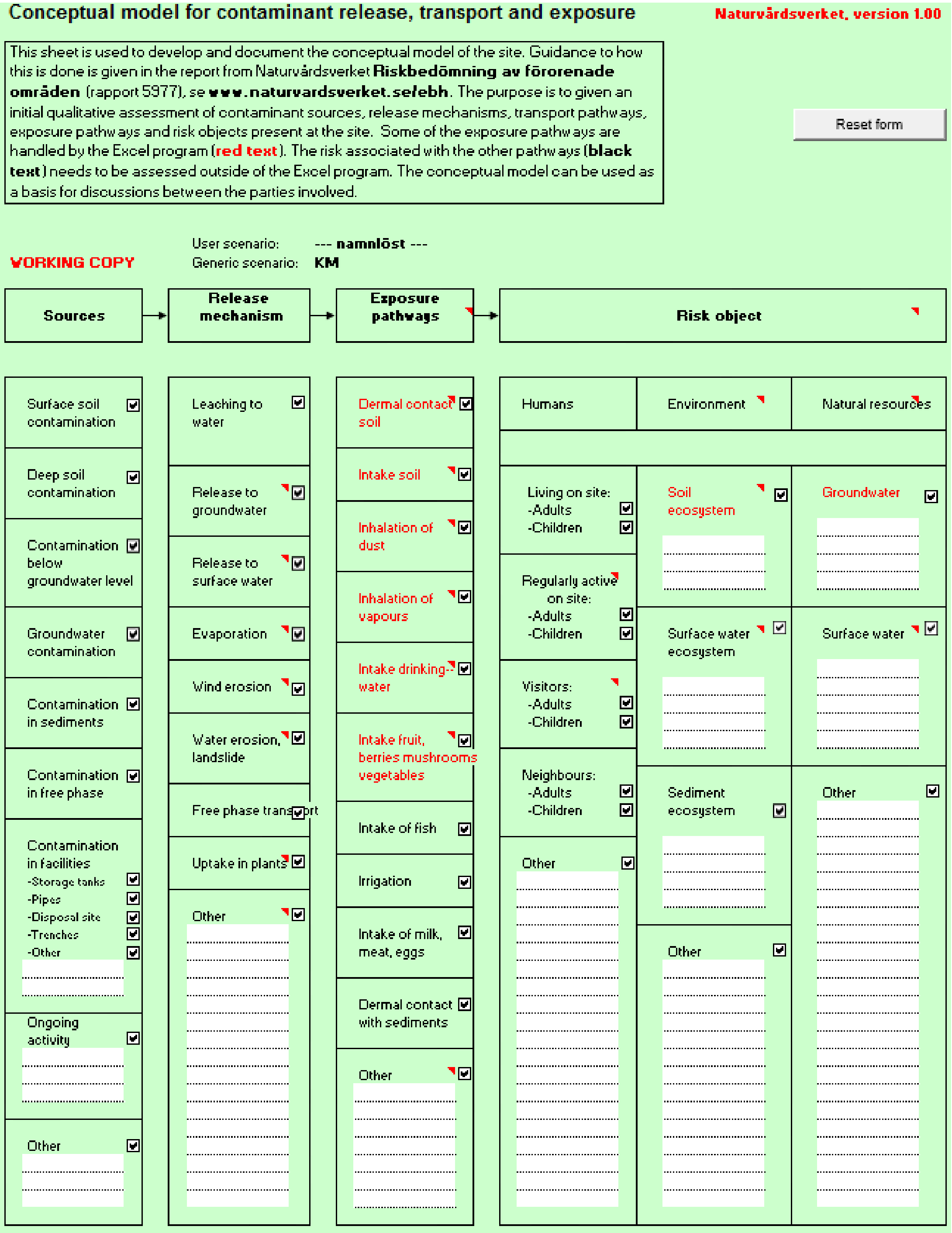
6.2 Software for site-specific soil generic guidelines by Kemakta AB

The software developed by Kemakta AB is used in Sweden to calculate the site-specific soil guidelines implementing in an Excel file the model used by SEPA to determine the soil generic guidelines. The excel file consists in nine sheets, each of them with a different purpose.

6.2.1 Conceptual model

The first sheet of the excel file is named "conceptual model" (Figure 42) and the parameters affecting the release, the transport and the exposure are reported in it. Starting from the left, the first column lists the possible sources of pollution, followed by the release mechanism and the exposure pathways. On the right side of the sheet the objects of the risk are reported. The cells with a ✓ are those that must be considered in the generic scenario (KM or MKM). The boxes with red text inside, as those of the exposure pathways, are directly connected to the pink cells in the sheet “Input” of the file. Moreover, these cells are those that strongly affect the determination of the soil guidelines. A separate case is constituted by the “surface water ecosystem” and “surface water” cells that, even if they are not containing red text, are always considered and also affect the outcomes. In fact, the user is not allowed to remove the ✓ from these two boxes because the protection of surface water and its ecosystem must be always guaranteed in the Swedish procedure (Elert, 2016; NATURVÅRDSVERKET (3), 2009).

It is possible to add more parameters in the boxes named “other” but these factors will not be considered by the model and has to be separately assessed.



Conceptual model for contaminant release, transport and exposure

Naturvårdsverket, version 1.00

This sheet is used to develop and document the conceptual model of the site. Guidance to how this is done is given in the report from Naturvårdsverket **Riskbedömning av förorenade områden** (rapport 5977), se **www.naturvardsverket.se/ebh**. The purpose is to given an initial qualitative assessment of contaminant sources, release mechanisms, transport pathways, exposure pathways and risk objects present at the site. Some of the exposure pathways are handled by the Excel program (**red text**). The risk associated with the other pathways (**black text**) needs to be assessed outside of the Excel program. The conceptual model can be used as a basis for discussions between the parties involved.

Reset form

WORKING COPY

User scenario: --- **namnlöst** ---
Generic scenario: **KM**

Sources → **Release mechanism** → **Exposure pathways** → **Risk object**

Sources

- Surface soil contamination ☑
- Deep soil contamination ☑
- Contamination below groundwater level ☑
- Groundwater contamination ☑
- Contamination in sediments ☑
- Contamination in free phase ☑
- Contamination in facilities
  - -Storage tanks ☑
  - -Pipes ☑
  - -Disposal site ☑
  - -Trenches ☑
  - -Other ☑
- Ongoing activity ☑
- Other ☑

Release mechanism

- Leaching to water ☑
- Release to groundwater ☑
- Release to surface water ☑
- Evaporation ☑
- Wind erosion ☑
- Water erosion, landslide ☑
- Free phase transport ☑
- Uptake in plants ☑
- Other ☑

Exposure pathways

- Dermal contact soil ☑
- Intake soil ☑
- Inhalation of dust ☑
- Inhalation of vapours ☑
- Intake drinking-water ☑
- Intake fruit, berries mushrooms vegetables ☑
- Intake of fish ☑
- Irrigation ☑
- Intake of milk, meat, eggs ☑
- Dermal contact with sediments ☑
- Other ☑

Risk object

Humans

- Living on site:
  - -Adults ☑
  - -Children ☑
- Regularly active on site:
  - -Adults ☑
  - -Children ☑
- Visitors:
  - -Adults ☑
  - -Children ☑
- Neighbours:
  - -Adults ☑
  - -Children ☑
- Other ☑

Environment

- Soil ecosystem ☑
- Surface water ecosystem ☑
- Sediment ecosystem ☑
- Other ☑

Natural resources

- Groundwater ☑
- Surface water ☑
- Other ☑

Figure 42: "Conceptual model" sheet of the software for the determination of site-specific soil guidelines.

6.2.2 “Input”

This sheet allows the user to modify and manipulate the inputs to the model.

Firstly, in the upper part of the sheet (Figure 44), a generic scenario has to be chosen (KM or MKM) so that the input values can be compared to those associated to the generic situation and a work mode selected between “working copy” and “Report” (Figure 43). There are no forced warnings in the first working mode, whilst they are present in the second one, with also compulsory comments. Once the generic scenario is selected, the default input values are reported in the orange cells and cannot be modified by the user. The own scenario to be modified can be named and described in the box on the top left of the sheet and, after it is saved clicking on the “Add new/Save changed” cell below, it appears as selected in the box “Choice of user scenario”. In the scrollbar it is possible to choose the user scenario to modify, i.e. to modify the values in the white cells. If no scenario is created, only KM or MKM can be selected, otherwise all the scenarios created and saved can be modified, allowing the user to evaluate different simulations.

The variation from the standard input values is reported in the third sheet of the file named “Comments” where it is also possible to add considerations to explain the motivations behind the changes in the inputs.

The contaminants for which soil guidelines must be determined (no more than 23) can be inserted using the scrollbars in the big box “Contaminants”. The compounds that can be selected are both the one provided by the database and those modified by the user, as it will be further explained in the chapter.

In the pink cells below the box “Contaminants” the exposure pathways are reported with the ✓ that can be removed only if in the sheet “Conceptual model” the pathway is excluded. On the right of the box “Exposure pathways” is the “Exposure parameters” one where it is possible to modify the exposure time and the consumption of plants. In the box “Scenario specific model parameters”, the type of base scenario must be chosen (KM or MKM) in order to define which value of exposure parameters, as daily soil ingestion, exposed skin surface and hours per day of exposure to vapors and dust, has to be adopted to define the soil guidelines.

The boxes “Soil and groundwater parameters” and “Contaminated site” are used to insert the features of the soil and the dimension of the site of study respectively. The length and the width of the site are calculated considering a rectangle that includes the polluted area. In particular, two sides of the rectangle have to be perpendicular and the other two parallel to the groundwater flow. In the same box, the user can add the guideline for contaminated soil below groundwater surface putting a ✓. This choice affects the spreading to groundwater and surface water and the intake of drinking water (NATURVÅRDSVERKET (3), 2009). The depth from groundwater surface at which contamination is present must be specified with a value greater than zero but lower than the thickness of the aquifer. The pollution of soil beneath groundwater surface is not considered in the general scenarios (KM and MKM).

Below, five boxes are present to edit the parameters about the transport model. In the first box on the left, the dilution to indoor and outdoor air is automatically calculated in the yellow cell by the program, as 1/DF, for vapor transport to indoor and outdoor air once the other parameters are inserted. In all the other cases, the dilution is calculated the same way (NATURVÅRDSVERKET (3), 2009). The pollutant to be considered must be chosen in the scrollbar. It must be highlighted that the choice of the compound has no effect on the calculation of the guidelines but enable the user to see the dilution factor calculated for the chosen compound.

The box about groundwater contains the information necessary to calculate the transport of the pollutant to groundwater, i.e. percolation, hydraulic conductivity (horizontal direction) and gradient and the aquifer thickness. The distance to the well is present as well, but it is considered only if the intake of drinking water is taken into account as exposure pathway. In the yellow cell is calculated the dilution in the groundwater at the well, using the other inputs.

The transport model for surface water considers either a lake or a river/stream. In the box “Transport model – surface water” it is possible to select which one should be included. Then, the volume and the turnover time of the lake or the flow rate of the stream are inserted. The dilution is calculated in the yellow cell through the input values.

If the user has calculated more precise site-specific dilution factors, it is possible to insert them in the box “Transport models – user dilution factors”, clicking on those available and marking them with a ✓ . The dilution factors are once again calculated as 1/DF.

In the box “Transport models – calculated water flow rates”, the flow rate in the contaminated soil and in the aquifer are calculated and reported in the two yellow cells. If the user’s inputs are consistent, the former should result lower than the latter (NATURVÅRDSVERKET (3), 2009).

The values to be used for the substances when considering the protection of soil environment have to be selected between the KM and the MKM ones, in the box “Protection of soil environment”. If other values should be used, a substance must be modified and saved as it will be explained at the end of this paragraph.

The box “Adjustment of guideline value” is used to add more considerations in the determination of the soil guideline, i.e. protection of groundwater and adjustment for acute toxicity or high background. The first two aspects can be excluded in this sheet, whilst the protection of groundwater can be neglected only removing the ✓ in the sheet “Conceptual model” (NATURVÅRDSVERKET (3), 2009). The distance to the protected groundwater must be specified so that the dilution can be automatically calculated in the yellow cell. If the user has a more reliable dilution factor, it can be inserted in the corresponding cell.

Since the surface water protection is always considered by the program, assuming that the pollution will always reach a surface water resource in the future, it is not present in the sheet “Input”.

Below the boxes for the transport model, it is possible to save, modify and remove scenarios.

At the bottom of the sheet “Input” (Figure 43 to Figure 45), the user has the possibility to create new substances modifying the parameters of the chemicals available in the database of the program. The user can also create a completely new substance simply reaching the end of the scrollbar “Create substance from existing” and selecting “No substance”. The name of the compound can be edited by the user and in the case of a chemical present in the database, e.g., lead, in the suggested name will appear “-mod”, e.g., lead-mod. In order to add the compound, the user has to click on “Create substance” and on “Remove substance” to delete it. In the scrollbar “Select substance parameter” the parameter to be changed with a user value can be selected and the reference, already present or just created, that justifies this variation can be inserted.

The last box of the sheet “Input” allows the user to modify a model parameter, e.g., diffusivity in pure air or water, wind speed, exposed skin area, bodyweight, years of exposure etc.

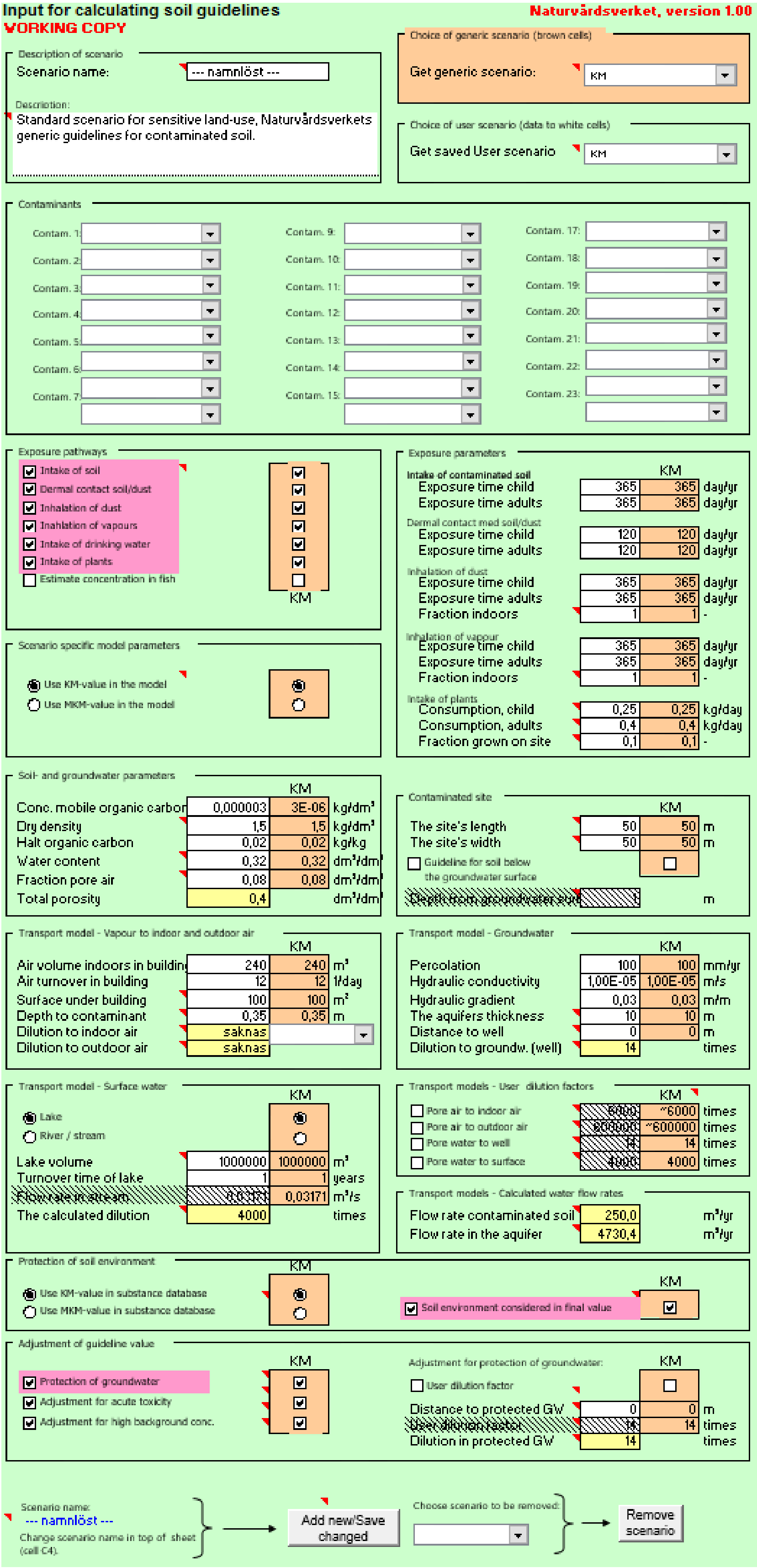
If an input value is considered as not realistic, the corresponding cell is highlighted in red to let the user know. However, the program will still calculate the guidelines with the input inserted by the user.

Work mode

● Working copy - No forced warnings, reports is marked draft copy

○ Report - Forced warnings, compulsory comments

Figure 43: “Work mode” box in the “Input” sheet.



Input for calculating soil guidelines
VORKING COPY
Naturvårdsverket, version 1.00

Description of scenario
Scenario name: --- namnlöst ---
Description:
Standard scenario for sensitive land-use, Naturvårdsverkets generic guidelines for contaminated soil.

Choice of generic scenario (brown cells)
Get generic scenario: KM

Choice of user scenario (data to white cells)
Get saved User scenario KM

Contaminants
Contam. 1:
Contam. 2:
Contam. 3:
Contam. 4:
Contam. 5:
Contam. 6:
Contam. 7:
Contam. 9:
Contam. 10:
Contam. 11:
Contam. 12:
Contam. 13:
Contam. 14:
Contam. 15:
Contam. 17:
Contam. 18:
Contam. 19:
Contam. 20:
Contam. 21:
Contam. 22:
Contam. 23:

Exposure pathways

	KM
☑ Intake of soil	☑
☑ Dermal contact soil/dust	☑
☑ Inhalation of dust	☑
☑ Inahlation of vapours	☑
☑ Intake of drinking water	☑
☑ Intake of plants	☑
☐ Estimate concentration in fish	☐

Exposure parameters

		KM	
Intake of contaminated soil			
Exposure time child	365	365	day/yr
Exposure time adults	365	365	day/yr
Dermal contact med soil/dust			
Exposure time child	120	120	day/yr
Exposure time adults	120	120	day/yr
Inhalation of dust			
Exposure time child	365	365	day/yr
Exposure time adults	365	365	day/yr
Fraction indoors	1	1	-
Inhalation of vapour			
Exposure time child	365	365	day/yr
Exposure time adults	365	365	day/yr
Fraction indoors	1	1	-
Intake of plants			
Consumption, child	0,25	0,25	kg/day
Consumption, adults	0,4	0,4	kg/day
Fraction grown on site	0,1	0,1	-

Scenario specific model parameters

● Use KM-value in the model	●
○ Use MKM-value in the model	○

Soil- and groundwater parameters

		KM	
Conc. mobile organic carbon	0,000003	3E-06	kg/dm³
Dry density	1,5	1,5	kg/dm³
Halt organic carbon	0,02	0,02	kg/kg
Water content	0,32	0,32	dm³/dm³
Fraction pore air	0,08	0,08	dm³/dm³
Total porosity	0,4		dm³/dm³

Contaminated site

		KM	
The site's length	50	50	m
The site's width	50	50	m
☐ Guideline for soil below the groundwater surface		☐	
Depth from groundwater surf	1		m

Transport model - Vapour to indoor and outdoor air

		KM	
Air volume indoors in building	240	240	m³
Air turnover in building	12	12	1/day
Surface under building	100	100	m²
Depth to contaminant	0,35	0,35	m
Dilution to indoor air	saknas		
Dilution to outdoor air	saknas		

Transport model - Groundwater

		KM	
Percolation	100	100	mm/yr
Hydraulic conductivity	1,00E-05	1,00E-05	m/s
Hydraulic gradient	0,03	0,03	m/m
The aquifers thickness	10	10	m
Distance to well	0	0	m
Dilution to groundw. (well)	14		times

Transport model - Surface water

		KM	
● Lake		●	
○ River / stream		○	
Lake volume	1000000	1000000	m³
Turnover time of lake	1	1	years
Flow rate in stream	0,03171	0,03171	m³/s
The calculated dilution	4000		times

Transport models - User dilution factors

		KM	
☐ Pore air to indoor air	6000	~6000	times
☐ Pore air to outdoor air	600000	~600000	times
☐ Pore water to well	14	14	times
☐ Pore water to surface	4000	4000	times

Transport models - Calculated water flow rates

Flow rate contaminated soil	250,0	m³/yr
Flow rate in the aquifer	4730,4	m³/yr

Protection of soil environment

	KM
● Use KM-value in substance database	●
○ Use MKM-value in substance database	○
☑ Soil environment considered in final value	☑

Adjustment of guideline value

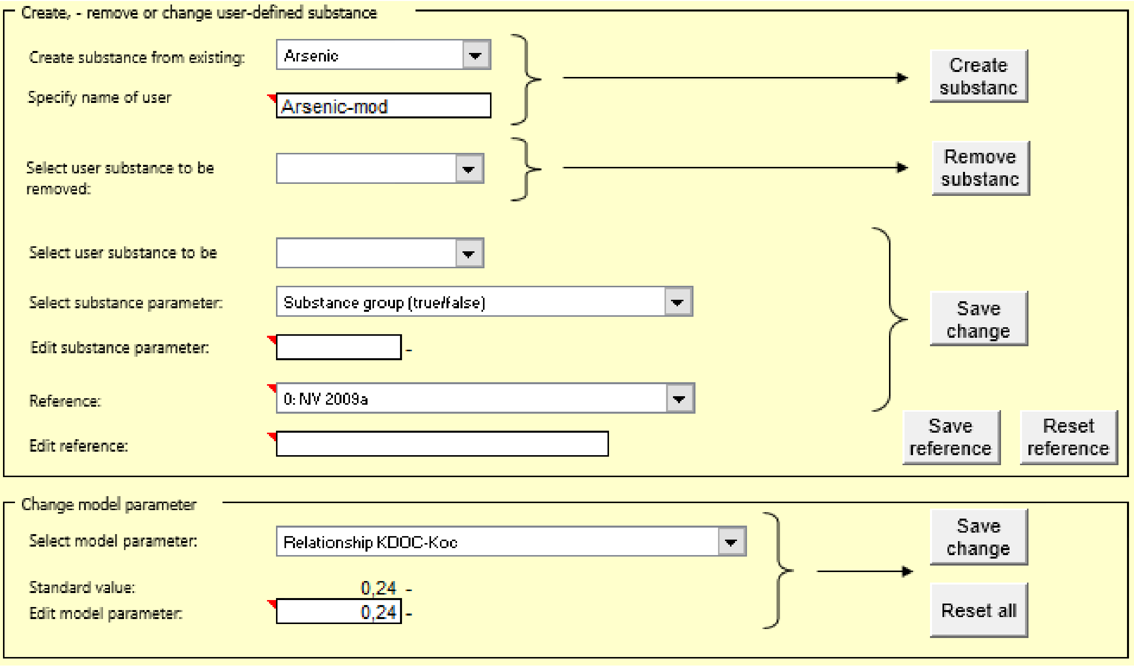
	KM
☑ Protection of groundwater	☑
☑ Adjustment for acute toxicity	☑
☑ Adjustment for high background conc.	☑

Adjustment for protection of groundwater:

		KM	
☐ User dilution factor		☐	
Distance to protected GW	0	0	m
User dilution factor	14	14	times
Dilution in protected GW	14		times

Scenario name:
--- namnlöst ---
Change scenario name in top of sheet (cell C4).

Figure 44: Upper part of the sheet "Inputs".


Create, - remove or change user-defined substance

Create substance from existing: Arsenic

Specify name of user: Arsenic-mod

Select user substance to be removed:

Select user substance to be

Select substance parameter: Substance group (true/false)

Edit substance parameter: -

Reference: 0: NV 2009a

Edit reference:

Change model parameter

Select model parameter: Relationship KDOC-Koc

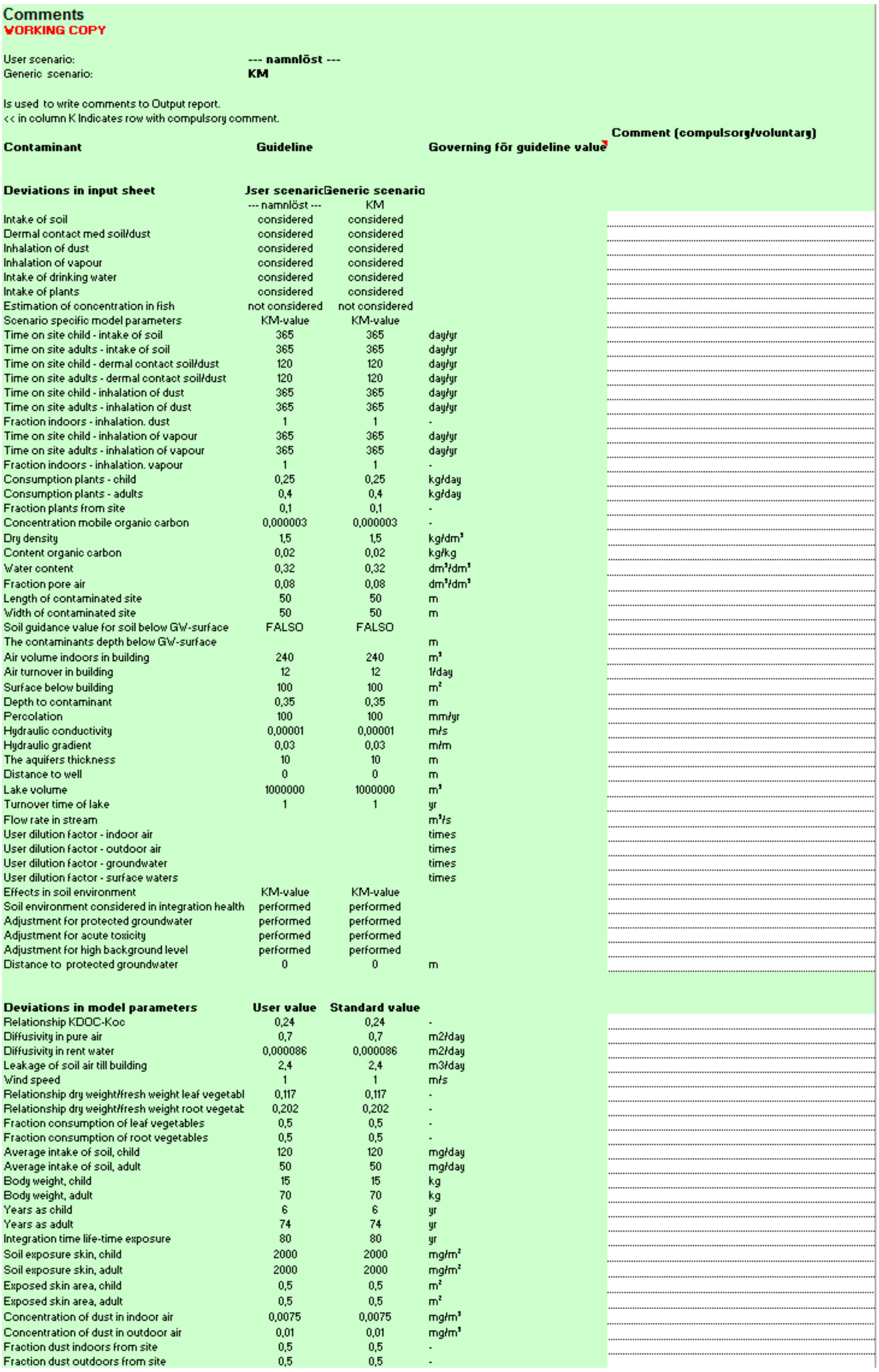
Standard value: 0,24 -

Edit model parameter: 0,24 -

Figure 45: The bottom part of the sheet "Input".

6.2.3 "Comments"

In the third sheet of the excel file (Figure 46), the changes applied by the user in the "Input" sheet are reported together with the default inputs for the generic scenario. On the right of the sheet, the user can write down a comment to explain the modification. If the line is highlighted in red, the comment is considered compulsory.



Comments
VORKING COPY

User scenario: --- namnlöst ---
Generic scenario: KM

Is used to write comments to Output report.
<< in column K Indicates row with compulsory comment.

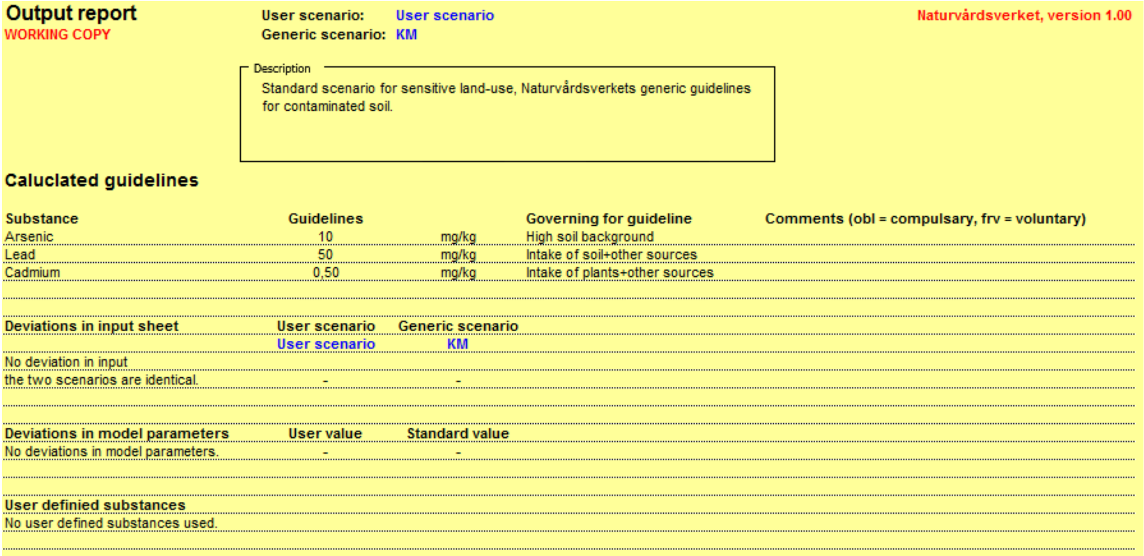
Contaminant	Guideline		Governing för guideline value	Comment (compulsory/voluntary)
Deviations in input sheet	**Jser scenario**	**Generic scenario**		
	--- namnlöst ---	KM		
Intake of soil	considered	considered		
Dermal contact med soil/dust	considered	considered		
Inhalation of dust	considered	considered		
Inhalation of vapour	considered	considered		
Intake of drinking water	considered	considered		
Intake of plants	considered	considered		
Estimation of concentration in fish	not considered	not considered		
Scenario specific model parameters	KM-value	KM-value		
Time on site child - intake of soil	365	365	day/yr	
Time on site adults - intake of soil	365	365	day/yr	
Time on site child - dermal contact soil/dust	120	120	day/yr	
Time on site adults - dermal contact soil/dust	120	120	day/yr	
Time on site child - inhalation of dust	365	365	day/yr	
Time on site adults - inhalation of dust	365	365	day/yr	
Fraction indoors - inhalation. dust	1	1	-	
Time on site child - inhalation of vapour	365	365	day/yr	
Time on site adults - inhalation of vapour	365	365	day/yr	
Fraction indoors - inhalation. vapour	1	1	-	
Consumption plants - child	0,25	0,25	kg/day	
Consumption plants - adults	0,4	0,4	kg/day	
Fraction plants from site	0,1	0,1	-	
Concentration mobile organic carbon	0,000003	0,000003	-	
Dry density	1,5	1,5	kg/dm^3	
Content organic carbon	0,02	0,02	kg/kg	
Water content	0,32	0,32	dm^3/dm^3	
Fraction pore air	0,08	0,08	dm^3/dm^3	
Length of contaminated site	50	50	m	
Width of contaminated site	50	50	m	
Soil guidance value for soil below GW-surface	FALSO	FALSO		
The contaminants depth below GW-surface			m	
Air volume indoors in building	240	240	m^3	
Air turnover in building	12	12	1/day	
Surface below building	100	100	m^2	
Depth to contaminant	0,35	0,35	m	
Percolation	100	100	mm/yr	
Hydraulic conductivity	0,00001	0,00001	m/s	
Hydraulic gradient	0,03	0,03	m/m	
The aquifers thickness	10	10	m	
Distance to well	0	0	m	
Lake volume	1000000	1000000	m^3	
Turnover time of lake	1	1	yr	
Flow rate in stream			m^3/s	
User dilution factor - indoor air			times	
User dilution factor - outdoor air			times	
User dilution factor - groundwater			times	
User dilution factor - surface waters			times	
Effects in soil environment	KM-value	KM-value		
Soil environment considered in integration health	performed	performed		
Adjustment for protected groundwater	performed	performed		
Adjustment for acute toxicity	performed	performed		
Adjustment for high background level	performed	performed		
Distance to protected groundwater	0	0	m	
Deviations in model parameters	**User value**	**Standard value**		
Relationship KDOC-Koc	0,24	0,24	-	
Diffusivity in pure air	0,7	0,7	m2/day	
Diffusivity in rent water	0,000086	0,000086	m2/day	
Leakage of soil air till building	2,4	2,4	m3/day	
Wind speed	1	1	m/s	
Relationship dry weight/fresh weight leaf vegetabl	0,117	0,117	-	
Relationship dry weight/fresh weight root vegetat	0,202	0,202	-	
Fraction consumption of leaf vegetables	0,5	0,5	-	
Fraction consumption of root vegetables	0,5	0,5	-	
Average intake of soil, child	120	120	mg/day	
Average intake of soil, adult	50	50	mg/day	
Body weight, child	15	15	kg	
Body weight, adult	70	70	kg	
Years as child	6	6	yr	
Years as adult	74	74	yr	
Integration time life-time exposure	80	80	yr	
Soil exposure skin, child	2000	2000	mg/m^2	
Soil exposure skin, adult	2000	2000	mg/m^2	
Exposed skin area, child	0,5	0,5	m^2	
Exposed skin area, adult	0,5	0,5	m^2	
Concentration of dust in indoor air	0,0075	0,0075	mg/m^3	
Concentration of dust in outdoor air	0,01	0,01	mg/m^3	
Fraction dust indoors from site	0,5	0,5	-	
Fraction dust outdoors from site	0,5	0,5	-	

Figure 46: The upper part of the "Comments" sheet.

6.2.4 "Output report"

This sheet reports the calculated guidelines for the substances inserted by the user and according to input values. For each calculated guideline, the main factor affecting its determination is reported in the column "Governing for guideline". Below, the variations applied in the "Input" sheet are listed in three parts: the deviation from the generic scenario, the deviation in model parameters and the new substances edited by the user. On the right it is possible to add compulsory (obl) or voluntary (frv) comments. In Figure 47 is illustrated the sheet "Output report" for the edited "User scenario" in which Arsenic, Lead and Cadmium are inserted as pollutants to calculate the guidelines.

The program, when calculating the final guideline, applies rounding so that the showed value is a even power of ten of 10, 12, 15, 18, 20, 25, 30, 35, 40, 50, 60, 70 and 80.



Output report
WORKING COPY

User scenario: User scenario
Generic scenario: KM

Naturvårdsverket, version 1.00

Description
Standard scenario for sensitive land-use, Naturvårdsverkets generic guidelines for contaminated soil.

Caluclated guidelines

Substance	Guidelines		Governing for guideline	Comments (obl = compulsary, frv = voluntary)
Arsenic	10	mg/kg	High soil background	
Lead	50	mg/kg	Intake of soil+other sources	
Cadmium	0,50	mg/kg	Intake of plants+other sources	

Deviations in input sheet	User scenario	Generic scenario
	User scenario	KM
No deviation in input		
the two scenarios are identical.	-	-

Deviations in model parameters	User value	Standard value
No deviations in model parameters.	-	-

User definied substances
No user defined substances used.

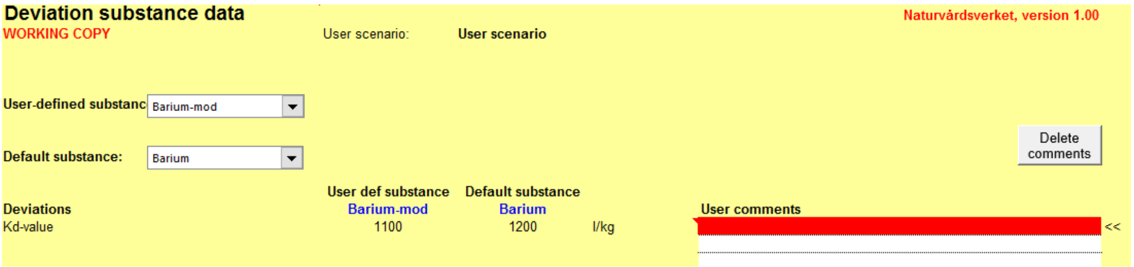
Figure 47: "Output report" sheet, with guidelines for As, Pb, Cd.

6.2.5 *"Deviation substances"*

In this sheet, the different properties between the user-modified substance and the corresponding original one, are reported. Next to the column with the parameters, the comments can be added and, if the line is colored in red, the user should add a comment.

It is also possible to show a list of all the parameters of the chemical modified by the user. In order to display the list of properties, the user has to select from the scrollbar "Default substance" the voice "no substance".

In Figure 48 is reported the example in which the user has changed the K_d value of barium, creating the substance "Barium-mod".


Deviation substance data
WORKING COPY
User scenario: **User scenario**
Naturvårdsverket, version 1.00

User-defined substanc: Barium-mod
Default substance: Barium

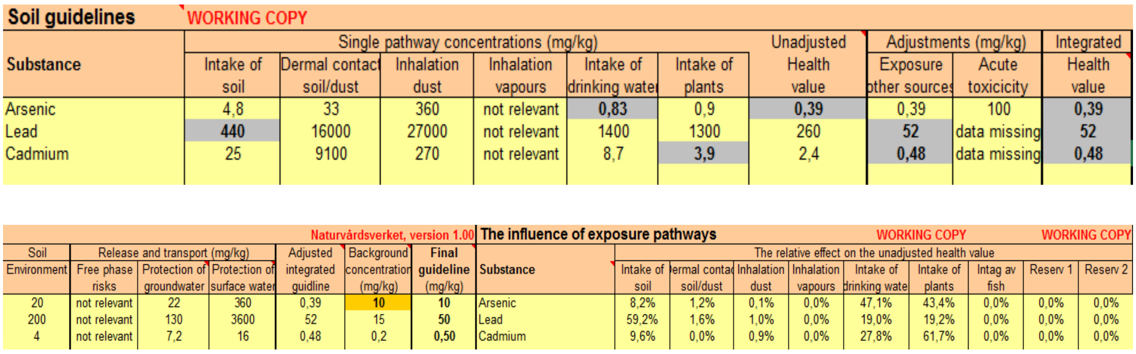
Deviations	User def substance Barium-mod	Default substance Barium		User comments
Kd-value	1100	1200	l/kg	

Figure 48: "Deviation substance data" sheet with a user Kd value for Ba.

6.2.6 *"Guidelines"*

The sheet "Guidelines" (Figure 49) reports in detail the partial determination of the soil guidelines, allowing the user to understand which are the factors that adjusted and determined the final benchmark value. In the table "Single pathway concentration" the guideline for each contaminant considered is reported for all the exposure pathways. On the right the unadjusted integrated health guideline is calculated and in the table "Adjustments" the required modifications are applied according to background exposure and acute toxicity considerations. Also the guidelines calculated for protection of soil environment and against release and transport are shown. The adjusted guideline for protection of health and environment is then compared to the background concentration of the pollutant, reported in the homonymous cell. The final guideline is shown in bold in the column "Final guideline". On the right of the sheet the table "The influence of exposure pathways" reports, for each substance, how relevant each exposure pathway, in terms of percentage, was in the determination of the integrated unadjusted health guideline.

The cells colored in gray correspond to the most important factor affecting the guideline calculation. In the case of the column "Background concentration" the cell is colored in orange if this value is used to adjust the final guideline. The final guideline value might differ from the one highlighted in gray or orange, due to the rounding applied by the program as explained before. For example, in Figure 49 it is possible to see that the final guideline for Pb is 50 mg/kg, but the real not-rounded value was 52 mg/kg, as reported in the gray cell under "Exposure other sources" column.



Soil guidelines WORKING COPY

Substance	Intake of soil	Dermal contact soil/dust	Inhalation dust	Inhalation vapours	Intake of drinking wate	Intake of plants	Unadjusted Health value	Exposure other sources	Acute toxicity	Integrated Health value
	Single pathway concentrations (mg/kg)							Adjustments (mg/kg)		
Arsenic	4,8	33	360	not relevant	**0,83**	0,9	**0,39**	0,39	100	**0,39**
Lead	**440**	16000	27000	not relevant	1400	1300	260	**52**	data missing	**52**
Cadmium	25	9100	270	not relevant	8,7	**3,9**	2,4	**0,48**	data missing	**0,48**

Naturvårdsverket, version 1.00

Soil Environment	Free phase risks	Protection of groundwater	Protection of surface water	Adjusted integrated guidline	Background concentration (mg/kg)	**Final guideline (mg/kg)**
	Release and transport (mg/kg)					
20	not relevant	22	360	0,39	**10**	**10**
200	not relevant	130	3600	52	15	**50**
4	not relevant	7,2	16	0,48	0,2	**0,50**

The influence of exposure pathways WORKING COPY WORKING COPY

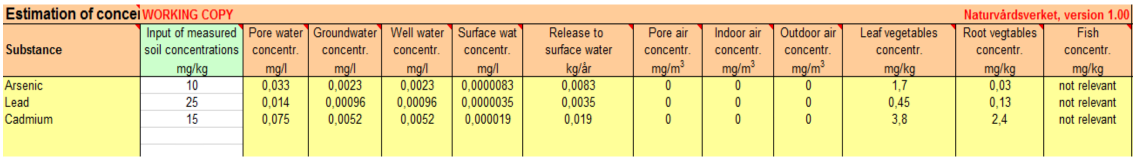
The relative effect on the unadjusted health value

Substance	Intake of soil	ermal contac soil/dust	Inhalation dust	Inhalation vapours	Intake of drinking wate	Intake of plants	Intag av fish	Reserv 1	Reserv 2
Arsenic	8,2%	1,2%	0,1%	0,0%	47,1%	43,4%	0,0%	0,0%	0,0%
Lead	59,2%	1,6%	1,0%	0,0%	19,0%	19,2%	0,0%	0,0%	0,0%
Cadmium	9,6%	0,0%	0,9%	0,0%	27,8%	61,7%	0,0%	0,0%	0,0%

Figure 49: "Guidelines" sheet with As, Pb and Cd as considered substances.

6.2.7 *"Concentrations"*

The sheet "Concentrations" is used to estimate the presence of pollution in the different media, using the same transport model adopted for the determination of the soil guidelines. The actual concentration of the pollutants added as inputs has to be inserted in the column "Input of measured soil concentration" so the presence of pollution in pore air and water, groundwater, well water, surface water, indoor and outdoor air, vegetables and fish as well as the release to surface water, can be determined and shown in the corresponding column. In Figure 50 the calculations are performed for As, Pb and Cr with user's input concentrations.



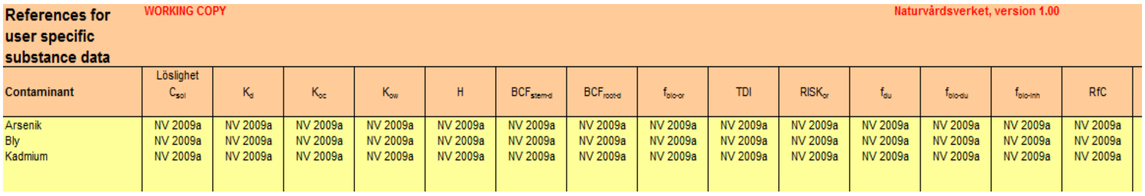
Estimation of concei WORKING COPY Naturvårdsverket, version 1.00

Substance	Input of measured soil concentrations mg/kg	Pore water concentr. mg/l	Groundwater concentr. mg/l	Well water concentr. mg/l	Surface wat concentr. mg/l	Release to surface water kg/år	Pore air concentr. mg/m^3	Indoor air concentr. mg/m^3	Outdoor air concentr. mg/m^3	Leaf vegetables concentr. mg/kg	Root vegtables concentr. mg/kg	Fish concentr. mg/kg
Arsenic	10	0,033	0,0023	0,0023	0,0000083	0,0083	0	0	0	1,7	0,03	not relevant
Lead	25	0,014	0,00096	0,00096	0,0000035	0,0035	0	0	0	0,45	0,13	not relevant
Cadmium	15	0,075	0,0052	0,0052	0,000019	0,019	0	0	0	3,8	2,4	not relevant

Figure 50: "Concentrations" sheet with As, Pb and Cr as considered substances.

6.2.8 *"User references"*

The substances, for which the guidelines are calculated, and their properties are reported with the associated reference in the only table present in the sheet. The user and generic scenarios' names and the default and user references are shown below the table (Figure 51).



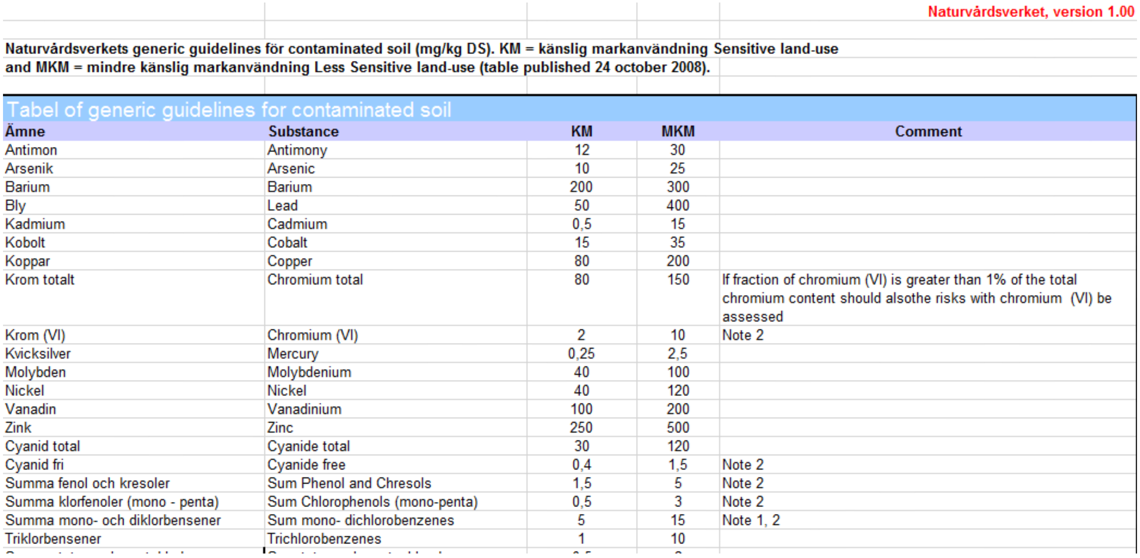
References for user specific substance data WORKING COPY Naturvårdsverket, version 1.00

Contaminant	Löslighet C_{sol}	K_d	K_{oc}	K_{ow}	H	BCF_{stem-d}	BCF_{root-d}	f_{bio-or}	TDI	$RISK_{or}$	f_{du}	f_{bio-du}	$f_{bio-inh}$	RfC
Arsenik	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a
Bly	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a
Kadmium	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a	NV 2009a

Figure 51: "User references" sheet with As, Pb and Cr as considered substances.

6.2.9 "Generic guidelines"

The generic guidelines for KM and MKM scenarios determined by SEPA are reported in this sheet that can be used to quickly compare the site-specific values with the general ones (Figure 52).



Naturvårdsverket, version 1.00

Naturvårdsverkets generic guidelines för contaminated soil (mg/kg DS). KM = känslig markanvändning Sensitive land-use and MKM = mindre känslig markanvändning Less Sensitive land-use (table published 24 october 2008).

Tabel of generic guidelines for contaminated soil

Ämne	Substance	KM	MKM	Comment
Antimon	Antimony	12	30	
Arsenik	Arsenic	10	25	
Barium	Barium	200	300	
Bly	Lead	50	400	
Kadmium	Cadmium	0,5	15	
Kobolt	Cobalt	15	35	
Koppar	Copper	80	200	
Krom totalt	Chromium total	80	150	If fraction of chromium (VI) is greater than 1% of the total chromium content should alsothe risks with chromium (VI) be assessed
Krom (VI)	Chromium (VI)	2	10	Note 2
Kvicksilver	Mercury	0,25	2,5	
Molybden	Molybdenium	40	100	
Nickel	Nickel	40	120	
Vanadin	Vanadinium	100	200	
Zink	Zinc	250	500	
Cyanid total	Cyanide total	30	120	
Cyanid fri	Cyanide free	0,4	1,5	Note 2
Summa fenol och kresoler	Sum Phenol and Chresols	1,5	5	Note 2
Summa klorfenoler (mono - penta)	Sum Chlorophenols (mono-penta)	0,5	3	Note 2
Summa mono- och diklorbensener	Sum mono- dichlorobenzenes	5	15	Note 1, 2
Triklorbensener	Trichlorobenzenes	1	10	

Figure 52: "Generic guidelines" sheet.

7 Case of study

The site for which the risk assessment is performed is Bollnäs Bro 4:4, located in the town of Bollnäs, in the Centre of Sweden (Figure 53).

Figure 53: Location of Bollnäs and of the site of study, Bollnäs Bro 4:4 (Engström and Örne, 2015; Ezilon Maps).

7.1.1 Geology

Drilling test conducted in 2015 showed that the property soil is covered with filling material with a depth variating between 0.5 and 4 meters. The material is mainly constituted by sand and gravel but also some residues from the activities performed at the site, e.g., coal and ashes. The natural soil nearby the site is mainly silt and till, i.e. unsorted glacial sediment. This information visible in the geological map of Bollnäs, reported in Figure 54 (Engström and Örne, 2015).

7.1.2 Surface water and groundwater

No surface water resources are located in the property, with the closest one constituted by the Ljusnan river, at 300 m east of the site, that flows into the Varpen lake. Bollnäs Bro 4:4 is crossed in the southern area by a culvert for storm water (Figure 55 a) that has two outlets: the first located where Ljusnan flows into the lake and the second in lake Varpen (Figure 55 b). Previous investigations found that the culvert drains the groundwater from the southern half of the property transporting it towards the outlets (Engström and Örne, 2015).

The site slopes to the south where there the nearest residential building are. The water table was detected between 0.5 and 3 m beneath surface. The groundwater levels and the plausible direction of groundwater flow are reported in Appendix 3. Due to the heterogeneity of the filling material used at the site, the groundwater flow can vary significantly, but the main direction is deemed to be the south. In the surrounding area, the flow direction is south-southeast, as in the southern part of the site, due to the presence of the culvert. However, some flow towards the east might occur in the northern part of the property (Engström and Örne, 2015).

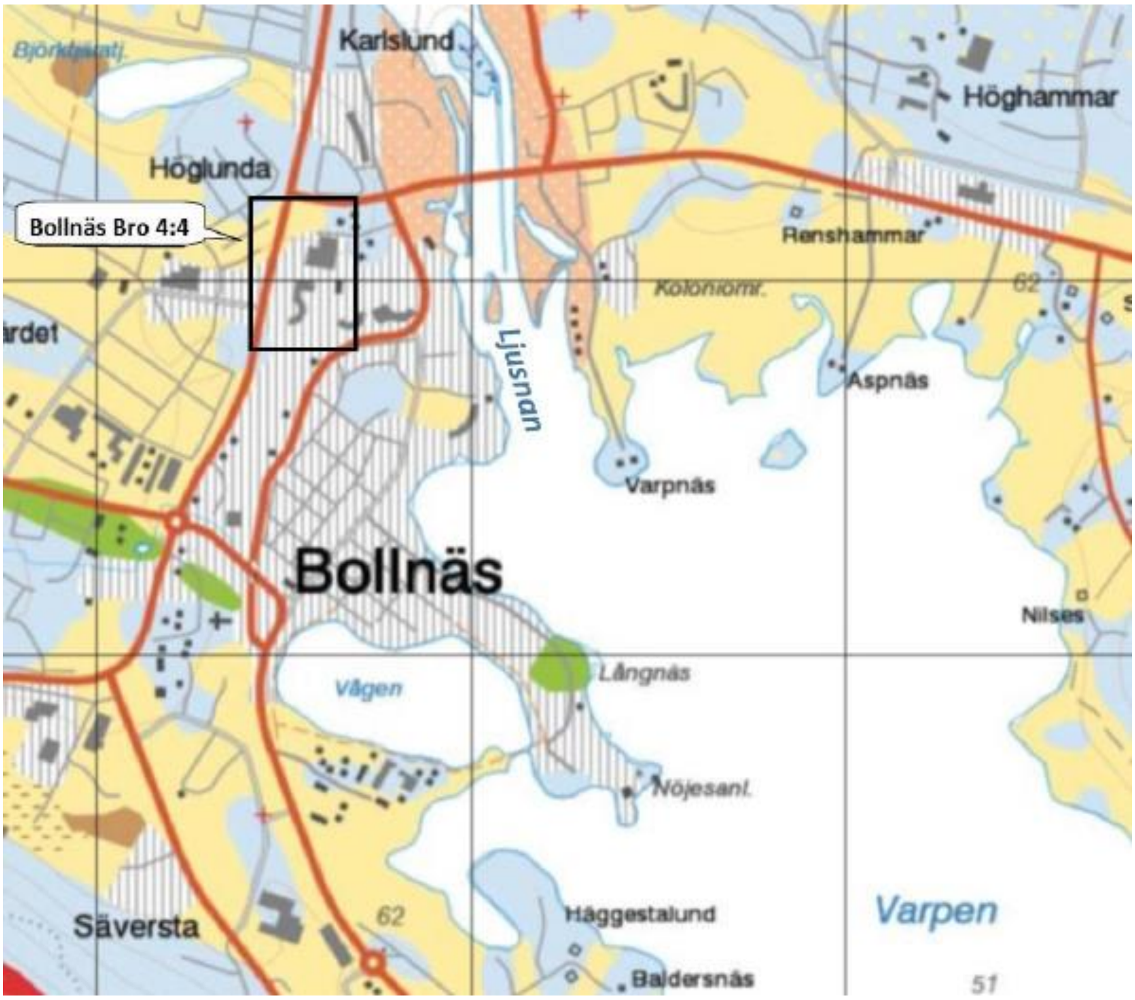


Figure 54: Geological map of the area of Bollnäs. The filling (striped area) covers the entire property of Bollnäs Bro 4:4 while the natural soil close to it is constituted by silt (yellow area) and moraine (blue area) (Engström and Örne, 2015).

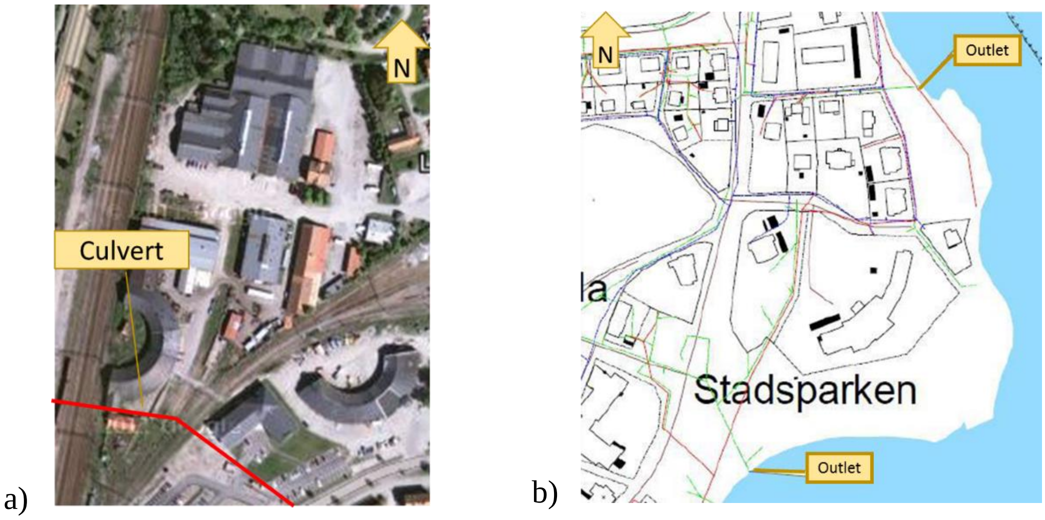


Figure 55: a) culvert for stromwater collection crossing the site of Bollnäs Bro 4:4; b) outlets of the culvert (Engström and Örne, 2015; Google Maps).

7.1.3 Past and present activities

In Bollnäs Bro 4:4 SJ (Swedish Transport Administration) coaches and locomotives have been stored, repaired and painted for about one century. Impregnation with creosote, coal storage, use of trichloroethylene for cleaning purposes occurred at the site and oil tanks were located in the area (Engström and Örne, 2015). The past activities performed at the site are reported in Figure 56.

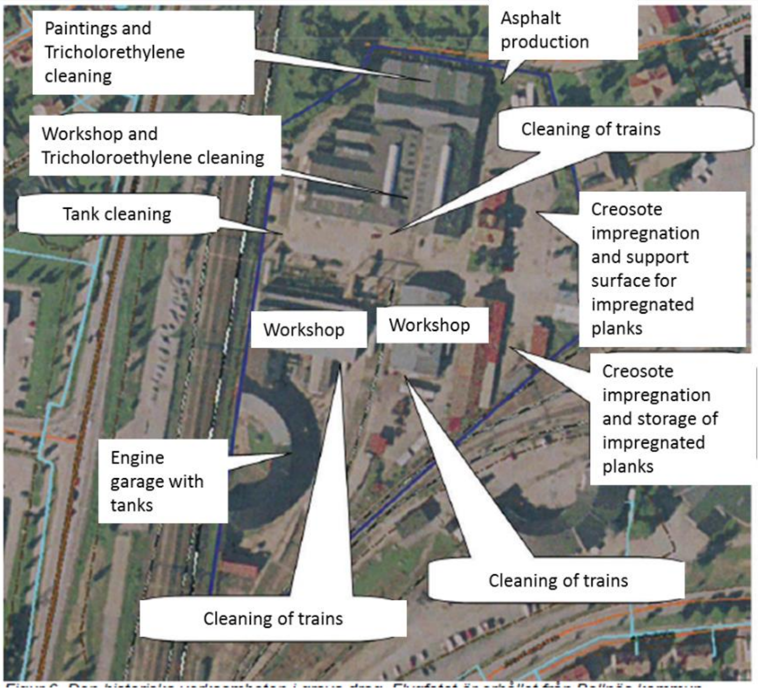


Figure 56: Historical map of the property Bollnäs Bro 4:4 with the activities performed on site (Engström and Örne, 2015).

At the present time, the area is open to the public and it can be classified as MKM with stores, offices, a glass blower and a recreational building for young people. The current activities on the properties are reported in Figure 57.

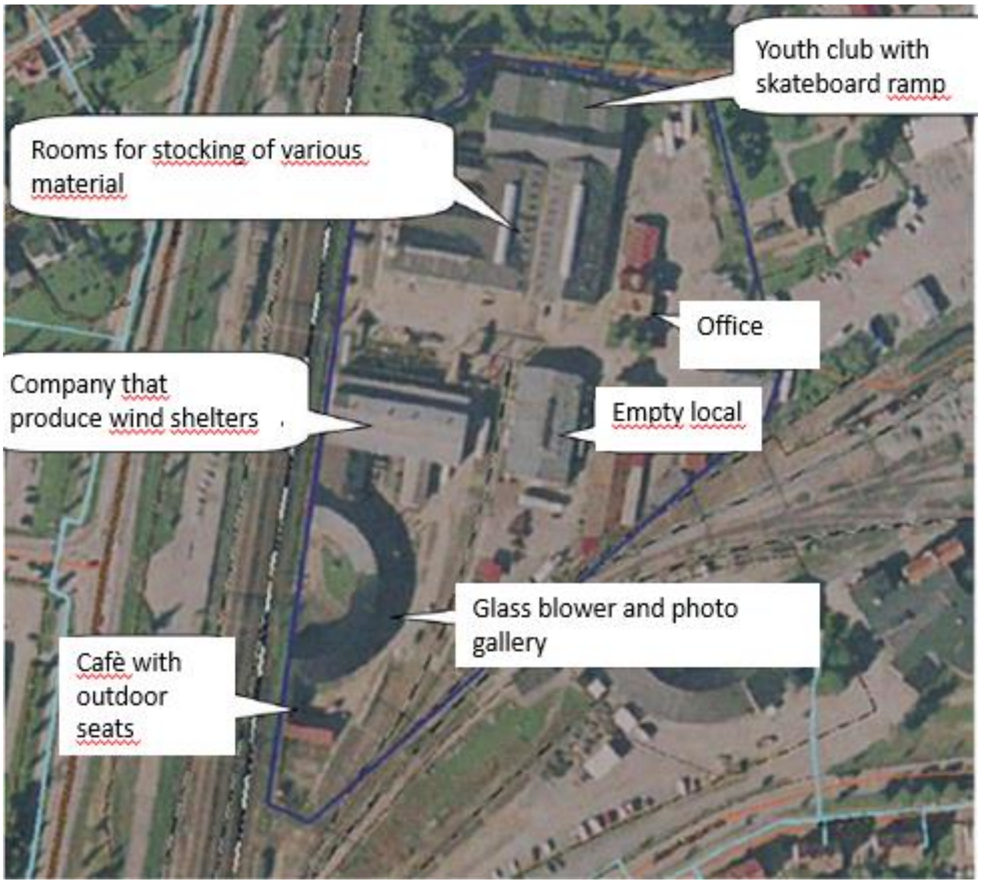


Figure 57: Map of the Bollnäs Bro 4:4 with current activities (Engström and Örne, 2015).

7.1.4 Targets to be protected

People that regularly work in the area or that come to visit it, as well as the residents living nearby the site, may be affected by the contamination. The closest private house is located immediately north of the property, while a residential area is located at 150 m from the southern border of the site (Engström and Örne, 2015).

No wells for drinking water purposes or areas of groundwater protection are located close to the polluted site. The river Ljusnan and the lake Varpen are the protected resources for surface water (Engström and Örne, 2015; SGU).

Due to the compact covering present on the site’s surface, there is no specific target to be protected when considering the soil environment (Engström and Örne, 2015).

7.1.5 Future land use

The municipality of Bollnäs intends to keep using the site for offices and working areas, to save the recreational building and a small structure at the gates of the property, the building where the glass shop and the coffee house are located a small part of the edifice where the wind shelters company is, due to their historical value. Moreover, it is planned to build a new and bigger recreational area for youngsters and visitors, with green spaces but no cultivation (Engström and Örne, 2015) (Figure 58).

Figure 58: Future land planning for the property Bollnäs Bro 4:4 (picture by Bollnäs Kommun).

7.1.6 Previous studies

Four studies have been performed in the property Bollnäs Bro 4:4:

- "Limited environmental engineering surveying of the property Bollnäs Bro 4: 4". SGI on behalf of Bollnäs municipality TSF Real Estate Group. 2008-04-28.
- "In-depth environmental engineering surveying of the property Bollnäs Bro 4: 4". SGI on behalf of Bollnäs municipality TSF Real Estate Group. 2008-06-16.

- "Additional studies". Sweco on behalf of Bollnäs municipality 2011-01-26.
- “Additional environmental technical soil studying including risk assessment of property Bollnäs Bro 4: 4”. Sweco on behalf of Bollnäs municipality 2015-11-26.

The last report includes the information gathered in the three previous ones.

The analysis performed in the previous studies reported high levels of PAHs, oil, benzene and metals, with lead above all, in soil. PAHs, oil, aliphatic hydrocarbons, trichloroethylene and metals are found in great amount in the groundwater. Twelve polluted sub-areas were identified by Sweco in the property. In Figure 59 are reported the sampling points were pollutants are detected at levels beyond the generic guidelines for contaminated soil (MKM) as well as the twelve sub-areas.

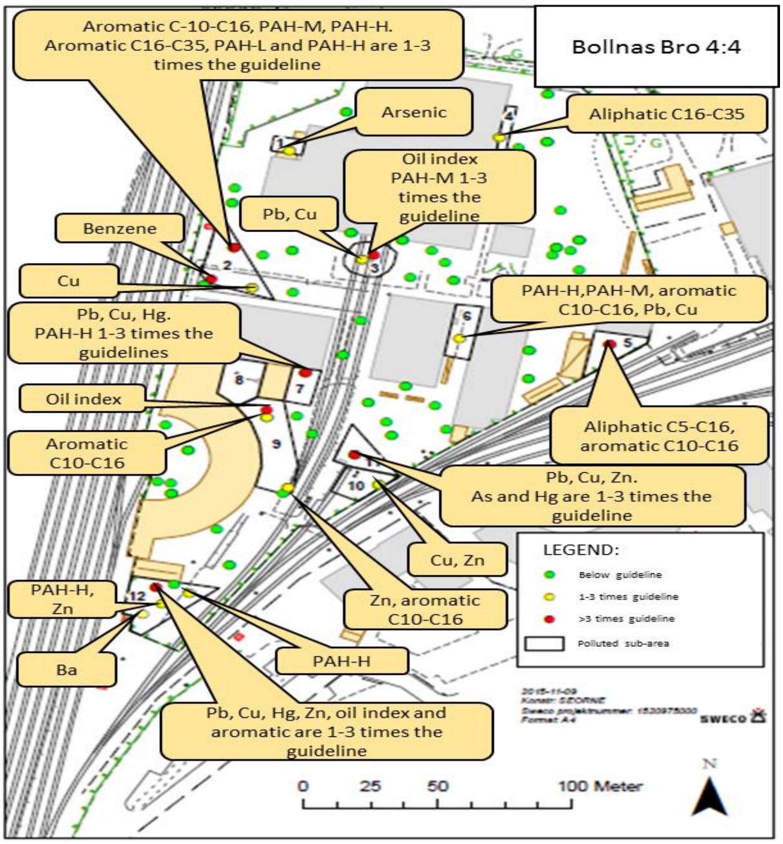


Figure 59: Sampling point where pollutants were found above the generic guidelines (MKM) for contaminated soil and the twelve contaminated sub-areas (Engström and Örne, 2015).

In Appendix 4, 5, 6 and 7 are reported the results of the soil and groundwater sampling performed at the site in the previous surveys.

7.2 Materials and methods

7.2.1 Literature study

The literature study was the first important step to have the overall view necessary to write the report. In order to illustrate the risk assessment procedure in general, the research of valid literature on the web was necessary. The description of the Italian and the Swedish risk assessment procedures required the consultation of material provided by the supervisors of both Politecnico di Milano and Kungliga Tekniska Högskolan (KTH). The reading of articles about leaching tests and metals' fate in soil resulted in the "Leaching test" and "Metals in soil" sections. The report on Bollnäs Bro 4: 4 by Sweco (Engström and Örne, 2015) was fundamental to identify the features of the site. In fact, the characterization of the site adopted for the report is based on the one developed by Sweco.

7.2.2 Sampling at the site

The report by Sweco (Engström and Örne, 2015), was used to choose the location of the soil sampling points analyzed in laboratory (see Appendix 2). The location to perform the sampling were chosen in correspondence of the sampling points where high concentrations of metals had been found in previous studies. In fact, the name of each sample is the code used for the corresponding previous one. The only exception is constituted by the samples taken inside the building in the south of the site. In this case, it was decided to take samples inside the building for two reasons: firstly, no sample from inside the structure was analyzed in the previous studies; secondly, the building is planned to be conserved and renovated. Only soil samples were taken on site at different depths according to those at which high levels of metals had been previously found. In the case of the sample taken in the building, the sampling point was chosen in order to not damage the electric wires crossing the area beneath surface and close to the furnace where metals were treated. The operations were performed with a scraper. The sampling points and their location are reported respectively in Table 9 and Figure 60 (Engström and Örne, 2015). The code name of the sample was determined by the sampling point and the depth, e.g., Building Surf., Building -0.2 M etc.

Table 9: Sampling points for analysis of soil polluted by metals.

Sampling point	**Number of samples**	**Depth (m)**
Building	2	Surface 0.2
1517	1	Surface 0.35 0.65
1522	2	0.35 0.65
1513	2	Surface 1.10
S7	4	Surface 0.5 0.8 (twice)
1506	3	0.4 0.6

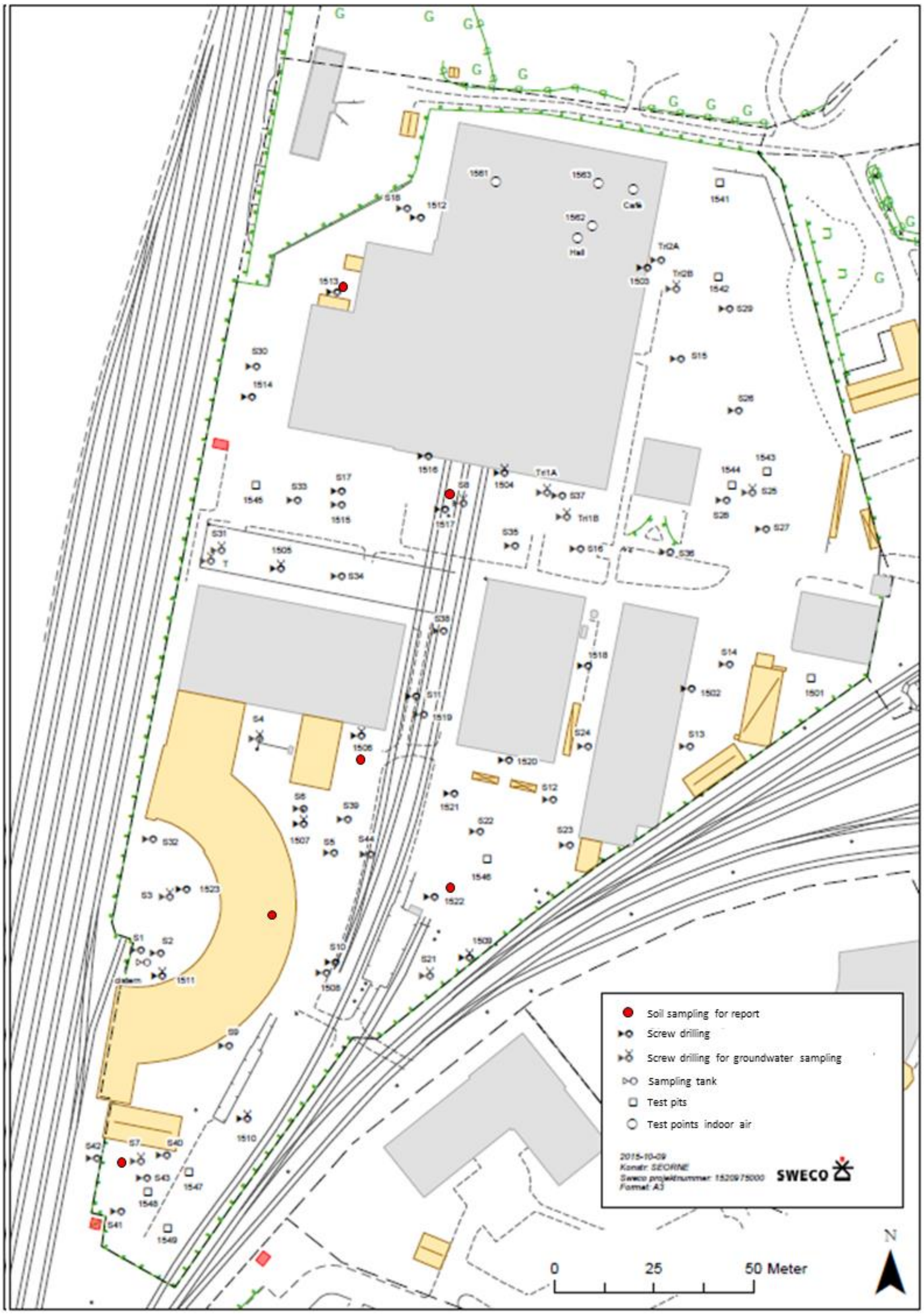


Figure 60: Soil sampling points location (Engström and Örne, 2015): the red points are in correspondence of the samples used for the laboratory analysis performed in this study.

7.2.3 Assessment of the risk

The two software presented before were used for the assessment of the risk: Risk-net 2.0, for the Italian procedure, and the Software for site-specific soil guidelines developed by Kemakta AB, for the Swedish one.

In the Swedish case, it was unnecessary to perform a comparison between the concentrations found on site and the generic MKM guidelines, because the procedure was already completed by Sweco (see Appendix 4, 5). The metals' concentrations detected in the soil samples taken on site for the laboratory analysis performed in this study, were instead compared to the generic guidelines for KM and MKM scenario (see Appendix 2). Then, site-specific guidelines were determined considering the future land use of the polluted area for the pollutants of interest at the site.

As first step of the Italian risk assessment, the CRS for the contaminants found at the site were compared to the CSC of each contaminants to determine which pollutants should be taken into account as inputs in Risk-net 2.0 to determine the CSRs. The data collected in the previous surveys and reported in Appendix 4, 5, 6 and 7 were used together with the concentrations calculated in the analyzed samples.

7.2.3.1 Assumptions – Risk-net 2.0

The inputs for the assessment of the risk were edited when the default settings were considered not fitting the features of the site of study.

"Opzioni"

The limitation constituted by the consideration of the C_{sat} in the determination of the CSRs and the risk was removed in Risk-net in order to obtain outputs that corresponded to the actual inputs (i.e. CRS). However, the C_{sat} was included in the process of the CSRs identification, as explained below.

“Modello Concettuale”

In the “Modello Concettuale” the leaching in groundwater and the contamination of groundwater were assessed on the vertical of the pollution, i.e. POC = 0.

No off-site receptors were considered, because adopting the residential/recreational scenario for the simulation.

“Selezione Contaminanti”

The data collected in the previous studies were used to compare the concentrations detected on site to the CSC in order to select the pollutants to be taken into account in the assessment of the risk.

For the organic compounds, some arrangements had to be made to obtain concentrations to compare to the Italian CSCs. First, it was necessary to convert the Swedish classes of organic compounds in the two main Italian classes, i.e. hydrocarbons C≤12 and C>12 and check if the CSC for recreational land use was exceeded. In order to do so, the classes “Aliphatic > C5-C8”, “Aliphatic > C8-C10”, “Aliphatic > C10-C12”, “Aromatic> C8-C10” and “Aromatic> C10-C16” were merged together summing up the concentrations detected and comparing the final value with the CSC for hydrocarbons C≤12. The sum of the classes “Aliphatic > C12-C16”, “Aliphatic > C16-C35”, “Aromatic> C10-C16” and “Aromatic> C16-C35” was compared to the CSC of hydrocarbons C>12. The class “Aromatic> C10-C16” was considered in both the cases due to the impossibility to properly divide the value in C10-12 and C12-16, consequently adopting a conservative assumption. Since the CSC for recreational purposes were exceeded in soil, the hydrocarbons were inserted in Risk-net 2.0 using the TPHCWG classification. The concentrations for the Swedish “PAH-L sum” were compared to the CSC of naphthalene while the “PAH-M sum” and “PAH-H sum” classes were merged together and the resulting concentration compared to the CSC of indenopyrene, chosen for the most strictly medium-high molecular weight PAH regulated in Italy. Since for groundwater the only chemical parameter regulated is the Total hydrocarbons, all the classes named before are summed up to compare the resulting value to the CSC. Due to the concentrations above the CSC, the TPHCWG classification was adopted. Both for soil and groundwater, the Swedish classes were adapted to obtain those of the TPHCWG method as reported in Table 10:

Table 10: Adaptation of Swedish classes for hydrocarbons to TPHCWG ones.

TPHCWG	**Swedish class**
Aliphatic C 5-6	Aliphatic > C5-C8
Aliphatic C >6-8	Aliphatic > C5-C8
Aliphatic C >8-10	Aliphatic > C8-C10
Aliphatic C >10-12	Aliphatic > C10-C12
Aliphatic C >12-16	Aliphatic > C12-C16
Aliphatic >C16-21	Aliphatic > C16-C35
Aliphatic >C21-C35	Aliphatic > C16-C35
Aromatic C >8-10	Aromatic > C8-C10
Aromatic C >10-12	Aromatic > C10-C16
Aromatic C >12-16	Aromatic > C10-C16
Aromatic C >16-21	Aromatic > C16-C35
Aromatic C >21-35	Aromatic > C16-C35

As it is possible to see, some Swedish classes are repeated more than once, e.g., Aliphatic > C5-C8, due to the impossibility to divide them in more TPHCWG classes. This means that a conservative assumption was adopted, overestimating the concentration of hydrocarbons for the specific TPHCWG class. The classes Aliphatic C5-C6 and Aliphatic >C6-C8, were both chosen with a fraction of n-hexane greater than the 53 %. This choice was a conservative one due to the more hazardous properties of a mixture with a larger presence of n-hexane.

In the case of Hg, following the guidelines by the Ministero dell’Ambiente e della Tutela del Territorio e del Mare (2015) three contaminants were inserted:

- Elementary mercury: to assess the risk associated to volatilization;
- Methylmercury: to assess the risk associated to direct contacts (i.e. soil ingestion and dermal contact);
- Mercury chloride: to assess the risk associated to the leaching in groundwater.

Due to the lack of a groundwater CSC for Mercury chloride, the same CSC, i.e.1 µg/l, was inserted in Risk-net to allow the calculations of the corresponding CSR.

Both Xylene and p-Xylene were inserted in the software, with the same CRS, because the first has a soil CSC and the second a groundwater CSC.

In the case of groundwater, even if data about concentration of PAHs were once again available divided in three classes (PAH-L, PAH-M, PAH-H) it was decided to compare the PAHs detected one by one. In fact, the number of organic contaminants individuated in groundwater was much greater than in soil (see Appendix 6 and 7). Moreover, Indenopyrene was inserted as contaminant in Risk-net even if the data available in groundwater were referred to Indeno(1,2,3-c,d)pyrene.

The contaminant considered for the three matrices are reported in Table 11.

Table 11: The contaminant inserted in Risk-net to assess the risk for surface and deep soil and groundwater.

Matrix	**Chemical compound**	
	Inorganics	**Organics**
Surface soil	- As - Cu - Hg - Pb - Zn	- Aliphatic C 5-6 (n-hexane >53%) - Aliphatic C > 6-8 (n-hexane >53%) - Aliphatic C > 8-10 - Aliphatic C > 10-12 - Aliphatic C > 12-16 - Aliphatic C > 16-21 - Aliphatic C > 21-35 - Aromatic C > 8-10 - Aromatic C > 10-12 - Aromatic C > 12-16 - Aromatic C > 16-21 - Aromatic C > 21-35 - Benzene - Indenopyrene - Naphthalene

Table 11: The contaminant inserted in Risk-net to assess the risk for surface and deep soil and groundwater.

Matrix	**Chemical compound**	
	Inorganics	**Organics**
Deep soil	- As - Cd - Co - Cu - Hg - Pb - Zn	- Aliphatic C 5-6 (n-hexane >53%) - Aliphatic C > 6-8 (n-hexane >53%) - Aliphatic C > 8-10 - Aliphatic C > 10-12 - Aliphatic C > 12-16 - Aliphatic C > 16-21 - Aliphatic C > 21-35 - Aromatic C > 8-10 - Aromatic C > 10-12 - Aromatic C > 12-16 - Aromatic C > 16-21 - Aromatic C > 21-35 - Ethylbenzene - Indenopyrene - Naphthalene - Toluene - Xylene - p-Xylene

Table 11: The contaminant inserted in Risk-net to assess the risk for surface and deep soil and groundwater.

Matrix	**Chemical compound**	
	Inorganics	**Organics**
Groundwater	- Cd - Fe - Mn - Ni - Pb - Zn	- Aliphatic C 5-6 (n-hexane >53%) - Aliphatic C > 6-8 (n-hexane >53%) - Aliphatic C > 8-10 - Aliphatic C > 10-12 - Aliphatic C > 12-16 - Aliphatic C > 16-21 - Aliphatic C > 21-35 - Aromatic C > 8-10 - Aromatic C > 10-12 - Aromatic C > 12-16 - Aromatic C > 16-21 - Aromatic C > 21-35 - Benzene - Benzo(a)anthracene - Benzo(a)pyrene - Benzo(b)fluoranthene - Benzo(ghi)perylene - Benzo(k)fluoranthene - Bromodichloromethane - Chrysene - 1,2-Dibromoethane - 1,4-Dichlorobenzene - 1,2-Dichloropropane - Indenopyrene - 1,1,2,2-Tetrachloroethane - 1,1,2-Trichloroethane - Trichloroethylene - Trichloromethane

The database used was the default one, but the K_d value for the Cu, Zn, As and Pb was changed with the site-specific and representative value measured with the laboratory analysis and reported in the chapter “Results”.

“Definizione CRS”

In order to define the CRS in the three matrices, it was firstly necessary to perform the neighborhood analysis to identify the geometry of the polluted area. ArcMap was used to draw the Thiessen’s polygons for the case of study, considering the sampling points given by literature (see Appendix 4, 5, 6 and 7) and those used to perform laboratory analysis in this report, for surface and deep soil. The network of piezometers was used for groundwater instead. The Thiessen’s polygons for the site of study are reported in Figure 61. Due to the impossibility to clearly distinguish different primary sources of pollution for the contaminants, only one unique source of pollution was identified. The CRS for each contaminant was defined as UCL95% when the number of available data was above 10 or as the maximum concentration otherwise. The number of data was established including all the polygons where the concentration of the specific compound or chemical parameter (i.e. the classes of hydrocarbons) was found above the CSC or that were included in the polluted area after the neighborhood analysis. The neighborhood analysis for the three matrices is reported in Figure 62 Figure 63 and Figure 64.

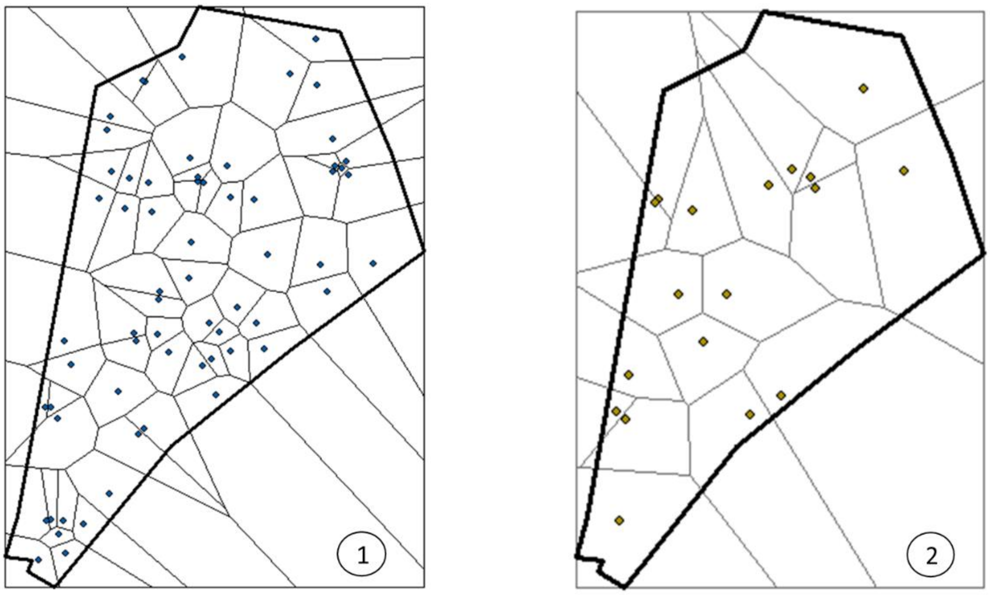


Figure 61: Subdivision of the polluted site in Thiessen’s polygons for surface and deep soil (1) and groundwater (2).

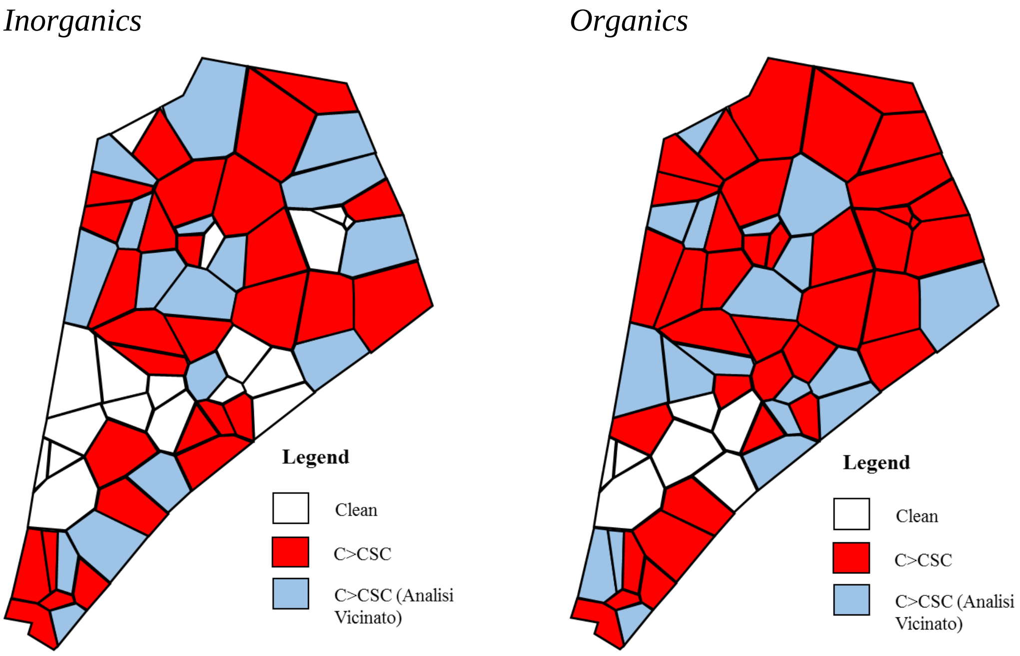


Figure 62: The neighborhood analysis for surface soil. On the left map the inorganic compounds were considered, on the right one the organics.

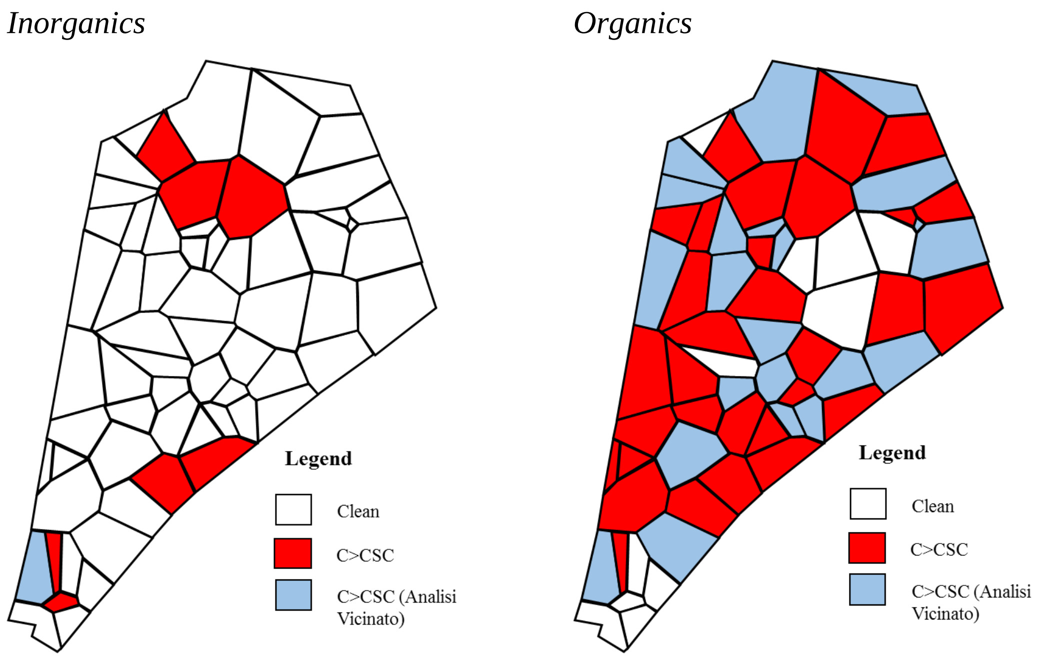


Figure 63: The neighborhood analysis for deep soil. On the left map the inorganic compounds were considered, on the right one the organics.

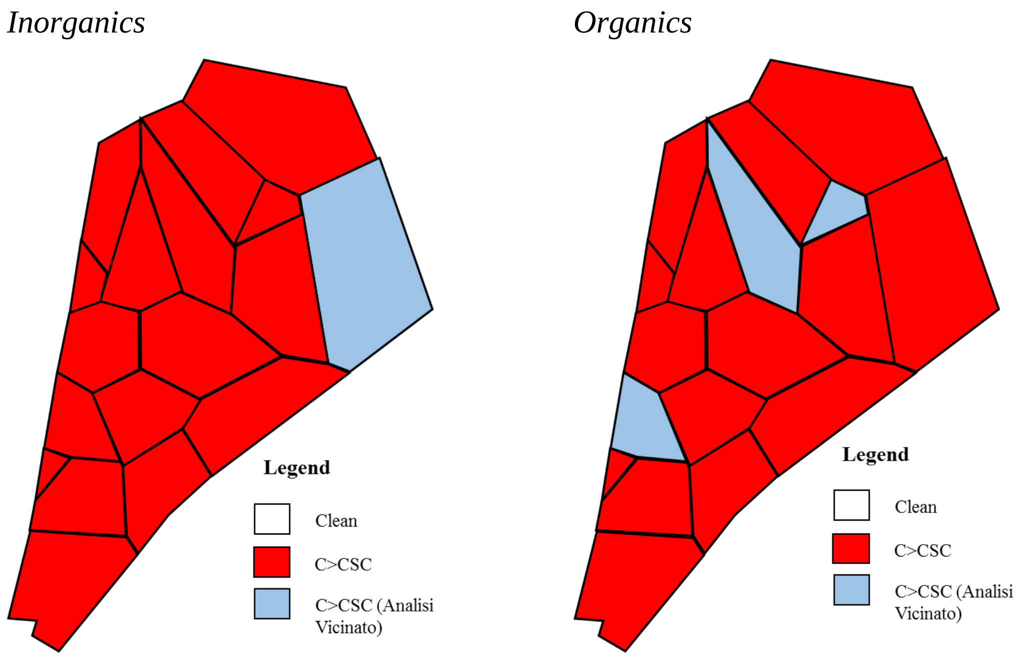


Figure 64: The neighborhood analysis for groundwater. On the left map the inorganic compounds were considered, on the right one the organics.

In some cases, the polygons that were added to the secondary source after the neighborhood analysis were lacking the data about the concentration of the specific chemical. Therefore, the level of pollution was assumed to be 0 in that polygon.

The resulting polluted area for the three matrices, was obtained merging the cells obtained for the neighborhood analysis of organic and inorganic compounds, because it was not possible to determine whether the sources of pollution were different for the two macro-classes of pollutants. The contaminated area was found to cover all the property of Bollnäs Bro 4:4 in all the three matrices.

"Recettori"

The receptors on site were the default ones for recreational land use, i.e. "Adjusted". This scenario was preferred to the industrial/commercial one because more conservative when assessing the risk posed to children that are constantly attending the site. No off-site receptors were considered.

"Parametri Esposizione"

The exposure parameters adopted for the simulation were changed inserting those for recreational land use (APAT, 2008). The exposure frequency and the inhalation rate of outdoor air inhalation were edited. Moreover, since the indoor inhalation is not considered by default in Risk-net, the same values of outdoor inhalation were adopted for the exposure parameters. In fact, it was considered unrealistic and improper to omit this exposure pathway, due to the future use of the site, that will bring many people, both young and adults, to spend a lot of time inside the buildings of the property.

"Caratteristiche sito"

The thickness of the pollution in the deep soil was defined equal to 1 m due to the average depth of the groundwater level from the ground level of 2 m.

The fraction of (Soil Organic Carbon) SOC in surface soil was assumed to be equal to the average value between those obtained for the samples studied at the laboratory (see Appendix 2) taken at maximum 1 m beneath ground level, i.e. 3,86 %. The conversion of the Loss On Ignition (LOI) value to the SOC was performed adopting a factor of 1,9. The fraction of SOC in the deep soil was defined as half of the one for surface soil, considering that usually the amount of SOM (Soil Organic Matter) decreases with depth.

The soil pH that was adopted was the average value obtained by the soil samples studied in laboratory with $CaCl_2$ liquid solution, i.e. 6,11. This solution was preferred to distilled water because it was considered more representative of the real conditions on site.

Sand was the chosen texture of the unsaturated zone, due to the lack of data about the soil parameters required by Risk-net and because it was the coarsest texture available in the software.

The average precipitation at the site was assumed to be of 550 cm/year (World Weather and Climate Information). The cracks areal fraction outdoor was posed equal to 1, i.e. site without pavement. In fact, the value for paved areas (0,1) would have resulted in an underestimation of the risk. Both the parameters were required to calculate the percolation and thus the leaching of pollutants.

For the saturated zone, the dimensions of the polluted area were assumed to be those of the rectangle that best included the site, i.e. 300 m in the direction perpendicular to groundwater flow and 180 m in the parallel one (Figure 65).

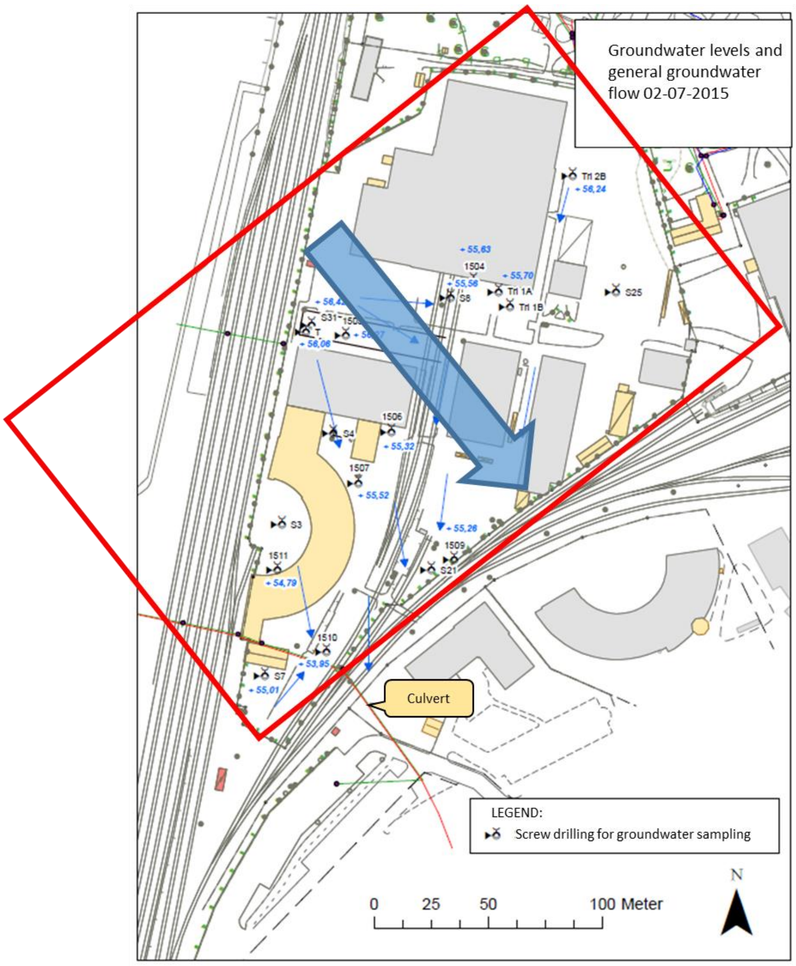


Figure 65: The blue arrow represents the plausible direction of groundwater flow and the red rectangle the schematic geometry representing the dimensions of the polluted site for groundwater matrix (Engström and Örne, 2015).

The average thickness of the aquifer was estimated to be 8 m. This value was calculated assuming a depth of 10 m to bedrocks and of 2 m to groundwater level for ground level.

The hydraulic conductivity was assumed to be 10^{-5} m/s, i.e. permeable material due to the coarse texture of the soil.

The hydraulic gradient was estimated using the data, collected by Sweco (2015) and reported in Appendix 3, about groundwater levels. The representative value for the hydraulic gradient was assumed equal to 0.002 m/m.

Due to the lack of data about the main wind direction the polluted area to be considered was safely determined adopting the longest segment of the polluted area as the side of the source representative rectangle parallel to the wind direction (Figure 66) with a resulting surface of 325x190 m^2. The average wind speed was assumed to be of 3.5 m/s (Word Weather and Climate Information).

Figure 66: The red rectangle represents the schematic polluted area for soil (Engström and Örne, 2015).

7.2.3.2 Inputs – Risk-net 2.0

The numerical inputs edited in Risk-net and the CRS for the selected contaminants are reported in Table 12 and Table 13 respectively.

Table 12: The numerical input to Risk-net edited for the risk assessment of the site of study.

Parameter	**Edited value**
Thickness of pollution in deep soil	1 m
Surface soil organic carbon	3.86%
Deep soil organic carbon	1.93%
Soil pH	6.11
Precipitation	55 cm/y
Cracks area for outdoor	1
Unsaturated zone texture	Sand
Thickness of the aquifer	8 m
Hydraulic conductivity of the saturated zone	10^{-5} m/s
Hydraulic gradient	0.002 m/m
Pollution source length along groundwater flow direction	180 m
Pollution source width perpendicular to groundwater flow	300 m
Pollution source length along wind direction	325 m
Pollution source width perpendicular to wind direction	190 m
Daily frequency of exposure – air inhalation indoor and outdoor (both adult and child)	3 h/day
Indoor and outdoor inhalation rate- child	1.9 m^3/h
Indoor and outdoor inhalation rate - adult	3.2 m^3/h

Table 13: The CRS for the contaminants considered in the risk assessment.

Chemical compound	**CRS**		
	Surface soil (mg/kg)	**Deep soil (mg/kg)**	**Groundwater (µg/l)**
Inorganics			
As	23	27	-
Cd	-	2,8	5,4
Co	-	26	-
Cu	4982	851	-
Fe	-	-	6130
Hg	20	14	-
Mn	-	-	10800
Ni	-	-	53,7
Pb	3146	351	365,5
Zn	851	3178	3800
Organics			
Aliphatic C 5-6 (n-hexane >53%)	10	10	10
Aliphatic C >6-8 (n-hexane >53%)	10	10	10
Aliphatic C >8-10	10	10,6	10
Aliphatic C >10-12	10	62,75	406
Aliphatic C >12-16	10,5	217,5	1620
Aliphatic >C16-21	112,4	195	3680
Aliphatic >C21-C35	112,4	195	3680
Aromatic C >8-10	1,6	7,68	10
Aromatic C >10-12	4,1	55,75	22,2
Aromatic C >12-16	4,1	55,75	22,2
Aromatic C >16-21	3,74	5	2
Aromatic C >21-35	3,74	5	2
Benzene	0,27	-	57
Benzo(a)anthracene	-	-	0,11
Benzo(a)pyrene	-	-	0,14
Benzo(b)fluoranthene	-	-	0,22

Table 13: The CRS for the contaminants considered in the risk assessment.

Chemical compound	**CRS**		
	Surface soil (mg/kg)	**Deep soil (mg/kg)**	**Groundwater (µg/l)**
Organics			
Benzo(ghi)perylene	-	-	0,11
Benzo(k)fluoranthene	-	-	0,12
Bromodichloromethane	-	-	1
Chrysene	-	-	0,44
1,4-Dichlorobenzene	-	-	1
1,2-Dibromoethane	-	-	0,1
1,2-Dichloropropane	-	-	0,5
Ethylbenzene	-	0,82	-
Indenopyrene	26,48	10,36	0,24
Naphthalene	11,55	42	-
1,1,2,2-Tetrachloroethane	-	-	0,5
Toluene	-	0,11	-
1,1,2-Trichloroethane	-	-	1
Trichloroethylene	-	-	45
Trichloromethane (chloroform)	-	-	1
Xylene	-	7,3	-
p-Xylene	-	7,3	-

7.2.3.3 CSR determination – Risk-net 2.0

The first individual CSR for the contaminants inserted in Risk-net, was determined choosing the lowest CSR between those proposed by the software for each of the exposure/migration pathways.

The second step in the determination of the final CSRs, consisted in checking the actual presence, above CSC, of those contaminants, for which the groundwater protection resulted decisive, in groundwater. The second smallest CSR was associated to those pollutants that were not found in the groundwater matrix above the corresponding CSC. If another CSR was not available, the contaminant was excluded from the list of pollutant for the specific matrix. This procedure was considered acceptable, even if the risk posed by the leaching was overlooked, due to the permeability of the soil matrix and the shallowness of the groundwater level. Therefore, acknowledged these favorable geological features for leaching, it was realistic to assume that the leaching towards groundwater was not relevant if the pollutant was not detected in groundwater. The CSR determined with this procedure was then compared to the CSC and if the former value resulted smaller than the latter, the CSC was adopted as remediation goal and the contaminant excluded from further assessments.

The CSR obtained was then compared to the C_{sat} proposed by the software. If the CSR resulted above the C_{sat}, the maximum concentration of the contaminant (C_{max}) found on site was adopted as new CSR, as suggested by the Italian guidelines (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2015).

The individual calculated CSRs were then adopted as CRS for a "forward" risk assessment and the calculation of the risk. A corrective coefficient was used to adjust the CSRs in order to satisfy the condition on both the single and cumulative risk. The last check consisted in comparing the final CSRs with the corresponding CSC. In the case of the hydrocarbons, the CSRs of the classes were summed up to compare the cumulative value to the CSC of hydrocarbons C<12 (HC<12) and hydrocarbons C>12 (HC>12). The CSRs obtained after this last confrontation were the remediation goals for the contaminants of concern at the site of study.

7.2.3.4 Assumptions – Software for site-specific soil guidelines by Kemakta AB

The generic scenario on which was based the assessment of the risk for the site of study, was a KM one. The motivation of this choice is that, even if there are no people permanently living at the site, they are supposed to stay more on the area, due to the recreational use, exposing a larger fraction of the skin, for example wearing shorts during summer.

“Conceptual model”

Dealing with the exposure pathways, those included in the calculation were:

- Dermal contact with soil;
- Intake of soil;
- Inhalation of dust;
- Inhalation of vapors;
- Intake of drinking water.

The intake of drinking water was included as well, even if there were not sensible groundwater reservoirs close to the site and wells for drinking water purposes, due to the importance of groundwater as a resource. If the site-specific guidelines result strongly influenced by this exposure pathway, the values will be re-calculated excluding the intake of drinking water.

Since no cultivation is or will occur at the site, the intake of plants was excluded.

The targets that were considered as relevant in the assessment of the risk posed by the pollution are:

- Adults regularly active on site;
- Adults and children visitors;
- Adults and children neighbors;
- Groundwater;
- Surface water ecosystem;
- Surface water;
- Sediment ecosystem.

The neighbors were taken into account due to the vicinity of residential houses.

The soil environment was excluded from the analysis because all the site’s surface soil had been covered with filling material making the formation of an environment impossible.

Groundwater was considered due to its intrinsic importance as a resource.

“Input”

The contaminants that were inserted in the sheet “Input” are those for which a site-specific K_d was estimated, i.e. Pb, As, Zn, Ba, Cu. Moreover, other pollutants of interest at the site of study were included in the risk assessment, basing the selection on the data collected by Sweco (Appendix 4 and 5). The chemicals added as inputs are reported in Table 14.

Table 14: Chemicals inserted in the Swedish software for site-specific soil guidelines as inputs.

Pollutant	
Inorganic	*Organic*
- As-mod[5] - Cd - Co - Cu-mod[4] - Cr - Hg - Ni - Pb-mod[4] - Zn-mod[4]	- Aliphatic > C8-C10 - Aliphatic > C10-C12 - Aliphatic > C12-C16 - Aliphatic > C16-C35 - Aromatic > C8-C10 - Aromatic > C10-C16 - Aromatic > C16-C35 - Benzene - 1,2-Dibromomethane - PAH-L - PAH-M - PAH-H - Trichloroethylene - Trichloromethane (chloroform) - Xylene

The adopted exposure parameters were those associated to the KM scenario, where more specific and reliable information about the site of study was lacking.

The exposure time for adults for intake of soil, inhalation of vapors and dust was fixed at 200 d/y (i.e. the value for MKM scenario) because this value corresponds to the number of workdays spent on site. For dermal contact with soil in adults, the MKM value of 90 d/y was used. The exposure time for children, associated to dermal contact with soil

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[5] Chemicals for which a site-specific K_d value was inserted.

and dust, is assumed to be the KM one, i.e. 120 d/y, due to the days spent in the area during summer. For the inhalation of dust and vapors by children, it was assumed that they will be present in the recreational building 4 h/d during the weekend and 2 h/d the remaining days of the week, i.e. 20 hours per week and 2.8 h/d on average. Since in the model a day of exposure consists in 8 h/d, the exposure time obtained for the case of study was 130 d/y. This value was determined multiplying the average daily exposure time for the days of the year and then dividing the result by the number of h/d required to consider a day of exposure (8 h/d). The fraction indoor was assumed to be 1 because, even if green areas will be present at the site, both the workers and the youngsters will spend a large amount of time inside buildings. Moreover, the inhalation indoor is more likely to be a relevant factor in the exposure, due to the lower dilution of air if compared with the outdoor area.

The content of organic carbon in soil was posed equal to the average one obtained from the laboratory analysis concerning the LOI, i.e. 7.33%. The conversion to the LOI value to the SOC was performed adopting a factor of 1.9. The water content adopted was the average obtained considering the soil samples analyzed at the laboratory, i.e. 11.5%.

The width and the length of the polluted area were determined defining the rectangle represented in Figure 67, drawn considering the main groundwater flow direction, and are of 300 m and 180 m respectively.

The percolation in the area was estimated to be much lower than the default value (100 mm/year) due to the presence of many buildings and the covering layer of asphalt. In particular, a value of 20 mm/year was adopted in the simulation.

The hydraulic conductivity (K) value was assumed to be of 10^{-5} m/s as the default value of the software, due to the coarse texture of the filling material in the soil that characterize it as a permeable one. The adopted K corresponded to the more permeable material found on site, i.e. sand and gravel, for safety reasons.

The hydraulic gradient was estimated using the data, collected by Sweco (2015) and reported in Appendix 3, about groundwater levels. The representative value for the hydraulic gradient was assumed equal to 0.002 m/m.

The average thickness of the aquifer was estimated to be 8 m. This value was calculated assuming a depth of 10 m to bedrocks and of 2 m to groundwater level for ground level.

The distance to well adopted was the same as for the MKM scenario, because the protection of groundwater at the site is not considered a primary issue.

In the transport model for vapors, the recreational building in the north of the site was considered. Assuming a height of 4 m, the air volume was estimated to be around 7200 m^3. The reliability of this value is proven by the fact that the same air volume was assumed by Sweco. The surface under the building was calculated as 1800 m^2.

The target for surface water was decided to be the small bay of lake Varpen, where the southern outlet of the culvert that crosses the site is located (Figure 67). Using the data provided by Peter Strömbäck of Bollnäs Municipality, the area of the "small lake" was calculated to be 220000 m^3, with an average depth of 4 m and a surface of 55000 m^2. The turnover time of the bay was calculated assuming that the outflow was constituted by the river Voxnan's flow rate, in the south of lake Varpen. Dividing the volume of the "small lake" by the Voxnan's flow rate of 38 m^3/s, the turnover time was 0.002 years.

Figure 67: The "small lake" used for the calculation of the site-specific guidelines with the Swedish software (Engström and Örne, 2015).

The K_d of the metals that were listed before was changed with the site-specific one, reported in the section "K_d determination" in "Results", calculated with the harmonic mean.

Once the site-specific inputs were inserted in the software, the guidelines for the contaminants of interest at the site of study were calculated and compared to the levels of pollution found on site.

7.2.3.5 Inputs – Software for site-specific soil guidelines by Kemakta AB

The numerical inputs edited in the Swedish software for the calculation of the site-specific guidelines are reported in Table 15.

Table 15: List of the numerical inputs edited in the Swedish software for the calculation of the site-specific guidelines.

Parameter	**Edited value**
Exposure time adults – Intake of soil	200 d/y
Exposure time adults – Inhalation of dust	200 d/y
Exposure time adults – Inhalation of vapor	200 d/y
Exposure time adults – Dermal contact with soil/dust	90 d/y
Exposure time children – Inhalation of dust	130 d/y
Exposure time children – Inhalation of vapor	130 d/y
Soil organic carbon	3.66 %
Water content	11.5 %
Site length	180 m
Site width	300 m
Air volume indoor	7200 m^3
Surface under building	1800 m^2
Lake volume	220 000 m^3
Turnover time of lake	0.002 y
Percolation	20 mm/y
Hydraulic gradient	0.002 m/m
Thickness of the aquifer	8 m
Distance to well	200 m

7.3 Results

7.3.1 Italian risk assessment

The outcomes of the Italian risk assessment are shown in this section.

7.3.1.1 CSR determination

The CSRs firstly calculated (CSR (1)) with Risk-net for surface soil, deep soil and groundwater are reported in Table 16 to Table 19. The final CSRs, listed in the last column on the right, were referred to the single contaminant without considering the cumulative effects.

Considering the values obtained for surface soil, soil ingestion resulted the most dangerous exposure pathway in five cases (i.e. As, Aliphatic >C16-21, Aliphatic >C Aliphatic >C21-35, Aromatic >C21-35, Indenopyrene), whilst the CSR was due to indoor vapor inhalation in four cases (Aliphatic >C6-8, Aliphatic >C8-10, Aliphatic >C10-12, Aliphatic >C12-16). Protection of groundwater was determinant for the remaining 11 contaminants (Cu, Pb, Hg, Zn, Aliphatic C5-C6, Aromatic >C8-10, Aromatic >C10-12, Aromatic >C12-16, Aromatic >C16-21, Benzene, Naphthalene).

For the pollutants of interest in deep soil, the CSRs were based on groundwater protection for 17 parameters (As, Cd, Co, Cu, Hg, Pb, Zn, Aliphatic C5-C6, Aliphatic >C6-8, Aromatic >C8-10, Aromatic >C10-12, Aromatic >C12-16, Aromatic >C16-21, Aromatic >C21-35, Indenopyrene, Naphthalene, Toluene) and on indoor vapor inhalation for 7 parameters (Aliphatic >C8-10, Aliphatic >C10-12, Aliphatic >C12-16, Aliphatic >C16-21, Aliphatic >C21-35, Ethylbenzene, Xylene).

For groundwater, the CSRs corresponded to the CSC for all the pollutants of concern. However, as shown Table 19, the risk posed by volatile chemicals for vapor inhalation might be an issue during the process of remediation to the CSCs.

Table 16: Individual CSR for surface soil.

Compound	CSR (mg/kg)							CSR (1)
	Exposure/migration pathway							
	Soil ingestion	Dermal contact	Vapor inhalation outdoor	Dust inhalation outdoor	Groundwater protection	Vapor inhalation indoor	Dust inhalation indoor	
Arsenic*	4.26E-01	4.50E+00	-	4.63E+04	1.68E+01	-	4.63E+04	4.26E-01
Copper*	3.13E+03	1.12E+05	-	[5.86E+09]	1.07E+03	-	[5.86E+09]	1.07E+03
Lead*	2.74E+02	9.78E+03	-	[5.13E+08]	1.18E+01	-	[5.13E+08]	1.18E+01
Elemental Mercury	-	-	4.82E+00	[1.26E+07]	1.58E-01	4.60E-01	[1.26E+07]	1.58E-01
Methylmercury	7.82E+00	2.79E+02	-	-	-	-	-	
Mercury chloride	2.35E+01	8.38E+02	-	[1.26E+07]	1.58E-01	-	[1.26E+07]	
Zinc*	2.35E+04	8.38E+05	-	[4.40E+10]	2.67E+03	-	[4.40E+10]	2.67E+03
Aliphatic C 5-6	4.69E+03	1.68E+04	1.07E+04	[2.80E+10]	3.40E+01	8.17E+01	[2.80E+10]	3.40E+01
Aliphatic C > 6-8	4.69E+03	1.68E+04	1.07E+04	[2.80E+10]	1.45E+02	8.17E+01	[2.80E+10]	8.17E+01
Aliphatic C > 8-10	7.82E+03	2.79E+04	8.05E+03	[2.10E+10]	1.33E+03	6.12E+01	[2.10E+10]	6.12E+01
Aliphatic C > 10-12	7.82E+03	2.79E+04	8.05E+03	[2.10E+10]	1.30E+04	2.86E+02	[2.10E+10]	2.86E+02
Aliphatic C > 12-16	7.82E+03	2.79E+04	8.05E+03	[2.10E+10]	2.05E+04	6.30E+02	[2.10E+10]	6.30E+02
Aliphatic C > 16-21	1.56E+05	5.59E+05	1.61E+05	[2.10E+10]	1.63E+07	8.78E+05	[2.10E+10]	1.56E+05
Aliphatic C > 21-35	1.25E+05	4.47E+05	1.61E+05	[2.10E+10]	1.63E+07	8.78E+05	[2.10E+10]	1.25E+05
Aromatic C > 8-10	3.13E+03	1.12E+04	3.21E+03	[8.37E+09]	5.17E+01	1.53E+02	[8.37E+09]	5.17E+01

Table 17: Individual CSR for surface soil.

Compound	CSR (mg/kg)							CSR (1)
	Exposure/migration pathway							
	Soil ingestion	**Dermal contact**	**Vapor inhalation outdoor**	**Dust inhalation outdoor**	**Groundwater protection**	**Vapor inhalation indoor**	**Dust inhalation indoor**	
Aromatic C > 10-12	3.13E+03	1.12E+04	3.21E+03	[8.37E+09]	1.29E+02	5.39E+02	[8.37E+09]	1.29E+02
Aromatic C > 12-16	3.13E+03	1.12E+04	8.43E+03	[8.37E+09]	2.58E+02	6.05E+03	[8.37E+09]	2.58E+02
Aromatic C > 16-21	2.35E+03	8.38E+03	4.32E+04	[8.37E+09]	6.47E+02	1.59E+05	[8.37E+09]	6.47E+02
Aromatic C > 21-35	2.35E+03	8.38E+03	1.37E+06	[8.37E+09]	5.16E+03	1.41E+08	[8.37E+09]	2.35E+03
Benzene	1.16E+01	3.68E+01	9.84E+00	[2.56E+07]	1.73E-02	7.48E-02	[2.56E+07]	1.73E-02
Indenopyrene	8.75E-01	2.13E+00	2.30E+03	[1.82E+06]	2.28E+01	1.33E+06	[1.82E+06]	8.75E-01
Naphthalene	1.56E+03	4.30E+03	5.17E+00	[5.88E+06]	9.01E-01	3.24E+00	[5.88E+06]	9.01E-01

Table 18: Individual CSR for deep soil.

Compound	**CSR (mg/kg)**			**CSR (1)**
	Exposure/migration pathway			
	Groundwater protection	**Vapor inhalation outdoor**	**Vapor inhalation indoor**	
Arsenic*	8.42E+00	-	-	8.42E+00
Cadmium	5.68E-01	-	-	5.68E-01
Cobalt	3.41E+00	-	-	3.41E+00
Copper*	5.35E+02	-	-	5.35E+02
Elemental Mercury	7.90E-02	4.82E+00	4.74E-01	7.88E-02
Methylmercury	-	-	-	
Mercury chloride	7.88E-02	-	-	
Lead*	5.91E+00	-	-	5.91E+00
Zinc*	1.34E+03	-	-	1.34E+03
Aliphatic C 5-6 (n-hexane > 53%)	1.05E+01	1.07E+04	8.17E+01	1.05E+01
Aliphatic C > 6-8 (n-hexane > 53%)	4.00E+01	1.07E+04	8.17E+01	4.00E+01
Aliphatic C > 8-10	3.39E+02	8.05E+03	6.12E+01	6.12E+01
Aliphatic C > 10-12	3.25E+03	8.05E+03	1.48E+02	1.48E+02
Aliphatic C > 12-16	5.14E+03	8.05E+03	3.25E+02	3.25E+02
Aliphatic C > 16-21	4.07E+06	2.04E+06	4.52E+05	4.52E+05
Aliphatic C > 21-35	4.07E+06	2.04E+06	4.52E+05	4.52E+05
Aromatic C > 8-10	1.30E+01	3.21E+03	7.92E+01	1.30E+01
Aromatic C > 10-12	3.24E+01	3.21E+03	2.78E+02	3.24E+01
Aromatic C > 12-16	6.46E+01	1.41E+04	3.12E+03	6.46E+01
Aromatic C > 16-21	1.62E+02	3.71E+05	8.20E+04	1.62E+02
Aromatic C > 21-35	1.29E+03	3.75E+08	7.31E+07	1.29E+03
Ethylbenzene	6.60E-01	3.07E+01	3.28E-01	3.28E-01
Indenopyrene	5.70E+00	4.81E+06	6.97E+05	5.70E+00
Naphthalene	2.25E-01	7.54E+00	1.67E+00	2.25E-01
Toluene	1.05E-01	8.05E+04	6.12E+02	1.05E-01
Xylene	-	1.61E+03	1.81E+01	1.81E+01
p-Xylene	1.11E-01	1.61E+03	1.61E+01	1.61E+01

Table 19: Individual CSR for groundwater.

Compound	**CSR (mg/l)**			**CSR (1)**
	Exposure/migration pathway			
	Groundwater protection (CSC)	**Vapor inhalation outdoor**	**Vapor inhalation indoor**	
Cadmium	5.00E-03	-	-	CSC
Iron	2.00E-01	-	-	CSC
Manganese	5.00E-02	-	-	CSC
Nichel	2.00E-02	-	-	CSC
Lead *	1.00E-02	-	-	CSC
Zinc*	3.00E+00	-	-	CSC
Alifatici C5-C6 (n-hexane > 53%)	3.50E-01	1.34E+01	1.75E-01	CSC
Alifatici >C6-C8 (n-hexane > 53%)	3.50E-01	8.55E+00	1.11E-01	CSC
Alifatici C >8-10	3.50E-01	3.57E+00	4.64E-02	CSC
Alifatici C >10-12	3.50E-01	3.92E+00	5.10E-02	CSC
Alifatici C >12-16	3.50E-01	5.45E+00	7.08E-02	CSC
Alifatici >C16-21	3.50E-01	9.58E+00	1.24E-01	CSC
Alifatici >C21-C35	3.50E-01	9.58E+00	1.24E-01	CSC
Aromatici C >8-10	3.50E-01	4.76E+02	6.50E+00	CSC
Aromatici C >10-12	3.50E-01	6.47E+02	8.96E+00	CSC
Aromatici C >12-16	3.50E-01	2.35E+03	4.14E+01	CSC
Aromatici C >16-21	3.50E-01	6.97E+03	3.10E+02	CSC
Aromatici C >21-35	3.50E-01	2.99E+05	3.12E+04	CSC
Benzene	1.00E-03	1.80E+00	2.54E-02	CSC
Benzo(a)anthracene	1.00E-04	7.71E+00	7.74E-01	CSC
Benzo(a)pyrene	1.00E-05	9.72E+00	8.35E-01	CSC
Benzo(b)fluoranthene	1.00E-04	1.25E+02	1.16E+01	CSC
Benzo(ghi)perylene	1.00E-05	3.62E+04	2.06E+03	CSC
Benzo(k)fluoranthene	5.00E-05	1.36E+02	1.24E+01	CSC
Bromodichloromethane	1.70E-04	1.05E+00	1.85E-02	CSC
Chrysene	5.00E-03	2.99E+01	3.21E+00	CSC

Table 19: Individual CSR for groundwater.

Compound	**CSR (mg/l)**			**CSR (1)**
	Exposure/migration pathway			
	Groundwater protection (CSC)	**Vapor inhalation outdoor**	**Vapor inhalation indoor**	
1,2-Dibromoethane	1.00E-06	1.28E-01	3.84E-03	CSC
1,4-Dichlorobenzene	5.00E-04	3.60E+00	5.91E-02	CSC
1,2-Dichloropropane	1.50E-04	2.83E+00	4.38E-02	CSC
Indenopyrene	1.00E-04	2.44E+02	1.94E+01	CSC
1,1,2,2-Tetrachloroethane	5.00E-05	1.68E+00	5.92E-02	CSC
1,1,2-Trichloroethane	2.00E-04	2.51E+00	5.50E-02	CSC
Trichloroethylene	2.70E-01	1.44E+00	1.98E-02	CSC
Trichloromethane	1.50E-03	9.48E-01	1.43E-02	CSC

The CSRs calculated for surface and deep soil, after checking the actual presence of the pollutant in groundwater and considering the CSC value, are reported in Table 20 and Table 21 respectively (CSR (2)). In the same tables, the chemicals that were excluded from the risk assessment due to the lack of another CSR have been marked (i.e. As, Co and Cu in deep soil).

Table 20: CSRs for surface soil after checking the contaminant presence in groundwater and considering the CSC.

Compound	**CSR (1) (mg/kg)**	**CSR (2) (mg/kg)**	**CSC residential (mg/kg)**	**CSR<CSC**
Arsenic*	4.26E-01	4.26E-01	2.00E+01	yes
Copper*	1.07E+03	3.13E+03	1.20E+02	no
Lead*	1.18E+01	1.18E+01	1.00E+02	yes
Elemental Mercury	1.58E-01	4.60E-01	1.00E+00	yes
Methylmercury				
Mercury chloride				
Zinc*	2.67E+03	2.67E+03	1.50E+02	no
Aliphatic C 5-6	3.40E+01	3.40E+01	1.00E+01	no
Aliphatic C > 6-8	8.17E+01	8.17E+01	1.00E+01	no
Aliphatic C > 8-10	6.12E+01	6.12E+01	1.00E+01	no
Aliphatic C > 10-12	2.86E+02	2.86E+02	1.00E+01	no
Aliphatic C > 12-16	6.30E+02	6.30E+02	5.00E+01	no
Aliphatic C > 16-21	1.56E+05	1.56E+05	5.00E+01	no
Aliphatic C > 21-35	1.25E+05	1.25E+05	5.00E+01	no
Aromatic C > 8-10	5.17E+01	5.17E+01	1.00E+01	no
Aromatic C > 10-12	1.29E+02	1.29E+02	1.00E+01	no
Aromatic C > 12-16	2.58E+02	2.58E+02	5.00E+01	no
Aromatic C > 16-21	6.47E+02	6.47E+02	5.00E+01	no
Aromatic C > 21-35	2.35E+03	2.35E+03	5.00E+01	no
Benzene	1.73E-02	1.73E-02	1.00E-01	yes
Indenopyrene	8.75E-01	8.75E-01	1.00E-01	no
Naphthalene	9.01E-01	3.24E+00	5.00E+00	yes

Table 21: CSRs for deep soil after checking the contaminant presence in groundwater and considering the CSC.

Compound	CSR (1) (mg/kg)	CSR (2) (mg/kg)	CSC residential (mg/kg)	CSR<CSC
Arsenic*	8.42E+00	-	2.00E+01	-
Cadmium	5.68E-01	5.68E-01	2.00E+00	yes
Cobalt	3.41E+00	-	2.00E+01	-
Copper*	5.35E+02	-	1.20E+02	-
Lead*	5.91E+00	5.91E+00	1.00E+02	yes
Elemental Mercury	7.88E-02	4.74E-01	1.00E+00	yes
Methylmercury				
Mercury chloride				
Zinc*	1.34E+03	1.34E+03	1.50E+02	no
Aliphatic C 5-6	1.05E+01	1.05E+01	1.00E+01	no
Aliphatic C > 6-8	4.00E+01	4.00E+01	1.00E+01	no
Aliphatic C > 8-10	6.12E+01	6.12E+01	1.00E+01	no
Aliphatic C > 10-12	1.48E+02	1.48E+02	1.00E+01	no
Aliphatic C > 12-16	3.25E+02	3.25E+02	5.00E+01	no
Aliphatic C > 16-21	4.52E+05	4.52E+05	5.00E+01	no
Aliphatic C > 21-35	4.52E+05	4.52E+05	5.00E+01	no
Aromatic C > 8-10	1.30E+01	1.30E+01	1.00E+01	no
Aromatic C > 10-12	3.24E+01	3.24E+01	1.00E+01	no
Aromatic C > 12-16	6.46E+01	6.46E+01	5.00E+01	no
Aromatic C > 16-21	1.62E+02	1.62E+02	5.00E+01	no
Aromatic C > 21-35	1.29E+03	1.29E+03	5.00E+01	no
Ethylbenzene	3.28E-01	3.28E-01	5.00E-01	yes
Indenopyrene	5.70E+00	5.70E+00	1.00E-01	no
Naphthalene	2.25E-01	1.67E+00	5.00E+00	yes
Toluene	1.05E-01	6.12E+02	5.00E-01	no
Xylene	1.81E+01	1.81E+01	5.00E-01	no
p-Xylene	1.11E+01	-	-	-

The CSRs (2) obtained for the surface soil were different from those calculated in the first step in six cases. Indoor vapor inhalation was the new exposure pathway that set the CSR for Hg, Aliphatic >C6-8, Aliphatic >C8-10, Aliphatic >C10-12, Aliphatic >C12-16 and Naphthalene. The CSR (2) resulted lower than the residential CSC for As, Hg, Pb, Benzene and Naphthalene that were thus removed from the list of the pollutants accounted for in the risk assessment.

In the case of deep soil, As, Co and Cu were excluded from the assessment due to the lack of CSR (2). The CSR (2) was different from the CSR (1) for Hg, Naphthalene and Toluene only. Five parameters were removed from the input (i.e. Cd, Hg, Pb, Ethylbenzene, Naphthalene) due to a CSR (2) smaller than the residential CSC. The p-Xylene was no longer considered because not detected in groundwater. Thus only Xylene, provided with a soil CSC, was included in further calculations.

The CSR (3) were then obtained considering the C_{sat} calculated by Risk-net. In Table 22 the contaminants for which the CSR (3) was set equal to the C_{max} in surface and deep soil are reported. For all the other contaminants CSR (3) was equal to CSR (2).

Table 22: CSRs that were set equal to C_{max} in surface and deep soil.

Compound	**CSR (2)(mg/kg)**	**C_{sat} (mg/kg)**	**CSR (3) (mg/kg)**
Surface soil			
Aliphatic C > 12-16	6.30E+02	6.78E+00	6.3E+01
Aliphatic C > 16-21	1.56E+05	2.30E+01	1.2 E+03
Aliphatic C > 21-35	1.25E+05	2.30E+01	1.2 E+03
Aromatic C > 16-21	6.47E+02	3.42E+02	5.00E+00
Aromatic C > 21-35	2.35E+03	1.41E+02	5.00E+00
Deep soil			
Alifatici C >12-16	3.25E+02	3.39E+00	1.40E+03
Alifatici >C16-21	4.52E+05	1.15E+01	2.00E+03
Alifatici >C21-C35	4.52E+05	1.15E+01	2.00E+03
Aromatic C > 21-35	1.29E+03	7.05E+01	4.70E+01

The final CSR (CSR (4)), calculated through a “forward” risk assessment and adjusted with a corrective coefficient, are reported in Table 23 and Table 24 for surface and deep soil respectively.

Table 23: Final surface soil CSRs to satisfy both individual and cumulative risk.

Compound	**CSR (3)(mg/kg)**	**Corrective factor (-)**	**CSR (4)(mg/kg)**	**R (-)**	**HI (-)**	**Risk for groundwater (-)**
Copper	3.13E+03	7.00E+00	**4.47E+02**	-	1.47E-01	4.18E-01
Zinc	2.67E+03	2.00E+00	**1.34E+03**	-	5.85E-02	5.00E-01
Aliphatic C 5-6	3.40E+01	4.70E+00	**7.23E+00**	-	8.85E-02	2.13E-01
Aliphatic C > 6-8	8.17E+01	4.70E+00	**1.74E+01**	-	2.13E-01	1.20E-01
Aliphatic C > 8-10	6.12E+01	4.70E+00	**1.30E+01**	-	2.13E-01	9.82E-03
Aliphatic C > 10-12	2.86E+02	4.70E+00	**6.09E+01**	-	2.13E-01	4.70E-03
Aliphatic C > 12-16	6.30E+01	-	**6.30E+01**	-	1.00E-01	3.07E-03
Aliphatic C > 16-21	1.20E+03	-	**1.20E+03**	-	1.73E-02	7.37E-05
Aliphatic C > 21-35	1.20E+03	-	**1.20E+03**	-	1.97E-02	7.37E-05
Aromatic C > 8-10	5.17E+01	4.70E+00	**1.10E+01**	-	7.17E-02	2.13E-01
Aromatic C > 10-12	1.29E+02	4.70E+00	**2.75E+01**	-	5.11E-02	2.13E-01
Aromatic C > 12-16	2.58E+02	-	**2.58E+02**	-	1.36E-01	1.00E+00
Aromatic C > 16-21	5.00E+00	-	**5.00E+00**	-	2.84E-03	7.73E-03
Aromatic C > 21-35	5.00E+00	-	**5.00E+00**	-	2.73E-03	9.70E-04
Indenopyrene	8.75E-01	1.42E+00	**6.16E-01**	9.94E-07	-	2.70E-02
Total risk						
Cumulative Risk			**Outdoor**	**9.94E-07**	**5.19E-01**	
Cumulative Hazard Index			**Indoor**	**4.62E-13**	**9.95E-01**	

Table 24: Final deep soil CSRs to satisfy both individual and cumulative risk.

Compound	CSR (3)(mg/kg)	Corrective factor (-)	CSR (4)(mg/kg)	R (-)	HI (-)	Risk for groundwater (-)
Zinc	1.34E+03	2.00E+00	**6.68E+02**	-	-	5.00E-01
Aliphatic C 5-6	1.05E+01	8.00E+00	**1.32E+00**	-	1.61E-02	1.25E-01
Aliphatic C > 6-8	4.00E+01	8.00E+00	**5.00E+00**	-	6.12E-02	1.25E-01
Aliphatic C > 8-10	6.12E+01	1.00E+01	**6.12E+00**	-	1.00E-01	1.80E-02
Aliphatic C > 10-12	1.48E+02	1.00E+01	**1.48E+01**	-	1.00E-01	4.55E-03
Aliphatic C > 12-16	1.40E+03	1.00E+01	**1.40E+02**	-	4.31E-01	2.72E-02
Aliphatic C > 16-21	2.00E+03	-	**2.00E+03**	-	4.42E-03	4.91E-04
Aliphatic C > 21-35	2.00E+03	-	**2.00E+03**	-	4.42E-03	4.91E-04
Aromatic C > 8-10	1.30E+01	8.00E+00	**1.62E+00**	-	2.04E-02	1.25E-01
Aromatic C > 10-12	3.24E+01	8.00E+00	**4.05E+00**	-	1.46E-02	1.25E-01
Aromatic C > 12-16	6.46E+01	8.00E+00	**8.07E+00**	-	2.59E-03	1.25E-01
Aromatic C > 16-21	1.62E+02	-	**1.62E+02**	-	1.97E-03	1.00E+00
Aromatic C > 21-35	4.70E+01	-	**4.70E+01**	-	6.43E-07	3.65E-02
Indenopyrene	5.70E+00	-	**5.70E+00**	8.17E-12	-	1.00E+00
Toluene	6.12E+02	1.00E+01	**6.12E+01**	-	1.00E-01	5.84E+02
Xylene	1.81E+01	1.00E+01	**1.81E+00**	-	1.00E-01	NA
Total risk						
Cumulative Risk			**Outdoor**	**1.19E-12**	**2.72E-2**	
Cumulative Hazard Index			**Indoor**	**8.17E-12**	**9.56E-1**	

No contaminant had a final CSR below the CSC, so the CSR calculated were used as the remediation goals. In Table 25 the CSR for HC<12 and HC>12 for both surface and deep soil are reported.

Table 25: Comparison between the CSR for HC<12 and HC>12, in surface and deep soil, and the corresponding CSC

Hydrocarbons	**CSR (mg/kg)**	**CSC residential (mg/kg)**
Surface soil		
HC<12	1.37E+02	1.00E+01
HC>12	2.73E+03	5.00E+01
Deep soil		
HC<12	3.29E+01	1.00E+01
HC>12	4.36E+03	5.00E+01

7.3.2 Swedish risk assessment

In this chapter are reported the results of the Swedish risk assessment.

7.3.2.1 Site-specific guidelines

The site-specific soil guidelines, calculated using the Swedish software and adopting the inputs described before are reported in Table 26.

The site-specific guidelines for the pollutants considered in the Swedish risk assessment resulted lower than the generic KM ones for 12 compounds out of 24. The benchmarks calculated for Pb, Zn, Aliphatic>C8-C10, Aromatic >C16-C35 and Trichloromethane were more than 3 times lower than their KM generic ones. In the case of Benzene and Trichloroethene the difference was of one order of magnitude (0.0035 mg/kg vs. 0.012 mg/kg and 0.06 vs 0.2 mg/kg respectively). The values determined for Aliphatic >C10-C12, Aliphatic >C12-C16 and Aliphatic >C16-C35 were the only ones that were found above the KM and MKM generic guidelines. The site-specific benchmarks for Arsenic and Cadmium corresponded to the generic KM guidelines.

Table 26: Site-specific soil guidelines calculated with the Swedish software. The cells where the site-specific guideline is below the generic MKM one are colored in yellow, those that are also below the KM generic benchmark are colored in red.

Compound	**Site-specific guideline (mg/kg$_{d.m.}$)**	**Compound**	**Site-specific guideline (mg/kg$_{d.m.}$)**
Arsenic-mod	10	Aliphatic > C16-C35	2500
Cadmium	0.50	Aromatic > C8-C10	18
Cobalt	10	Aromatic > C10-C16	5.0
Copper-mod	50	Aromatic > C16-C35	3.0
Chromium total	100	Benzene	0.0035
Mercury	0.40	1.2-dibromoethane	0.0012
Nickel	25	PAH L	1.8
Lead-mod	15	PAH M	5.0
Zinc-mod	80	PAH H	1.8
Aliphatic > C8-C10	250	Trichloroethylene	0.060
Aliphatic > C10-C12	1000	Trichloromethane (chloroform)	0.12
Aliphatic > C12-C16	1000	Xylene	6.0

Since the intake of drinking water was significant in the determination of the site-specific guideline for 1,2-dibromethane and Cd only, it was not necessary to recalculate the site-specific guidelines excluding the cited exposure pathway.

7.4 Discussion

7.4.1 Italian Risk Assessment

7.4.1.1 CSR determination

The process to determine the CSRs for the contaminants of concern at the case study consisted in four steps that were necessary to identify the remediation goals that satisfied both individual and cumulative risk.

Groundwater

As expected, the CSRs for groundwater protection were the CSCs, thus one of the three matrices was immediately removed from the assessment as secondary source of pollution. However, the presence of many organic volatile compounds that were found to pose risk due to indoor and outdoor vapor inhalation, might be an issue. In fact, even if ensuring the remediation of the matrix to the CSCs, the time required to reach these levels in groundwater might be relevant. The risk posed by vapor inhalation indoor resulted particularly high for Aliphatic C5-C6, Aliphatic >C6-8, Aliphatic >C8-10, Aliphatic >C10-12, Aliphatic >C12-16, Aliphatic >C16-21, Aliphatic >C21-35 as proved by the corresponding CSR that resulted lower than the CSC. Considering the CRS and CSC values of the contaminants found in groundwater reported in Table 27, it is possible to identify which contaminants require a significant effort to respect the CSC at the site.

Table 27: CRS and CSC for groundwater.

Compound	**CRS (µg/l)**	**CSC (µg/l)**
Cadmium	5.4	5
Iron	6130	200
Manganese	365.5	10
Nichel	10800	50
Lead *	53.7	20
Zinc*	3800	3000
Aliphatic C 5-6 (n-hexane >53%)	10	350
Aliphatic C > 6-8 (n-hexane >53%)	10	350
Aliphatic C > 8-10	10	350
Aliphatic C > 10-12	406	350
Aliphatic C > 12-16	1620	350
Aliphatic C > 16-21	3680	350
Aliphatic C > 21-35	3680	350
Aromatic C > 8-10	10	350
Aromatic C > 10-12	22.2	350
Aromatic C > 12-16	22.2	350
Aromatic C > 16-21	2	350
Aromatic C > 21-35	2	350
Benzene	57	1
Benzo(a)anthracene	0.11	0.10
Benzo(a)pyrene	0.14	0.01
Benzo(b)fluoranthene	0.22	0.10
Benzo(ghi)perylene	0.11	0.01
Benzo(k)fluoranthene	0.12	0.05
Bromodichloromethane	1	0.17
Chrysene	0.44	5
1.2-Dibromoethane	1	1
1.4-Dichlorobenzene	0.1	0.001
1.2-Dichloropropane	0.5	0.150
Indenopyrene	0.24	0.1
1.1.2.2-Tetrachloroethane	0.5	0.05
1.1.2-Trichloroethane	1	0.2

Table 27: CRS and CSC for groundwater.

Compound	**CRS (µg/l)**	**CSC (µg/l)**
Trichloroethylene	45	2
Trichloromethane	1	0.15

The CRS of Fe resulted 30 times bigger than the CSC, and the presence of the metal above the CSC in most groundwater samples defined it as a problematic pollutant. These high levels of dissolved Fe might be due to the redox conditions and the poor dissolved oxygen. In fact, the amount of Fe^{+2}, soluble, decreases as the dissolved oxygen increases. Therefore, more investigations about the groundwater redox conditions should be performed. Mn and Ni had CRSs much higher than the CSC, but they were found at levels above the acceptable limit only once. Therefore, they are not of primary concern at the site. The same conclusions can be drawn for Benzene and 1,1,2,2-Tetrachloroethane.

In the case of PAHs (i.e. Benzo(a)pyrene, Benzo(ghi)perylene, Benzo(k)fluoranthene, Chrysene) and 1,4-Dichlorobenzene, which had a CRS one order of magnitude greater than the CSC, their wise presence over the entire site area might make the remediation more difficult.

The comparison between the CRS of the TPHCWG hydrocarbons subclasses and their CSC was not relevant and reported in the table just for completeness. Considering that the Total hydrocarbons parameter was found exceeding the CSC only once when performing the neighborhood analysis, it was clear that these contaminants were not a relevant issue for groundwater remediation.

The presence of volatile compounds might pose harm to humans due to vapor inhalation outdoor and primarily indoor, particularly those for which a CSR below the CSC was calculated (i.e. Aliphatic C5-C6, Aliphatic >C6-8, Aliphatic >C8-10, Aliphatic >C10-12 and Aliphatic >C12-16). Moreover, the time required to remove the pollutants to acceptable level might be significant for those spread at the site, possibly compromising an immediate use of the site for the established purposes. Therefore, direct measures in the building present at the site should be taken to assess the actual risk posed by these chemicals. The overall critical contamination of groundwater, combined with the presence of the culvert that crosses the site discharging the collected water in the neighboring lake and river, requires an emergency action to stop pollution spreading. A possible solution could be the installation of a hydraulic barrier downstream the groundwater direction avoiding the pollutants spreading beneath the property.

Pollutants with CSC as the remediation goal in surface and deep soil

As presented in the “Results”, the CSRs (2), which take into account the pollutant presence in groundwater, caused some chemicals to be excluded from further calculations in deep soil and to change the individual temporary CSR (1) of other substances both in surface soil and deep soil. The “omission” of the theoretical risk related to groundwater protection for these contaminants was justified by the shallowness of the groundwater level and the permeability of the soil that both enhance the migration of pollutants to the aquifer. The compounds that were excluded due to a CSR lower than the CSC, thus set as the new remediation goal, and the risk-driving exposure/migration pathway are reported in Table 28. The removal of As, Co and Cu from the list of input chemicals for deep soil was a consequence of the non-volatility of these inorganic pollutants, which had a CSR for groundwater protection only.

Table 28: Contaminants that were excluded from further calculations in Risk-net due to a CSR<CSC and risk-driving exposure/migration pathway.

Compound	**Exposure/migration pathway**
Surface soil	
As	*Soil ingestion*
Pb	*Groundwater protection*
Zn	*Groundwater protection*
Naphthalene	*Vapor inhalation indoor*
Benzene	*Groundwater protection*
Deep soil	
As	*Groundwater protection*
Cd	*Groundwater protection*
Co	*Groundwater protection*
Cu	*Groundwater protection*
Pb	*Groundwater protection*
Ethylbenzene	*Indoor vapor inhalation*
Naphthalene	*Indoor vapor inhalation*

The main issue that caused a CSR value below the CSC was the contaminant leaching towards groundwater. This is consistent with the hydrogeology of the site that, with the permeable soil and the shallow aquifer, poses groundwater in danger . The fact that indoor vapor inhalation poses a harm to humans, not only because of groundwater pollution, but to the organic pollution in soil as well, proves again that direct measures of vapors in the buildings at the site are recommended to assess the actual risk.

Surface soil

The CSR (3), i.e. the final individual CSR, was either related to soil ingestion, groundwater protection or indoor vapor inhalation, in the case of surface soil. Soil ingestion indicates that the harm posed to humans, especially children, in recreational outdoor spaces, where they would be in contact with soil, could be relevant. Therefore, not only the indoor exposure is critical at the site, but the removal and replacement of the surface layer of soil might be required to properly use the green areas at the site.

The final CSRs that respected both individual and cumulative risk were calculated using a corrective factor for the most critical compounds. The spatial distribution of the pollution and the CSR value were considered too; so, if the CSR was close to the CSC or the contamination largely spread, it was chosen not to further reduce the CSR to avoid excessive remediation costs.

A corrective factor of 4.7 was set for the CSR of HC<12 to reduce the cumulative HI that would have resulted much higher than the acceptable limit (i.e., 1). Even if the presence of HC<12 in soil is a relevant issue at the site due to the spatial spreading of these contaminants, the reduction of the CSRs of the single classes of hydrocarbons brought to a CSR for HC<12 that was one order of magnitude greater than the CSC. Therefore, the remediation goal for these organic pollutants was not excessively strict. The same conclusion could be drawn for HC<12 (CRS: 35 mg/kg), obtained summing up the CRSs of the TPHCGW classes, which does not represent a challenging obstacle to the remediation.

The CSR of Zn, instead, was halved to avoid risk for groundwater exceeding 1.

Cu had its CSR reduced by a factor of 7 because of the high HI. This remediation goal seems possible to achieve due to the almost “punctual” contamination with unacceptable levels of Cu. A problem might be posed by the high concentrations at which the pollutant was found at the site, with a maximum concentration detected of 10000 mg/kg, i.e. more than 20 times the CSR. The only efficient way to reduce Cu concentrations to acceptable levels consists in the removal of the first layer of soil or in covering the soil surface to avoid direct exposure.

Indenopyrene’s CSR was corrected with a factor of 1.42 to reduce the R caused soil ingestion, dermal contact and dust inhalation outdoor. The reduction of the levels of Indenopyrene in surface soil might be problematic due to the great difference between the CRS and the CSR, 26.5 mg/kg and 0.62 mg/kg respectively, and the spreading of the pollution at the site. The removal of the upper layer of soil might be the most efficient solution, but the process could be economically unsustainable due to the large area that would be involved. However, it must not be forgotten that the concentrations obtained summing up those of the two Swedish classes (PAH-L and PAH-M) was conservatively used as the one for Indenopyrene. Therefore, the levels of this pollutant were overestimated.

The remediation of As to acceptable levels (i.e., CSC) in surface soil does not represent a problem as well. In fact, the CRS (23 mg/kg) resulted slightly above the CSC for residential purposes (20 mg/kg) and the areal extension of the pollution is not relevant. However, since As does not pose harm by inhalation of vapors, covering the ground surface should be sufficient to protect the attenders of the site and avoid excessive costs. Moreover, it would allow the use of the site in the short term.

Hg, on the other hand, requires a remediation goal much lower than the CRS of surface soil (1 mg/kg and 20 mg/kg respectively). However, only few samples had Hg above the CSC, so the replacement of the surface layer of soil should be sufficient to solve the problem caused by this pollutant.

Pb was the most critical metal at the site, because present at high concentration in a large portion of the site. Therefore, the removal of the surface layer of soil, that appears to be the only short-term-solution, might be very expansive.

The solution to deal with the surface soil pollution might thus consist in both a replacement of the upper soil layer, where high levels of contaminants were detected, and a covering where no risk from vapor inhalation was calculated.

Deep soil

More contaminants required corrective factors in deep soil than in surface soil to set the final CSR.

The corrective factor of Zn was halved to ensure a risk for groundwater below 1, as for surface soil. Zn was found in a limited number of sampling points, but at high concentrations (up to 30 times the CSC for residential areas).

The CSRs of the two smallest aliphatic fraction (i.e., Aliphatic C5-6 and Aliphatic >C6-C8) and those of the aromatics with less than 16 carbons atoms were reduced by 8 times to ensure the respect of the cumulative HI and avoid the harm posed by indoor vapor inhalation. For the same reason, a corrective coefficient of 10 was used for the CSRs of Aliphatic >C8-10, Aliphatic >C10-12 and Aliphatic >C12-16, Toluene and Xylene. The CSR for HC>12, of 4360 mg/kg, resulted much higher than the CSC 50 mg/kg (two order of magnitude), thus the remediation goal is not strict at all. The same occurred for HC<12 but the difference was less relevant (33 mg/kg vs. 10 mg/kg). However, many samples showed levels of HC<12 far above the CSC, as proved by the value of the CRS for the chemical parameter (147 mg/kg). Even if the presence of hydrocarbons in deep soil was not as critical as in the surface soil, ensuring the CSR might be quite challenging somewhere at the site.

The CSR of Toluene did not respect the groundwater risk, but, as discussed before, the calculated risk was considered not reliable because no trace of the compound was detected in the groundwater samples. Both the CSRs of Toluene and Xylene were significantly greater than the CSC and, even if the CRS of Xylene in deep soil was greater than the CSR (7.3 mg/kg vs. 1.8 mg/kg), both the contaminations were localized in few sampling points.

The satisfaction of the remediation goals of Cd, Hg and Pb, that consisted in the CSC, was not a big issue if considering the limited areal extension of the pollution. Since these chemicals are metals, it might however be critical to satisfy the CSR in significantly polluted samples. This may occur in the case of Hg and Pb that were detected in deep soil at levels much greater than the CSC.

As, Co and Cu, that were not detected in groundwater, do not pose risk even if present at the site at values above the CSC. Therefore, they are not remediation targets in deep soil.

The CSC was the remediation goal of Indenopyrene and Naphthalene as well. The presence of Indenopyrene in deep soil resulted quite significant and the CRS (10 mg/kg) was one order of magnitude bigger than the CSC (0.1 mg/kg). However, it must be recalled that the contaminant was used to represent the sum of two Swedish classes of PAHs. Therefore, it is likely that the harm posed by this compound had been overestimated. In the second case, the contaminant was not found at levels much greater than the CSC except in one sampling point where a concentration of 42 mg/kg was detected. Therefore, the removal of the contaminated soil in the small area around the sampling point might solve part of the problem related to the presence of Naphthalene, also due to limited number of other polluted samples.

Due to the heterogeneity of soil pollution in deep soil the possible remediation techniques are stabilization (even if it is not a remediation process since it does not remove the contaminants), to prevent metals from leaching in groundwater, and soil vapor extraction (SVE) to remove organic volatile compounds and metallic Hg. In order to avoid organic compounds disturbing the stabilization process, SVE should be performed first. However, even if the coarse soil texture that characterizes almost all the site is adequate for SVE, two major problems remain. The first one is the presence of people, both attenders and workers, at the site at the current time. The second one is the shallowness of the aquifer that might be a problem when extracting vapors. Therefore, the most realistic solution to allow the property be used for the planned purposes in the short term would be to continuously monitor the air inside the existing buildings and replace the soil with clean one where the pollution reaches dangerous levels.

7.4.2 Swedish Risk Assessment

7.4.2.1 Site-specific guidelines

The calculation of the site-specific guidelines for those pollutants that were considered as relevantly harmful at the site showed that for half of them the site-specific guideline resulted smaller than the generic KM one. Therefore, the harm posed by these substances (i.e., Co, Cu, Ni, Pb, Zn, Aromatic >C16-C35, Benzene, 1,2-Dibromoethane, PAH-L, Trichloroethylene, Trichloromethane and Xylene) resulted more significant than in the default scenario implemented by the Swedish software by Kemakta AB in the case of sensitive land use. The remediation effort that will be put into practice by the municipality and the authorities should target these critical pollutants to avoid possible adverse effects on human and environment.

The site-specific guideline resulted below the MKM generic values for 9 out of 24 chemicals included in the risk assessment (i.e., As, Cd, Cr, Hg, Aliphatic >C8-C10, Aromatic >C8-C10, Aromatic >C10-C16, Aromatic >C16-C35, PAH M and PAH H). The harm posed by these contaminants might be an issue if the land use of the site was classified as MKM, due to the greater danger caused by these substances when compared to the default MKM conditions.

Considering Cu, Zn, As and Pb, for which the K_d was replaced with the one calculated performing the leaching test, the resulting site-specific guideline was lower than the KM generic one in the case of Cu, Pb and Zn, whilst below the MKM benchmark for As. This fact proves that the mobility of these four metals at the site is an issue and poses greater harm than in the generic scenario. Moreover, it must be noticed that the site-specific guideline for Cu, Zn and Pb resulted below the KM generic guideline, even if the exposure parameters used in the assessment were less conservative than in the KM scenario (e.g.,, lower time of exposure). The site-specific guideline for As matches the generic KM one, due to the adjustment for background concentration that set the value at 10 mg/kg, corresponding to the background concentration itself. In fact, the harm posed to human health by As is so serious that the pollutant should not exceed the natural levels found in the environment.

The site-specific guidelines most lowered if compared to the KM generic values were those of Benzene and Trichloroethene. The features of the scenario used to represent the site caused these two contaminants to be the most affecting and posing the greatest harm.

The exposure target or pathway that drove the site-specific guideline, showed in the "Output report" sheet of the software, is reported in Table 29 for each contaminant.

Table 29: Exposure target or pathway driving the site-specific guidelines.

Compound	**Governing the guideline**	**Compound**	**Governing the guideline**
Arsenic-mod	*High soil background*	Aliphatic > C16-C35	*Protection free phase*
Cadmium	*Intake of groundwater+other sources*	Aromatic > C8-C10	*Protection of groundwater*
Cobalt	*High soil background*	Aromatic > C10-C16	*Protection of groundwater*
Copper-mod	*Protection of groundwater*	Aromatic > C16-C35	*Protection of groundwater*
Chromium total	*Protection of groundwater*	Benzene	*Protection of groundwater*
Mercury	*Protection of groundwater*	1,2-dibromoethane	*Intake of groundwater*
Nickel	*High soil background*	PAH L	*Protection of groundwater*
Lead-mod	*High soil background*	PAH M	*Protection of groundwater*
Zinc-mod	*Protection of groundwater*	PAH H	*Protection of groundwater*
Aliphatic > C8-C10	*Protection of groundwater*	Trichloroethylene	*Protection of groundwater*
Aliphatic > C10-C12	*Protection free phase*	Trichloromethane (chloroform)	*Protection of groundwater*
Aliphatic > C12-C16	*Protection free phase*	Xylen	*Protection of groundwater*

The majority of the site-specific guidelines (15 out of 24) were related to groundwater protection. The groundwater resource was included in the protected targets, even if there was no sensitive groundwater resource in the vicinity of the site, due to its intrinsic value and the consequent possible harm that can be posed to humans and environment. Of these 15 chemicals, 10 are organics. The presence of organic pollutants in groundwater is a serious issue due to the toxic and carcinogenic properties of these compounds. Therefore, the actual impact on groundwater reservoir beneath the site, but also on the neighboring river and lake, might pose harm to humans and environment. In fact, the presence of a culvert, crossing the properties, collecting polluted infiltration water, and discharging it into the river and the lake, can be critical. Even if it is true that the dilution occurring in the two water bodies is enough to reduce significantly the levels of pollution, in the immediate surroundings of the discharging points the hazard might be high. The only solution to assess the situation is to perform direct measurements at the discharging points of the culvert.

The background concentration was determinant for As, Co, Ni, and Pb. The guidelines were adjusted in order to consider the background exposure, but the unadjusted values for Co, Ni and Pb were lower than the final guideline due to groundwater protection. In the case of Pb, the relevance of this target was expected, due to the significant mobility of the metal under the soil conditions found at the site. The relevance of groundwater protection in the site-specific guidelines was not a surprise due to the permeability of the upper layer of soil, where the highest levels of pollution were detected, and the shallowness of the aquifer. Both these factors exposed groundwater to the pollution in soil.

The protection from free phase, possible only in the case of organic compounds, drove the risk only for Aliphatic >C10-C12, Aliphatic >C12-C16 and Aliphatic >C16-C35, i.e. those chemical for which the site-specific guideline resulted higher than the KM and MKM generic values.

The intake of groundwater, i.e. the adverse effects on human health caused by ingestion of polluted water, was the exposure pathway that influenced the most the site-specific guidelines for Cd and 1,2-Dibromoethane. The exposure due to other sources of pollution lowered the Cd final site-specific value, showing that the background exposure to this metal might pose harm to humans.

As in Sweden the remediation targets have to be discussed, the remediation goals might be higher than the site-specific guidelines lower than the corresponding KM generic values, due to the “ambiguous” land use of the site, that can be seen as halfway between a KM and MKM one. In this case, it might be excessive to refer to such low target levels due to the conservative assumptions made in the study. On the other hand, the site-specific guidelines lower than the MKM generic values might be adopted as the remediation goals because of the conservative assumptions the risk assessment was based on. In fact, these values, between the KM and MKM generic guidelines, mirror the “particular” land use planned for the site, with coexistence of working and recreational zones.

Metals have to be removed in the areas where children might come in direct contact with them. More site-specific analyses about contaminant fate in soil are advisory, with particular attention on chemicals for which the site-specific guideline was lower than the generic KM value. Direct measurements to assess the exposure to vapors should be performed in the buildings at the site in order to ensure workers safety. A direct survey of the pollution levels at the two discharging points of the culvert is necessary as well, to properly assess the risk posed to humans and environment.

7.4.3 Italian CSR and Swedish site-specific guidelines for soil

The site-specific guidelines for the contaminants of concern at the site, resulting from the two approaches, were different.

The mathematical models as well as the physio-chemical and toxicological features of the contaminants of the two methodologies, are not considered in the discussion of the results, because this was not the aim of the study.

The CSRs, for both surface soil and deep soil, and the Swedish site-specific guidelines are compared in Table 30 for the contaminants of concern included in both the risk assessments.

Table 30: Pollutants for which both a CSR in soil and a Swedish site-specific guideline were calculated. For each contaminant, the lowest value is colored in yellow.

Swedish pollutant	**Italian pollutant**	**CSR (mg/kg)**		**Swedish site-specific guideline (mg/kg)**
		Surface soil	**Deep soil**	
Arsenic-mod	Arsenic*	20		10
Cadmium	Cadmium		2	0.5
Copper-mod	Copper*	447		50
Mercury	Mercury	1	1	0.4
Lead-mod	Lead*	100	100	15
Zinc-mod	Zinc*	1336	668	80
Aliphatic > C8-C10	Aliphatic C > 8-10	13	6	250
Aliphatic > C10-C12	Aliphatic C > 10-12	61	15	1000
Aliphatic > C12-C16	Aliphatic C > 12-16	63	140	1000
Aliphatic > C16-C35	Aliphatic C > 16-21	1200	2000	2500
Aliphatic > C16-C35	Aliphatic C > 21-35	1200	2000	2500
Aromatic > C8-C10	Aromatic C > 8-10	11	1.6	18
Aromatic > C10-C16	Aromatic C > 10-12	28	4	5
Aromatic > C10-C16	Aromatic C > 12-16	258	8	5
Aromatic > C16-C35	Aromatic C > 16-21	5	162	3
Aromatic > C16-C35	Aromatic C > 21-35	5	47	3
Benzene	Benzene	0.1		0.0035
PAH L	Naphthalene	5	5	1.8
PAH M + PAH H	Indenopyrene	0.62	5.7	6.8
Xylene	Xylene		1.8	6

The Swedish site-specific guideline resulted the lowest one for most the pollutants. The values obtained for all the heavy metals were lower than the Italian CSR, showing that the harm posed by these contaminants is considered critical by the Swedish authorities. However, the Italian CSRs calculated at first (CSR (1)) were much lower than the final remediation goal and caused either the exclusion form the risk assessment (if they were not detected in groundwater and no other CSR was available) or the replacement with the CSC as the remediation goal. The only exception was Zn, which did not pose significant risk and had a CSR above the CSC. Whilst the metal resulted as not a primary issue at the site based on the Italian approach, the site-specific conditions resulted in significant risk in the Swedish procedure. Even if in both cases groundwater protection was determinant, the estimated harm resulted more relevant in the Swedish approach, maybe influenced by the permeability of the soil texture. Arsenic was the inorganic pollutant with the smallest difference between the two outcomes. In the Swedish case, the harm posed by As resulted particularly significant and the site-specific guidelines was set equal to the background concentration. The intake of drinking water, not considered in the Italian methodology, was critical for As and Cd in the Swedish approach, due to their adverse effects via this exposure pathway.

The CSRs for all the Aliphatics and the Aromatics with less than 12 carbon atoms were lower than the site-specific guideline based on the Swedish methodology. Indoor vapor inhalation was the most relevant exposure pathway for some pollutants in the Italian approach, as well as groundwater protection and soil ingestion. On the other hand, in the Swedish approach the decisive factor was either the presence of free phase or groundwater protection. The outcomes for these contaminants were partly caused by the same critical pathway (i.e., groundwater protection), but the relevance of indoor vapor inhalation was negligible in the resulting Swedish guideline. This occurred even if the indoor exposure time was greater in the Swedish model than in the Italian one. A possible explanation might be the presence of an input concentration in the Italian model that, if high, causes a greater risk posed by volatile compounds. The volatilization model and the toxic properties of the classes of compounds could be pointed as reasonable motivations too and should be further investigated.

The site-specific guidelines of Aromatics with more than 12 carbon atoms were lower than the Italian CSRs. The difference between the two approaches was either great or small due to the diverse hazard posed by the same substances in surface or deep soil in the Italian case. However, groundwater protection was decisive in both the assessments for all the classes, except for Aromatic >C21-35 in surface soil.

Benzene and Naphthalene’s Italian remediation goals were the CSC, thus it is not surprising that the Swedish site-specific guidelines were lower than these values. Groundwater protection was the only pathway of concern related to these contaminants in the Swedish approach, with drinking water as the second most important, but not decisive in the final guidelines. In the Italian case, indoor inhalation of vapors was the major issue for Naphthalene, whilst groundwater protection was decisive in the CSR of Benzene, as in the Swedish approach. The Swedish site-specific guideline for Naphthalene was lower than the Italian CSR, as the contaminant represents the Swedish class of light PAHs (PAH L). The mix of low molecular weight PAHs in the Swedish class might be at the basis of the different issues that caused the two final values.

The Italian CSR for Indenopyrene was smaller than the Swedish site-specific guideline, obtained summing up the values obtained for PAH M and PAH H. Since Indenopyrene was selected as representative of PAH M + PAH H, a more conservative outcome in the Italian approach was expected than in the Swedish one. Whilst the intake of soil resulted the primary issue related to Indenopyrene in surface soil, groundwater protection was decisive for the CSR of deep soil, as in the Swedish case.

Indoor vapor inhalation determined an Italian CSR lower than the Swedish site-specific guideline, based on groundwater protection. The CSR obtained for p-Xylene, that was inserted to determine the risk posed to groundwater, was even lower, but it was not considered due to the absence of the compound in groundwater.

Even if the Swedish site-specific guidelines were lower than the Italian CSRs for most the contaminants, it must not be forgotten that the former are negotiated by the parties involved in the risk assessment and are not legally binding values, while the latter are compulsory remediation goals for the site. The same reasoning can be done for chemicals requiring the CSC as the remediation goal. Therefore, it is not possible to determine which of the two approaches would result in the greatest remediation costs.

7.4.4 Comparison between the Italian and the Swedish approach to contaminated sites

The Italian and Swedish approaches for contaminated sites vary a lot. The different assumptions and inputs required to estimate the hazard posed by a contaminated area to humans and the environment influence the risk assessment outcomes. The strengths and weaknesses of the two approaches are briefly reported in Table 31.

Considerations about ecotoxicity of pollutants for terrestrial and aquatic living beings, present in the Swedish approach, is not considered in the Italian one, which limits the assessment of the environmental risk to the impact on groundwater pollutant concentrations. Therefore, even if the implementation of a model for the evaluation of the adverse effects on living beings is challenging, it might improve the environmental risk assessment.

The development of the conceptual model of the site requires a much greater effort in the Italian risk assessment than in the Swedish one. This is shown by the two software as well. The number of parameters required by Risk-net is huge if compared to the limited amount of editable values in the software by Kemakta AB. Therefore, the risk assessment with site-specific conditions appears more realistic in the Italian approach. At the same time, the details required to develop the conceptual model for an Italian risk assessment entails a great amount of data and information that might increase significantly both the costs and the time required to perform the process. Furthermore, a greater number of parameters means a higher possibility of criticism from the authorities about the values used. This would cause the procedure to last longer or to be repeated, delaying the remediation actions at the site. On the other hand, the Swedish approach, even if not significantly detailed, allows the performer to rapidly repeat the calculation of the site-specific guidelines as many times as necessary, by using different input data.

The different complexity of the two approaches is reflected in the selection of the contaminants of concern as well. First, whilst in the Italian procedure the contaminants found above the CSC (even if only once) must be considered, the pollutants considered in the Swedish approach are selected giving motivations that might be others than the detection of levels of chemicals above the generic guideline (e.g. ecotoxicological studies). Moreover, a greater number of chemicals is regulated in Italy than in Sweden.

One aspect that clearly affects the outcomes is the fact that in the Italian risk assessment a CRS is required, differently from the Swedish methodology. The neighborhood analysis in the Italian approach, that both defines the CRS and the area of the secondary sources of pollution in the matrices, might cause the overestimation of the actual risk posed by the pollution. The possibility to distinguish more secondary sources ensures a more realistic assessment, but once again implies a greater effort and longer time to perform the assessment.

The exclusion of groundwater protection in the Swedish generic less-sensitive land use (MKM) scenario can be negotiated. However, the importance of water resources should not be underestimated; because with population growth and increase in water demand, polluted groundwater reservoirs might affect the daily life of people in the future. Whilst in Sweden water demand is not an issue, in developing countries or densely populated countries, it is of primary importance to ensure good quality groundwater resources.

The exposure pathways are another key point that distinguish the Italian risk assessment from the Swedish one. The intake of plants and groundwater drinking are not considered in the Italian approach. The intake of plants is an interesting exposure pathway, that can be relevant in rural areas. Even if the implementation of a realistic model is challenging due to the different variables that affect the process (e.g., type of plant, age of the plant, climate, human ingestion rate, etc.), it might bring a positive contribute to the reliability of the assessment. The exposure consequent to the intake of drinking water is substituted, in Italy, by ensuring the respect of the drinking water standards in the aquifer. Therefore, the remediation of groundwater to the CSCs can be problematic due to the low target concentrations.

The assessment of the risk posed by pollution to the off-site receptors of the Italian approach should be included in the Swedish assessment. In fact, even if it is generally unlikely that off-site inhalation of vapors and dust drive the CSR values, it is also true that the harm posed to people in the surroundings of the site must not be underestimated (e.g., a school or a hospital might be sensible targets).

The Italian approach considers pollution sources in three different matrices (surface soil, deep soil, and groundwater). Contaminants in surface soil or deep soil in fact pose different risks, as shown by the outcomes of the two risk assessments performed in this study. For example, the harm posed by metals (with the exception of Hg) to humans, due to ingestion of soil or dermal contact, is negligible if the chemicals are not in the surface layer of the soil. This ensures more reliable outcomes that do not overestimate the actual risk.

A great advantage of the Swedish procedure is the already cited “flexibility”. In fact, the possibility to choose, with proper motivations, the contaminants to assess and the remediation goals, allow a more site-specific remediation procedure.

In Italy, the legally-binding character of the calculated target values and the great number of regulated substances might make the remediation unsustainable, both in terms of costs and time required to reach the remediation goals.

The evaluation of the risk in terms of R and HI is possible in the Italian risk assessment, while it is not provided for in the Swedish methodology. The possibility to check the risk posed by each contaminant though the single exposure pathway allows the performer of the assessment to focus the remediation on the critical issues.

The two countries adopt different approaches to deal with the carcinogenic risk, but the outcomes are almost the same. In fact, even if an incremental risk of 10^{-5} is considered in in the Swedish approach for a single contaminant, instead of 10^{-6} as in the Italian regulation, acute toxicity and background exposure accounted for in the Swedish approach lower significantly the resulting guidelines.

The cumulative risk and hazard posed by many pollutants is not considered in the Swedish methodology and should be included.

A last consideration involves the leaching of metals. Whilst in Risk-net the K_d provided by the database is a function of pH, in the software by Kemakta AB just one value can be edited. In the case study, a leaching test was performed to determine a site-specific K_d for the metals of concern. As explained in Appendix 1 and 2, the fate of metals in soil is not related only to soil pH, and other parameters (i.e. SOM, and particle size distribution in particular) are important as well. Therefore, a K_d based on leaching tests is more reliable than a value based on soil pH only.

The outdoor areal cracks, required in the Italian model and not present in the Swedish one, can be either 1, for unpaved surfaces, and 0.1 for paved surfaces.

Table 31: Strengths and weaknesses of the Italian and Swedish approaches.

Country	Strengths	Weaknesses
ITALY	- Detailed - Risk calculation - Three matrices - Off-site receptors - Site-specific conceptual model - CRS as input - Protection of groundwater in both generic scenarios - Cumulative R and HI - Metals' K_d also as f(pH)	- Too complex - Often cause an overestimation of the risk - High time and financial demanding - No ecotoxicological aspect - CSC difficult to be reached - Groundwater CSC are drinking water standards - Areal cracks not realistic
SWEDEN	- Simple - Quick to be applied - Intake of drinking water - Intake of plants - Ecotoxicological aspects - Input pollutants object of discussion - Site-specific guidelines are not legally binding	- Not very site-specific - Not defined remediation goals - No risk calculation - Groundwater protection not considered in MKM - Limited number of editable parameters - No pollutant concentration as input - No distinction between surface and deep soil - No cumulative risk - No off-site receptors - Metals' K_d not as f(pH)

8 Conclusions

The evaluation of the adverse effects that a polluted area might cause on humans and the environment constitutes a serious issue. Risk assessment is the procedure to estimate the actual entity of such theoretical negative impact and determine the remediation goals at the site of study. The approach to a contaminated site significantly differs from country to country, thus the comparison between diverse procedures is fundamental to identify the most efficient, reliable and realistic one.

The study focuses on the Italian and the Swedish methodology. The two assessments of the risk were performed for the site of Bollnäs Bro 4:4, in the Swedish community of Bollnäs. Due to the hazard posed by the heavy metals detected in the property, soil samples were taken on site to determine the site-specific K_d to be inserted in both the Italian and the Swedish risk assessment software.

The remediation goals determined by applying the Italian methodology showed that the levels of pollution in groundwater must be reduced to the corresponding CSC of each contaminant. The CSRs in surface soil were driven by soil ingestion, indoor vapor inhalation and protection of groundwater, whilst only the two last exposure pathways resulted decisive for deep soil CSRs. The remediation goal of 10 pollutants matched the CSC itself, due to the low CSRs. Arsenic, Co and Cu were excluded from the calculation of the final CSRs of deep soil, because not posing a relevant risk. The CSRs of some contaminants of concern in soil were adjusted with a corrective coefficient to respect the cumulative R and HI. The remediation goals of the tree matrices indicated the combination of stabilization and soil vapor extraction as possible remediation solution. However, the risk posed by surface soil contamination could be reduced substituting the upper layer of soil with a new, clean one. The great groundwater pollution requires, instead, an emergency action to stop the spreading of the contamination and the closure of the culvert that crosses the property collecting contaminated water. Moreover, direct measurements to assess the quality of vapors in the building of the site are required.

The Swedish site-specific guidelines determined for the site of study resulted below the generic KM value for half of the contaminants of interest, and below the MKM value in 9 more cases. Therefore, the contaminants that were proved to pose a higher risk than in the KM generic scenario, should be the main object of discussion between the involved parties to determine the remediation goals that can ensure the safety of people and the environment. The main guideline-driving exposure pathway was groundwater protection, but high background concentration and free phase protection were present as well. The results of the Swedish risk assessment suggested to perform analysis at the discharging points of the culvert and to remove the soil in the areas where children might come in direct contact with it.

The Swedish site-specific guidelines resulted smaller than the Italian CSRs for the majority of the contaminants. However, due to the different nature of the two outcomes, the former are remediation goals whilst the latter are object of discussion, it was not possible to determine which procedure would have required the highest costs.

The Italian and the Swedish methodologies showed strengths and weaknesses. The Italian risk assessment is more detailed, but also more time and resource consuming than the Swedish one. The simplicity of the Swedish approach reduces the realism of the conceptual model and limits the site-specificity of the assessment, but allows a quick simulation of different scenarios. The Italian methodology contemplates the presence of off-site receptors whilst the Swedish procedure includes the intake of drinking water (substituted, in Italy, by the respect of the drinking water standards in the aquifer), plants and ecotoxicological considerations. The “flexibility” in the selection of the assessed contaminants and the remediation goals that characterize the Swedish approach to contaminated sites is opposed to the fine-legally-regulated, Italian procedure.

Further studies, focused on the physio-chemical and toxicological properties of the pollutants as well as the mathematical models used to reproduce the transport of contaminants in the environment, and the consequent exposure of living beings to harmful substances, are required to perform a complete critical comparison between the Italian and Swedish methodologies to assess the risk.

APPENDIX 1 – Site-Specific Parameters for Risk Assessment

1 Introduction

In order to perform a more reliable risk assessment, the pollutants mobility must be determined. The mobility of metals in soil is in terms of K_d, i.e. the soil to liquid partition coefficient. Therefore, the measurement of site-specific K_d for the relevant metals found at the site is a fundamental step.

In this appendix, the background about the fate of metals in soil is reported.

2 Metals' fate in soil

2.1 Metals in soil

Metal fate and transport in soil is affected by both the physiochemical properties of the metal itself and the soil matrix properties (Dube et al., 2000). The soil is a complex and heterogeneous media, with both chemical and physical properties that can vary a lot in space and time affecting the fate of substances present in the media. In particular, when dealing with the presence of heavy metals, it is fundamental to estimate and evaluate the adsorbing capacity of the soil because it has consequences in agricultural issues, e.g., uptake of pollutants, for water quality and in remediation of polluted sites (Bradl, 2004).

Since the retention process of metals on soil is often unidentified, it is common to use the term sorption which indicates the loss of a metal ion from the aqueous to the contiguous solid phase (Bradl, 2004). Sorption includes all the processes that remove metals from the soil water and the most important is adsorption, i.e. the bi-dimensional accumulation of metals on the soil surface due to intermolecular interactions between the two phases (Bradl, 2004). Functional groups are, in particular, fundamental for adsorption. Soil organic matter has usually a lot of these functional groups that are able to release their protons in the solution, allowing the adsorption of metal ions (Bradl, 2004). Carboxyl groups and ferric oxides are the most important functional groups for positively charged heavy metals and negatively charged ones, as As, respectively (Qinzhong et al., 2013; WSDE, 2003).

There are different parameters that can influence the sorption and the distribution of metals in the soil metal concentration, soil pH, soil type, i.e. both texture and composition, the liquid to solid ratio (L/S ratio) and the ionic strength of the soilwater (Bradl, 2004; Dube et al., 2000; WSDE, 2003).

In general, it is proven that the higher the pH, the lower the mobilization of most metals (Bradl, 2004; Dube et al., 2000; Hayan et al., 2013; Yujun et al., 2001). At higher pH, the number of negative charges increases, enhancing the adsorption of positively charged metals on the soil surface (Bradl, 2004; Hayan et al., 2013; Yujun et al., 2001). When the pH decreases, the competition between hydrogen ions and metals present in the solution for the soil surface increases, which causes a higher amount of soluble metals (Hayan et al., 2013; Yujun et al., 2001). These considerations are not valid for heavy metals that form complexes with oxygen, as Cr and As, that are found in the soil solution at basic pH values in the form of chromate and arsenate respectively (Norrström, 2015; Qinzhong et al., 2013).

The presence of organic matter in soil significantly affects the solubility of heavy metals (Bradl, 2004; Dube et al., 2000; Yujun et al., 2001). SOM includes all the organic constituents in soil and the most important substances when considering adsorption of metals are the humic ones (Dube et al., 2000). The presence of the already cited functional groups and the usually negatively charged surface, defines SOM as a fundamental factor in metals retention (Bradl, 2004; Dube et al., 2000). However, it must be said that the SOM charge is greatly pH-dependent (Dube et al., 2000).

The texture and the type of the soil can affect the leaching of metals as well (Bradl, 2004; Dube et al., 2000). The amount of heavy metals adsorbed on clay is for example higher than on coarser soils, because of the weak pH influence on Cation Exchange Capacity and the great surface available (Bradl, 2004; Dube et al., 2000). A high presence of clay, which is characterized by a negatively charged surface, should ensure an increased fraction of metals adsorbed on the solid phase (Dube et al., 2000; Yujun et al., 2001).

The ionic strength, i.e. the correlation between the charge of ions in solution and their concentration, can impacts the solubility of ionic species as metals, with greater solubility at higher ionic strength (WSDE, 2003).

2.2 Methods for soil characteristics

When performing laboratory analysis on soil samples, it can be relevant to determine the characteristics of the solid matrix to understand which are the processes that may affect the fate of contaminants.

2.2.1 Soil texture

The particle size of the soil can be relevant for the adsorption of metals. Therefore, the texture of the soil must be determined, for example performing sieving, to identify the possible influence of particles size on the release of metals.

2.2.2 pH

The pH of the soil, as explained before, is one important factor that can determine the partition of metals. Usually, the samples are added in a liquid solution as distilled water or $CaCl_2$ solution, waiting one day for equilibrium to be reached and then measuring the pH of the solution. The use of $CaCl_2$ is estimated to be more representative of the actual conditions at the site from where the samples are taken.

2.2.3 Soil organic content

In order to assess the soil organic matter content, different procedures can be performed and one of these consists in the determination of the weight loss on ignition (LOI) (Bojko and Kabala, 2014). This method is in fact inexpensive, easy to perform, rapid and it requires no specialized knowledge (Sutherland, 1998). The organic matter of the soil, rich in functional groups that can enhance the adsorption of metals, is determined putting the soil samples, previously dried at 105 °C, in an oven at 600 °C for some hours (5 to 17) for the determination of the LOI. The LOI (%) can be calculated with the following formula (Sutherland, 1998):

$$LOI = \frac{W_d - W_{600}}{W_d} \, 100 \, [\%]$$

Where W_d is the sample weight after drying at 105 °C and W_{600} the sample weight after combustion at 600 °C.

The high temperature is used to ensures that the organic matter present in the soil sample is combusted in the oven, leaving the mineral fraction only (Bojko and Kabala, 2014).

The distinction between soil organic matter (SOM) and soil organic carbon (SOC) should be highlighted. The LOI procedure indicates the fraction of SOM of which, on average, 58% is organic carbon, 40% oxygen and 2% hydrogen. However, this representative value for SOC is shown to be too high according to analysis performed in the last 120 years. Therefore, the usual factor to convert SOC to SOM, called “van Bemmelen factor”, equal to 1.724, should be substituted by a factor equal to 1,9 that corresponds to the assumption that 50% of SOM is carbon (Pribyl, 2009).

2.3 Leaching test

The process by which soluble species are dissolved from a solid, e.g., soil, rock or waste, into a fluid by diffusion or percolation is called leaching (WSDE, 2003).

Leaching tests are used to evaluate the leaching behavior in the environment and can be performed on field or at a laboratory.

The most used field tests consist in lysimeters or pilot landfills. A lysimeter is a container, of variable dimensions, that is posed in the unsaturated zone to analyze the factors affecting the leaching, as well as percolation and evapotranspiration (WSDE, 2003).

The leaching test performed at laboratory contemplates the contact between one or more samples of the studied material and a liquid that is then analyzed to identify the substances that are present in it and consequently likely to be released in the environment. There are two main types of laboratory leaching tests: single extraction/batch tests or multiple extraction/flow-around/flow-through test. The first ones are called also “static” tests, the second ones “dynamic” (WSDE, 2003).

In the static tests, a sample of material is mixed with a fixed amount of solution without renovating it, for the time required to reach equilibrium (hours to days). The leachate is analyzed or at the end of the test or at various times to determine the kinetics of the leaching (variation in concentration over time). The single extraction tests are based on the assumption that the equilibrium is reached by the end of the test, even if this may not be the actual situation. (WSDE, 2003).

The liquid solution used in dynamic tests is instead continuously or periodically renewed. The time required for these tests is longer than for static ones (days to months). The multiple extraction leaching tests provide information about the kinetics of the release of chemicals from the solid matrix. The three main types of dynamic tests are: serial batch tests, flow-through tests and flow-around tests. In a serial batch test, the leaching fluid and a portion of the soil sample are mixed at a fixed L/S ratio for an established time. The leachate is then removed and replaced as many time as requested. In flow-through and flow-around tests, the leaching fluid is continuously flowing through and around the solid matrix respectively (WSDE, 2003).

The results obtained from the leaching test are usually aimed at two objectives: either the assessment of the property of the used material or the simulation of the leaching occurring at the case study. Examples are the classification of hazardous waste or the assessment of the release of contaminants from polluted soil.

There are different factors affecting the leaching that are connected to the leaching fluid, the particle size and the scenario evaluated (WSDE, 2003).

2.3.1 Leaching fluid

The fluid used to extract compounds from the solid matrix has the greatest influence on the leaching because the solubility of the constituents in the liquid determines their partition between the solid matrix and the solution. While the solubility of inorganic compounds is affected by pH and redox potential, in the case of organic chemicals polarity and partitioning coefficient are fundamental (WSDE, 2003).

The volume of leaching fluid can affect the results of the test, in terms of concentration and number of species found in the leachate. The L/S ratio expresses this relationship between the solid matrix and the liquid. A lower amount of less soluble compounds and a higher amount of more soluble ones is likely to be found in the leachate, if a small L/S ratio is used. A higher L/S ratio, instead, usually implies more species to be released in the leachate (WSDE, 2003). It is broadly acknowledged that, for example, a L/S ratio of 2 is representative of the short-term leaching, while a L/S ratio of 10 can simulate the leaching in the long period.

2.3.2 Soil material

Since the soil surface exposed to the leaching fluid affects the leaching, the smaller the particles, the larger the contact between soil and liquid phase during the test. If the soil that has to be analyzed is very heterogeneous, it can result difficult to take a representative sample. Moreover, impurities and big particles should be removed before performing the test (WSDE, 2003).

2.4 Heavy metals extraction for total concentration

The traces of heavy metals are a serious environmental issue and the determination of their presence in a monitored site is really important in order to evaluate if the background levels are exceeded. In particular, if the leaching of metals from soil is studied in laboratory, the total amount of chemicals must be established for the calculation of the solid to liquid partition coefficient (K_d).

The most diffused methods for the determination of total heavy metals content are the spectroscopic techniques, but the drawback of these procedures is that the soil sample must be firstly converted in a liquid solution. In order to do so, sample digestion must be performed through a strong acid and heating up the soil samples. Heating systems that can be used for this purpose are sand-baths, heating plates or pressure digestion blocks. The adoption of microwaves, both in closed and open systems, can significantly reduce the time required for the process (Sastre et al., 2002).

The use of open systems enhances the acid evaporation, reducing the problems that might occur, due to the high acid concentration, during the analysis for the total metals' content. On the other hand, volatile compounds, as Hg, are lost.

A possible procedure for the extraction of heavy metals, recommended by USEPA, contemplates the use of nitric acid and a heating system to perform the digestion. In fact, nitric acid is strong enough to solubilize heavy metals present in ashes and soil with an SOC up to 38% (SOM around 70%). The soil sample is heated at around 130 °C for a couple of hours until the digestion is complete and the resulting solution can be filtered and then analyzed for the determination of metals' content (Sastre et al., 2002).

APPENDIX 2 – Laboratory Analysis and Leaching Test

This appendix reports about the measurements performed in order to characterize the soil at the case study and the site-specific K_d for Cu, Zn, As, and Pb.

1 Materials and methods

1.1 Laboratory analysis

The analysis on the soil samples collected at the site were performed at the KTH’s laboratory. After sieving at 4 mm to remove coarse material, the following analyses were performed: pH, moisture content and LOI, leaching test for metals and total metals concentrations. Part of the equipment used to perform the laboratory work are reported in Figure 68.

Figure 68: Part of the equipment used to perform the laboratory analysis. From the top-left, clockwise: calibrated combination electrode to determine solution pH; recipient for absorption of moisture of heated soil samples; high precision scale to weight soil samples; Acrodisc paper filters to filter the solution for total concentration of metals; plate for digestion of SOM; centrifuge for leaching test.

1.1.1 Soil texture

The texture was roughly estimated combining the information gathered by Sweco in the last report and the consistency of the solid material. Part of the soil samples was rolled to form a cylinder and, whenever it was not possible, the soil was proven to be coarse, i.e. sand/gravel.

1.1.2 Soil pH determination

For each sample, 6 g of soil were put into two plastic vessels and 15 ml of deionized water and 0.01 M $CaCl_2$ were added. The vessels were closed with lid and shaken by hand for

30 s and let rest for 18 and half hours. The pH was measured with a calibrated combination electrode in the clear part of the solution.

1.1.3 Loss on ignition

The porcelain crucibles, with the soil already used for the moisture content, were put in oven at 600 °C for six hours. After cooling down, they were weighted with a high-precision scale. Then, the LOI was calculated with the formula described in the "Background" chapter.

1.1.4 Leaching test for heavy metals

The procedure adopted in this study consisted in a two stage batch leaching test using 0.001 M $CaCl_2$ as solution (EU standard ISO/TS 21268-1). The first test was performed with a liquid-solid ratio (L/S) equal to 2; 30 g of the sieved soil and 60 ml of 0.001 M $CaCl_2$ were added to an acid-washed bottle and shaked for 6 hours. Then the samples were centrifuged at 4000 round per minute (rpm), for 10 minutes. The supernatant was then removed with a pipette, the pH was measured on one part of it with a calibrated combination electrode. The rest of the supernatant was filtered through a filter with the pore size of 0.45 µm. The sample was acidified with Suprapure concentrated HNO_3. The samples were stored in a refrigerator at 4°C until analyses with ICP-MS. .

The second leaching test was performed with a L/S ratio of 8. The bottles, with the 30 g of soil used for the first test, were shaked on a shaker for 18 hours after the addition of 240 ml of 0.001 M $CaCl_2$. The samples were centrifuged at 4000 rpm for 10 minutes The supernatant was filtered through a filter with the pore size of 0.45 µm. The samples were acidified with Suprapure concentrated HNO_3 The samples were stored in a refrigerator at 4°C until analysis with ICP-MS.

1.1.5 Extraction with nitric acid for total metals concentration

1 g of soil was mixed with 15 ml of Suprapure 65% HNO_3. The test tubes were left open and heated on a plate at around 120 °C until a brown fume was seen. When the fume

became colorless, the test tubes were removed and the solution filtered with a Acrodisc paper filter and diluted with distilled water to the volume of 50 ml.

1.2 Data processing

The metals considered, and for which the concentration in soil and the site-specific K_d were calculated, were those found above the generic guidelines (MKM) in soil in the previous surveys (Appendix 4 and 5): Pb, As, Zn, and Cu. As previously explained, it was not possible to measure Hg concentration in soil samples due to the laboratory procedure.

1.2.1 Soil pH variation

The variation in the pH-value before and during the leaching tests was reported in the "Results" chapter to assess the effects of different L/S ratios and contact time on K_d. The pH trend and the variation range were used to evaluate if some metals could have changed chemical form.

1.2.2 Calculation of metals' total concentration in soil

In order to estimate the metal total concentration on dry soil matter, necessary to determine the K_d, the concentration in the soil extract was converted using the following formula:

$$C_{\frac{mg}{kg}} = C_{\frac{\mu g}{l}} \times 0.001 \times \frac{V_{solution}}{W_{soil} - 0.01 \times M_n \times W_{soil}} \left[\frac{mg}{kg_{d.m.}}\right]$$

Where:

- $C_{mg/kg}$ is the concentration of the metal on dry matter;
- $C_{\mu g/l}$ is the concentration obtained in the soil extract;
- $V_{solution}$ is the volume of extract sent to the laboratory, [l];
- W_{soil} is the weight of soil [kg];
- M_n is the moisture content of soil [%].
-

1.2.3 Comparison with drinking water guidelines

The concentration of metals in the leachate, for L/S ratio 2, were compared to the drinking water standards in order to have a first idea of the pollution released in soil water.

1.2.4 Kd determination

The K_d for each metal was calculated using the formula:

$$K_d = \frac{C_{soil}}{C_{water}}\ [l/kg]$$

Where:

- C_{soil} is the total concentration of metal on soil dry matter [mg/$kg_{d.m.}$];
- C_{water} is the concentration of metal in the leachate (assumed to be the same as in soil water).

Since two different L/S ratios where used, the K_d was estimated both for L/S ratio 2 and L/S ratio 8. In addition, the K_d for a L/S ratio 10 was obtained using the concentrations corresponding to L/S ratio 2 and 8 with the mass balance expressed by the formula below:

$$C_{10} = \frac{(C_2 \times V_2) + (C_8 \times V_8)}{V_{10}}\ \left[\frac{mg}{l}\right]$$

Where:

- C_{10} is the concentration in the leachate at L/S ratio 10 [mg/l];
- $V_{10} = V_2 + V_8$ is the volume of leachate at L/S ratio 10 [l];
- C_2 is the concentration in the leachate at L/S ratio 2 [mg/l];
- V_2 is the volume of leachate at L/S ratio 2 [l];
- C_8 is the concentration in the leachate at L/S ratio 8 [mg/l];
- V_8 is the volume of leachate at L/S ratio 8 [l].

In the study, the mass of soil used for the leaching test was equal to 30 g, therefore V_2 is 60 ml, V_8 240 ml and V_{10} 300 ml.

The K_d values obtained for each metal in the samples were compared with the corresponding pH and LOI in order to evaluate the influence of these two parameters on the mobility of the pollutant and the consequences of different L/S ratios. The pH that was selected as representative of the soil sample to interpolate the data, was the one measured at the beginning of the laboratory analysis with distilled water.

In order to determine the representative K_d for each metal, the harmonic mean was used, considering the values obtained in the analyzed soil samples:

$$H = \frac{n}{\sum_{i=1}^{n} \frac{1}{x_i}}$$

Where H is the harmonic mean of the real positive numbers $x_1, x_2, \ldots, x_n$.

The harmonic mean was chosen because it enhances the lower values instead of the higher ones. Therefore, the obtained representative K_d is conservative (lower the K_d higher the leaching) and ensures more safety in the assessment of the risk (Elert, 2015).

Adopting the most precautionary approach, the K_d corresponding to a L/S ratio 2 was chosen to substitute the default one in the software. In fact, considering this value means to assess the leaching in the short period, i.e. a greater release of pollutants in soil water.

2 Results

2.1 Soil texture

The soil texture for the analyzed soil samples was constituted by filling material, i.e. sand and gravel, except in the case of the sample 1513 -1.10 M, where clay was the main constituent. The soil texture of the samples is reported in Table 32.

Table 32: Soil texture of the samples analyzed at laboratory.

Soil Sample	**Soil Texture**
Building Surf.	Filling
Building – 0.2 M	Filling
1517 SURF.	Filling (mainly gravel)
1522 - 0.35 M	Filling
1522 - 0.65 M	Clay
1513 Surf.	Filling
1513 - 1.10 M	Sand
S7 Surf.	Filling
S7 - 0.5 M	Sand
S7 - 0.8 M (I)	Filling
S7 - 0.8 M (II)	Filling
1506 Surf.	Filling
1506 - 0.4 M	Filling
1506 - 0.6 M	Filling

2.2 Soil pH variation

The pH values measured before and in the two steps of the leaching test are reported in Table 33.The variation of soil pH in each sample is reported in Figure 69.

Table 33: pH values before and in the two steps of the leaching test.

Soil Sample	**Soil pH**			
	Distilled water	*0.01 M $CaCl_2$*	*After leaching L/S ratio 2 with 0.001 M $CaCl_2$*	*After leaching L/S ratio 8 with 0.001 M $CaCl_2$*
Building Surf.	6.75	6.48	6.99	6.78
Building – 0.2 M	6.69	6.46	7.36	7.59
1517 SURF.	6.6	5.47	7.37	7.09
1522 - 0.35 M	7.91	7.04	8.04	8.08
1522 - 0.65 M	7.79	7.18	7.64	7.8
1513 Surf.	6.33	5.08	6.36	6.47
1513 - 1.10 M	6.58	5.43	6.54	6.47
S7 Surf.	6.94	6.18	7.53	6.89
S7 - 0.5 M	6.99	5.98	6.76	6.61
S7 - 0.8 M (I)	7.43	6.28	6.89	7.08
S7 - 0.8 M (II)	7	5.8	7.23	6.98
1506 Surf.	6.34	5.06	7.12	6.55
1506 - 0.4 M	7.75	6.94	7.55	7.72
1506 - 0.6 M	7.32	6.22	6.84	7.13

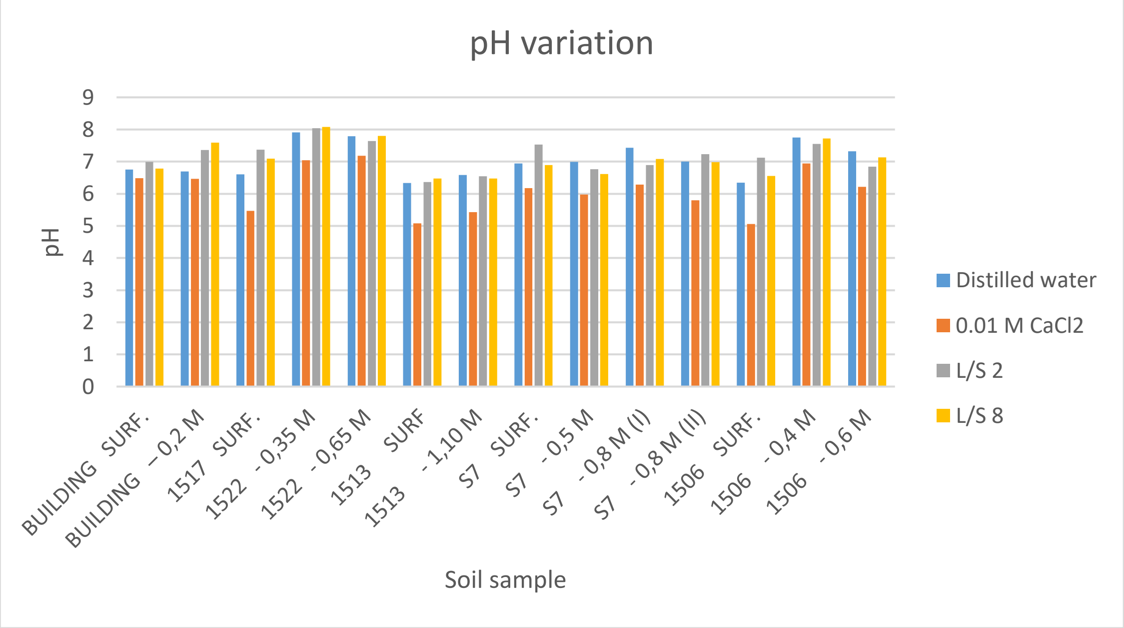


Figure 69: Soil pH variation before and during leaching test in the analyzed samples.

In all the soil samples the soil pH measured using distilled water resulted higher than the one with 0.01 M $CaCl_2$. The greatest variation, of 1.3, occurs in the samples 1513 Surf. and 1506 Surf..

Considering the pH in the two phases of the leaching test, the solution pH was found to increase in half of the samples and to decrease in the remaining ones passing from L/S ratio 2 to L/S ratio 8. The pH variation is in general smaller than in the case of the two first analysis, with the maximum difference equal to 0.64 in correspondence of sample S7 Surf..

The soil pH detected in each sample reached the highest value four times when distilled water was used before the leaching test, in samples 1513 – 1.10 M, S7 – 0.8 M (I), 1506 - 0.4 M and 1506 – 0.6 M, five times after the leaching test with L/S ratio 2, in samples Building Surf., 1517 Surf., S7 Surf., S7 – 0.8 M (II) and 1506 Surf., and four times at the end of the leaching test with L/S ratio 8, in samples Building – 0.2 M, 1522 – 0.35 M, 1522 – 0.65 M and 1513 Surf.. In all the soil samples the lowest pH was detected before the leaching test using 0.01 M $CaCl_2$ as solution.

2.3 Loss on ignition

The LOI for the samples analyzed in laboratory is reported in Table 34.

Table 34: LOI of the soil samples analyzed in laboratory.

Soil Sample	**LOI (%)**
Building Surf.	8.51
Building – 0.2 M	5.83
1517 SURF.	0.50
1522 - 0.35 M	10.71
1522 - 0.65 M	25.21
1513 Surf.	3.85
1513 - 1.10 M	3.07
S7 Surf.	1.01
S7 - 0.5 M	5.06
S7 - 0.8 M (I)	4.92
S7 - 0.8 M (II)	5.56
1506 Surf.	0.57
1506 - 0.4 M	25.20
1506 - 0.6 M	2.64
Average	7.33

The LOI varies significantly in the analyzed soil samples, with the lowest value of 0.5% found in correspondence of sample 1517 Surf. and the highest one in sample 1522 – 0.65 M for which the LOI reached the 25.21%.

The fraction of SOM was found to decrease with depth in the sampling points Building and 1513, whilst the samples taken in the sampling points 1522, S7 and 1506 showed an increased LOI with depth.

2.4 Leaching test

The concentration of the toxic metals of interest at the site, i.e. Cu, Zn, As, Pb, found in the leachate of the two-step leaching test are reported in Table 35.

Table 35: Concentration of Cu, Zn, As, Pb in the leachate after the two-step leaching test at L/S ratio 2 and 8.

Soil Sample	**Cu (µg/l)**	**Zn (µg/l)**	**As (µg/l)**	**Pb (µg/l)**
L/S ratio 2				
Building Surf.	466.48	334.81	5.96	10.68
Building – 0.2 M	497.43	321.29	5.30	35.27
1517 SURF.	24.52	110.07	1.55	14.18
1522 - 0.35 M	13.71	51.74	1.81	1.94
1522 - 0.65 M	37.74	76.46	0.25	3.95
1513 Surf.	147.48	683.89	10.71	536.95
1513 - 1.10 M	337.48	822.29	8.55	259.45
S7 Surf.	49.01	173.00	1.29	20.91
S7 - 0.5 M	285.56	1292.54	9.57	435.67
S7 - 0.8 M (I)	58.65	148.87	14.56	35.65
S7 - 0.8 M (II)	455.68	1131.57	12.58	900.89
1506 Surf.	36.17	71.05	1.47	29.60
1506 - 0.4 M	34.41	99.59	0.75	5.62
1506 - 0.6 M	127.32	325.68	10.92	59.46
L/S ratio 8				
Building Surf.	103.29	144.01	3.79	34.77
Building – 0.2 M	99.85	112.09	1.55	10.22
1517 SURF.	13.70	49.01	0.59	5.74
1522 - 0.35 M	27.85	81.71	2.56	9.47
1522 - 0.65 M	27.00	56.20	0.24	13.87
1513 Surf.	57.06	226.73	4.94	131.80
1513 - 1.10 M	50.00	127.32	2.91	25.41
S7 Surf.	16.72	67.25	0.21	2.13
S7 - 0.5 M	48.66	233.32	2.68	46.38
S7 - 0.8 M (I)	14.95	42.23	2.75	6.51
S7 - 0.8 M (II)	63.14	187.98	2.76	91.10
1506 Surf.	17.34	63.08	0.56	8.46
1506 - 0.4 M	104.83	39.15	1.39	62.40
1506 - 0.6 M	42.79	139.15	6.03	13.99

The concentration of metals in the leachate was found to be greater after the step with L/S ratio 2 than with L/S ratio 8, in most the samples. In the sample Building Surf., Pb concentration in the leachate was higher for a L/S ratio 8 as in sample 1522 – 0.65 M. The presence of As, Cu and Pb in the leachate was more significant at L/S ratio 8 in the case of sample 1506 – 0.4 M. 1522 – 0.35 M was the only analyzed soil sample in which all the four toxic metals were found at higher concentrations in the leachate after the leaching with L/S ratio 10.

The highest concentrations detected were 497.43 µg/l, 1131,57 µg/l, 14.56 µg/l and 900,89 µg/l for Cu, Zn, As and Pb respectively whilst the lowest ones resulted 13.70 µg/l, 39.15 µg/l, 0.21 µg/l and 1.94 µg/l. The greatest levels of metals in the leachate were all found at L/S ratio 2, while the lowest ones corresponded to a L/S ratio 8, with the exception of Pb.

2.5 Total metals’ concentration in soil

The concentration of Cu, Zn, As, Pb detected in the samples sent to the external lab for the determination of the total amount of contaminants in soil, is reported in Table 36.

Table 36: The concentration of Cu, Zn, As, Pb in the solution samples for total concentration of metals in soil.

Soil Sample	**Cu (µg/l)**	**Zn (µg/l)**	**As (µg/l)**	**Pb (µg/l)**
Building Surf.	4880	7558	597	9623
Building – 0.2 M	4953	5778	212	7013
1517 SURF.	147	313	7.9	61
1522 - 0.35 M	4319	7784	271	5758
1522 - 0.65 M	77446	18856	283	67235
1513 Surf.	846	2091	66	2284
1513 - 1.10 M	720	1449	102	689
S7 Surf.	407	2116	5.9	177
S7 - 0.5 M	1237	4591	69	1383
S7 - 0.8 M (I)	424	774	82	347
S7 - 0.8 M (II)	1570	2614	76	3048
1506 Surf.	253	879	13	214
1506 - 0.4 M	43525	7403	190	44782
1506 - 0.6 M	421	1261	106	278

The highest concentrations of Cu, Zn and Pb in the leachate, of 77 446 µg/l, 18856 µg/l and 67235 µg/l respectively, were all found in the sample 1522 – 0.65 M, whilst the greatest presence of As, 597 µg/l, was detected in correspondence of the sample Building Surf.. The lowest values for Cu, Zn and Pb (147 µg/l, 313 µg/l and 61 µg/l) were all detected in sample 1517 Surf., the one for As corresponded to the soil sample S7 Surf. instead.

The corresponding total concentration of the four metals on soil dry matter is reported in Table 37.

Table 37: The total concentration of Cu, Zn, As, Pb in the soil samples expressed in terms of mg/kg of dry matter.

Soil Sample	**Cu (mg/kg$_{d.m.}$)**	**Zn (mg/kg$_{d.m.}$)**	**As (mg/kg$_{d.m.}$)**	**Pb (mg/kg$_{d.m.}$)**
Building Surf.	248	384	30	489
Building – 0.2 M	250	292	11	354
1517 SURF.	8.1	17	0.43	3.37
1522 - 0.35 M	246	444	15	328
1522 - 0.65 M	5134	1250	19	4457
1513 Surf.	48	119	3.7	130
1513 - 1.10 M	43	86	6.1	41
S7 Surf.	22	115	0.3	10
S7 - 0.5 M	70	259	3.9	78
S7 - 0.8 M (I)	23	42	4.5	19
S7 - 0.8 M (II)	88	146	4.2	170
1506 Surf.	13	46	0.71	11
1506 - 0.4 M	2833	482	12	2915
1506 - 0.6 M	26	77	6.5	17

The highest calculated toxic metals' concentrations on soil dry matter, i.e. 5134 mg/kg, 1250 mg/kg, 19 mg/kg and 4457 mg/kg for Cu, Zn, As and Pb respectively, corresponded to the sample 1522 – 0.65 M. The lowest concentrations calculated for Cu, Zn and Pb (8,1 mg/kg, 17 mg/kg and 3,37 mg/kg) were found in correspondence to the same soil sample, i.e. 1517 Surf., with only As for which the lowest level of pollution was determined in sample S7 Surf as it happened considering the concentration in the solution reported in the previous table.

2.6 Comparison with drinking water guidelines

The comparison between the concentration of the metals considered in the analysis that was detected in the leachate, at L/S ratio 2, and the drinking water standard is shown in Table 38, where the values in red are those above the guideline.

Table 38: Comparison between the concentration of Cu, Zn, As, Pb in the leachate at L/S ratio 2 and the drinking water guideline. The concentrations above the guideline are reported in red.

Soil Sample	**Cu (µg/l)**	**Zn (µg/l)**	**As (µg/l)**	**Pb (µg/l)**
Drinking water guideline	**2000**	**1000**	**10**	**10**
L/S ratio 2				
Building Surf.	466.48	334.81	5.96	10.68
Building – 0.2 M	497.43	321.29	5.30	35.27
1517 SURF.	24.52	110.07	1.55	14.18
1522 - 0.35 M	13.71	51.74	1.81	1.94
1522 - 0.65 M	37.74	76.46	0.25	3.95
1513 Surf.	147.48	683.89	10.71	536.95
1513 - 1.10 M	337.48	822.29	8.55	259.45
S7 Surf.	49.01	173.00	1.29	20.91
S7 - 0.5 M	285.56	1292.54	9.57	435.67
S7 - 0.8 M (I)	58.65	148.87	14.56	35.65
S7 - 0.8 M (II)	455.68	1131.57	12.58	900.89
1506 Surf.	36.17	71.05	1.47	29.60
1506 - 0.4 M	34.41	99.59	0.75	5.62
1506 - 0.6 M	127.32	325.68	10.92	59.46

The drinking water guidelines were exceeded twice for Zn, four times for As and twenty times for Pb, whilst the levels of Cu resulted always below the guideline limit.

2.7 Comparison with generic KM and MKM guidelines

In Table 39 are reported the Swedish soil generic guidelines for Cu, Zn, As and Pb, both for KM and MKM scenarios, to compare them to the concentrations calculated in the analyzed samples.

Table 39: Comparison between the concentration of Cu, Zn, As and Pb detected in the analyzed soil samples and the generic guidelines for KM and MKM scenarios. The cells with concentrations above the KM guideline are reported in yellow, whilst those exceeding both KM and MKM are colored in red.

Soil Sample	**Cu (mg/kg$_{d.m.}$)**	**Zn (mg/kg$_{d.m.}$)**	**As (mg/kg$_{d.m.}$)**	**Pb (mg/kg$_{d.m.}$)**
KM guideline	**80**	**250**	**10**	**50**
MKM guidelines	**200**	**500**	**25**	**400**
Building Surf.	248	384	30	489
Building – 0.2 M	250	292	11	354
1517 Surf.	8.1	17	0.43	3.37
1522 - 0.35 M	246	444	15	328
1522 - 0.65 M	5134	1250	19	4457
1513 Surf.	48	119	3.7	130
1513 - 1.10 M	43	86	6.1	41
S7 Surf.	22	115	0.3	10
S7 - 0.5 M	70	259	3.9	78
S7 - 0.8 M (I)	23	42	4.5	19
S7 - 0.8 M (II)	88	146	4.2	170
1506 Surf.	13	46	0.71	11
1506 - 0.4 M	2833	482	12	2915
1506 - 0.6 M	26	77	6.5	17

Pb was the toxic metal that was found in concentrations above the generic guidelines most of the times, but in 5 samples out of 8 only the KM guideline was exceeded. Cu, with five samples in which concentration was greater than the MKM standard, resulted as the metal that could pose significant harm considering both land uses. The samples Building Surf., Building – 0.2 M, 1522 – 0.35 M, 1522 – 0.65 M and 1506 – 0.4 M presented concentrations of Cu, Zn, As and Pb above either or both KM and MKM guidelines. The soil sample 1522 – 0.65 M, in particular, presented concentration of Cu, Zn and Pb above MKM standards, of 5134 mg/kg (25 times the MKM guidelines), 1250 mg/kg (more than twice the MKM guideline) and 4457 mg/kg (more than 10 times the MKM guideline) respectively, and could thus be pointed as the most hazardous one. The generic guidelines for KM and MKM scenarios were not exceeded in samples 1517 Surf., 1513 Surf., 1513 – 1.10 M, S7 Surf., S7 – 0.8 M (I), 1506 Surf and 1506 – 0.6 M.

2.8 K_d determination

The concentration of Cu, Zn, As, Pb in the leachate of a leaching test with a L/S ratio 10, calculated using the values reported in Table 38, are reported in Table 40.

Table 40: The derived concentrations of Cu, Zn, As, Pb in the leachate of a leaching test at L/S ratio 10.

Soil Sample	**Cu (µg/l)**	**Zn (µg/l)**	**As (µg/l)**	**Pb (µg/l)**
Building Surf.	175.93	182.17	4.23	29.95
Building – 0.2 M	179.36	153.93	2.30	15.23
1517 SURF.	15.86	61.22	0.78	7.42
1522 - 0.35 M	25.02	75.72	2.41	7.96
1522 - 0.65 M	29.15	60.25	0.24	11.88
1513 Surf.	75.14	318.17	6.10	212.83
1513 - 1.10 M	107.49	266.32	4.04	72.22
S7 Surf.	23.18	88.40	0.43	5.89
S7 - 0.5 M	96.04	445.17	4.06	124.24
S7 - 0.8 M (I)	23.69	63.56	5.11	12.33
S7 - 0.8 M (II)	141.64	376.70	4.72	253.06
1506 Surf.	21.10	64.68	0.74	12.69
1506 - 0.4 M	90.75	51.24	1.26	51.04
1506 - 0.6 M	59.70	176.46	7.01	23.08

The highest metals’ concentrations for the derived L/S ratio 10 were found in correspondence of four different samples. In sample Building – 0.2 M Cu concentration resulted 179.36 µg/l, while the highest level of Zn, 445.17 µg/l, corresponded to sample S7 – 0.5 M. The soil samples 1506 – 0.6 M and S7 – 0.8 M (II) were those for which the maximum concentrations of As and Pb were calculated, i.e. 7.01 µg/l and 253.06 µg/l.

The lowest concentrations of As and Pb, 0.43 µg/l and 5.89 µg/l respectively, both corresponded to sample S7 Surf.. In the case of Cu the smallest amount, of 15.86 µg/l, was associated to sample 1517 Surf., whilst for Zn sample 1506 – 0.4 M was the one with the lowest concentration of metal, equal to 51.24 µg/l.

The K_d values for the considered metals in the soil samples are reported in Table 41 and the trend for the three L/S ratios is shown in Figure 70 to Figure 73.

Table 41: Kd values for Cu, Zn, As, Pb at L/S 2, 8 and 10.

Soil Sample	**K_d (l/kg)**			
	Cu	**Zn**	**As**	**Pb**
L/S ratio 2				
Building Surf.	531	1147	5092	45774
Building – 0.2 M	502	907	2014	10031
1517 SURF.	330	157	280	238
1522 - 0.35 M	17960	8574	8523	169069
1522 - 0.65 M	136030	16346	74438	1128004
1513 Surf.	327	174	350	243
1513 - 1.10 M	127	105	711	158
S7 Surf.	453	667	248	461
S7 - 0.5 M	244	200	406	179
S7 - 0.8 M (I)	392	282	307	528
S7 - 0.8 M (II)	192	129	336	189
1506 Surf.	369	652	484	380
1506 - 0.4 M	82324	4839	16390	518842
1506 - 0.6 M	201	236	592	285
L/S ratio 8				
Building Surf.	2400	2665	7996	14056
Building – 0.2 M	2503	2601	6896	34613
1517 SURF.	591	352	738	588
1522 - 0.35 M	8838	5429	6025	34660
1522 - 0.65 M	190120	22241	78160	321415
1513 Surf.	845	526	759	988
1513 - 1.10 M	855	675	2091	1609
S7 Surf.	1327	1715	1532	4526
S7 - 0.5 M	1433	1110	1451	1682
S7 - 0.8 M (I)	1538	992	1623	2893

Table 41: Kd values for Cu, Zn, As, Pb at L/S 2, 8 and 10.

Soil Sample	**K_d (l/kg)**			
	Cu	**Zn**	**As**	**Pb**
L/S ratio 8				
S7 - 0.8 M (II)	1386	775	1530	1865
1506 Surf.	769	735	1263	1331
1506 - 0.4 M	27025	12309	8910	46714
1506 - 0.6 M	599	552	1073	1212
L/S ratio 10				
Building Surf.	1409	2107	7177	16318
Building – 0.2 M	1393	1894	4645	23229
1517 SURF.	510	282	556	454
1522 - 0.35 M	9837	5859	6400	41213
1522 - 0.65 M	176114	20745	77387	375052
1513 Surf.	642	375	615	612
1513 - 1.10 M	398	323	1506	566
S7 Surf.	957	1305	753	1639
S7 - 0.5 M	726	582	958	628
S7 - 0.8 M (I)	970	659	873	1526
S7 - 0.8 M (II)	618	387	894	671
1506 Surf.	632	717	956	887
1506 - 0.4 M	31219	9405	9805	57107
1506 - 0.6 M	429	435	923	734

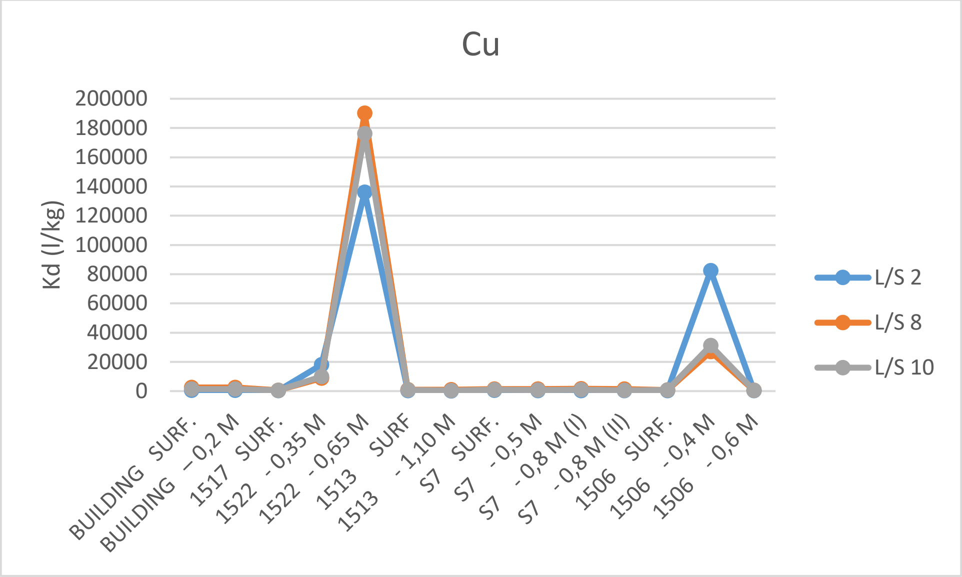


Figure 70: Trend of Kd values for Cu at L/S 2, 8 and 10.

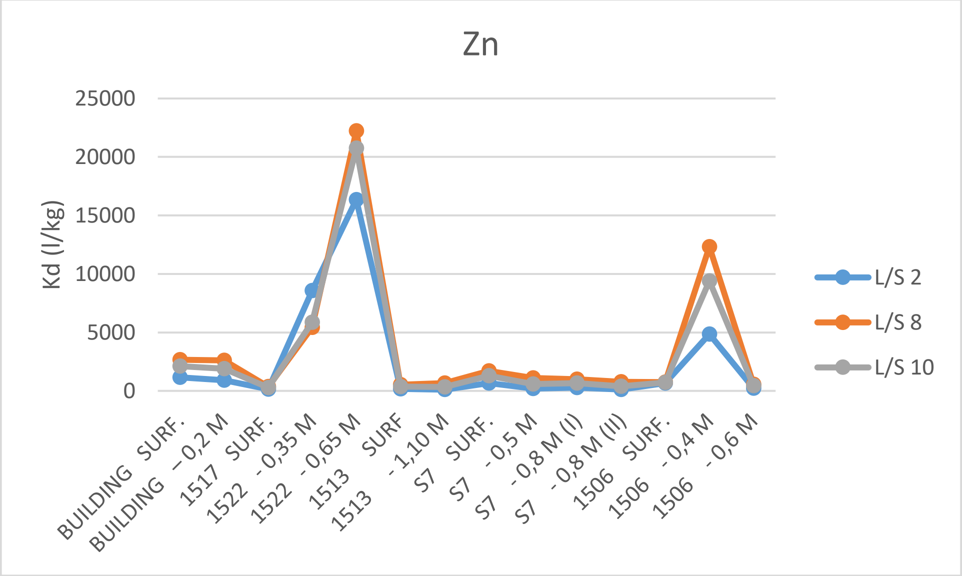


Figure 71: Trend of Kd values for Zn at L/S 2, 8 and 10.

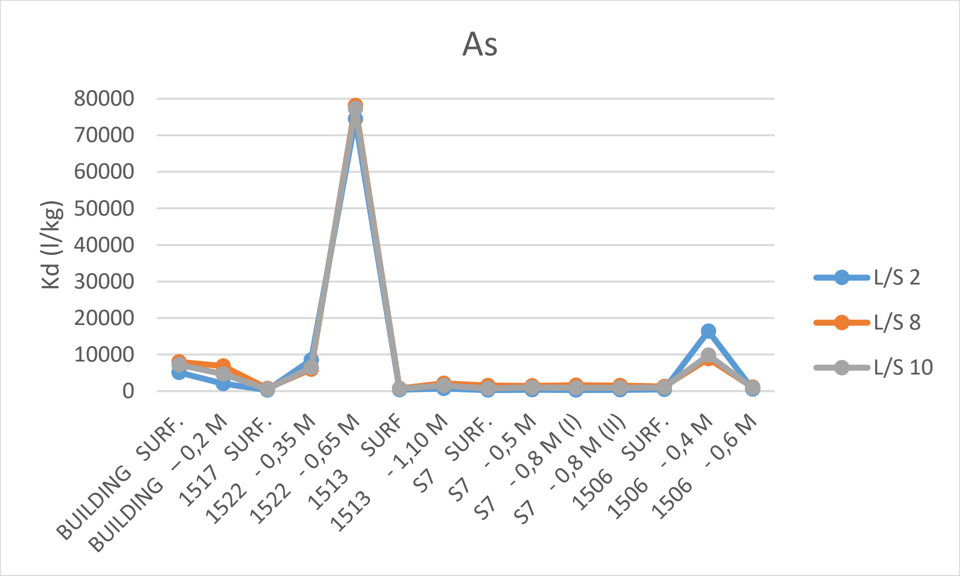


Figure 72: Trend of Kd values for As at L/S 2, 8 and 10.

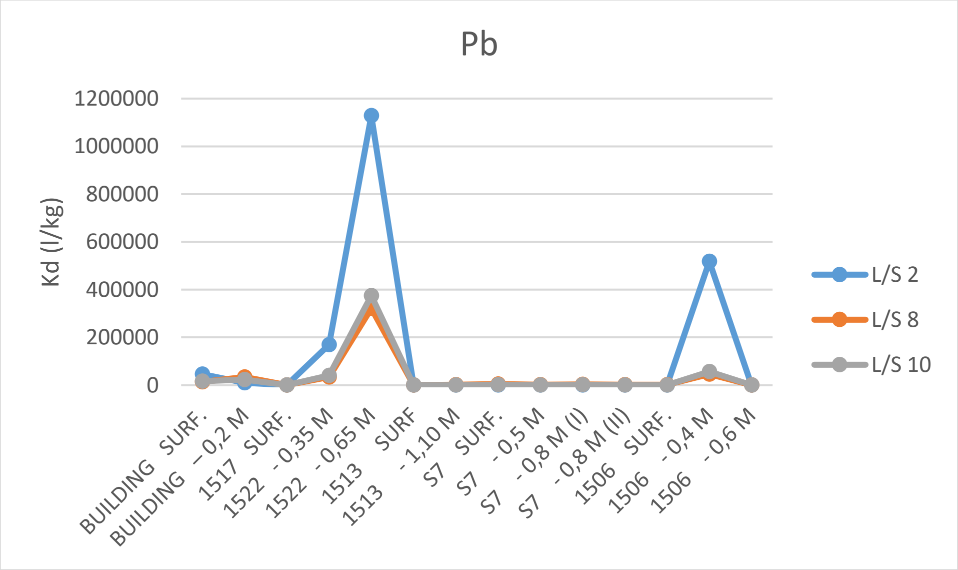


Figure 73: Trend of Kd values for Pb at L/S 2, 8 and 10.

The peaks in the K_d values of Cu, Zn and As, of 190 120 l/kg, 22 241 l/kg and 78 160 l/kg respectively, were all found in correspondence of sample 1522 – 0.65 M at L/S ratio 8, whilst the greatest K_d for Pb resulted in sample 1522 – 0,65 but at L/S ratio 2. The lowest K_d of Cu, Zn and Pb, equal to 127 l/kg, 105 l/kg and 158 l/kg, were determined in sample 1513 – 1.10 M at L/S ratio 2. In the case of As, the lowest K_d value of 280 l/kg was found at L/S ratio 2 as the other metals but in sample 1517 Surf..

In the case of Cu, most of the samples showed the highest K_d at L/S ratio 8 and the lowest ones at L/S ratio 2. The only exceptions were samples 1522 – 0.35 M and 1506 – 0.4 M in which the opposite occurred. The same happened for Zn, with the K_d corresponding to a L/S ratio 8 resulting the greatest in all the samples excluding sample 1522 – 0.35 M. The K_d values for As reached the highest values at L/S ratio 8 in most the samples as well with only samples 1522 – 0.35 M and 1506 – 0.4 M showing a higher K_d at L/S ratio 2. Pb was the only analyzed metal that had four soil samples in which the calculated K_d resulted higher at L/S ratio 2 than at L/S ratio 8, i.e. Building Surf., 1522 – 0.35 M, 1522 – 0.65 M and 1506 – 0.4 M. For all the metals, the K_d associated to a L/S ratio 10 was always between the values at L/S ratio 2 and 8.

The representative K_d of each metal calculated using the harmonic mean, at L/S ratio 2 and 10 are reported in Table 42.

Table 42: Representative Kd values for Cu, Zn, As, Pb at L/S 2 and 10.

Soil Sample	**Representative K_d (l/kg)**			
	Cu	**Zn**	**As**	**Pb**
L/S ratio 2	353	294	556	390
L/S ratio 10	844	669	1220	1112
Final value	**353**	**294**	**556**	**390**

2.9 Kd and soil pH

The correlation between soil pH and K_d of Cu, Zn, As and Pb is shown in Figure 74 to Figure 77. In the case of Pb, the highest K_d, found in correspondence of sample 1522 – 0.65 M at L/S ratio 2, was excluded from the graph in order to make the trend more visible.

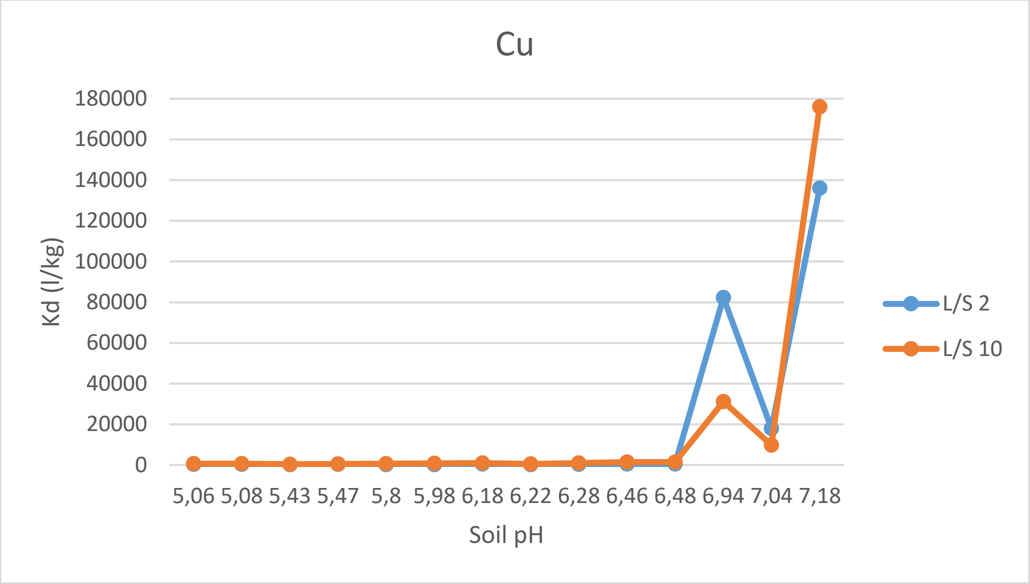


Figure 74: Variation in Kd values for Cu with pH at L/S 2 and 10.

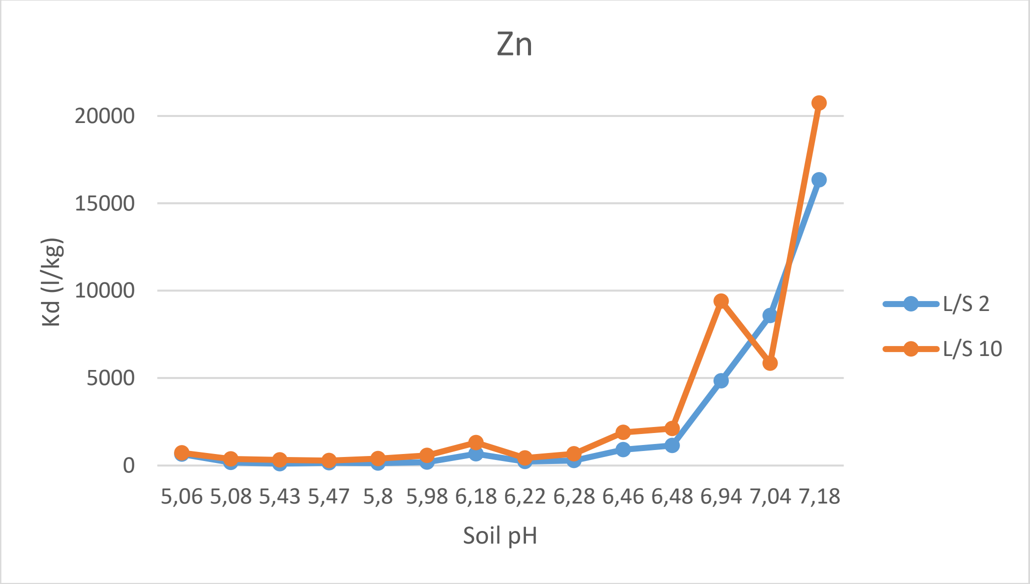


Figure 75: Variation in Kd values for Zn with pH at L/S 2 and 10.

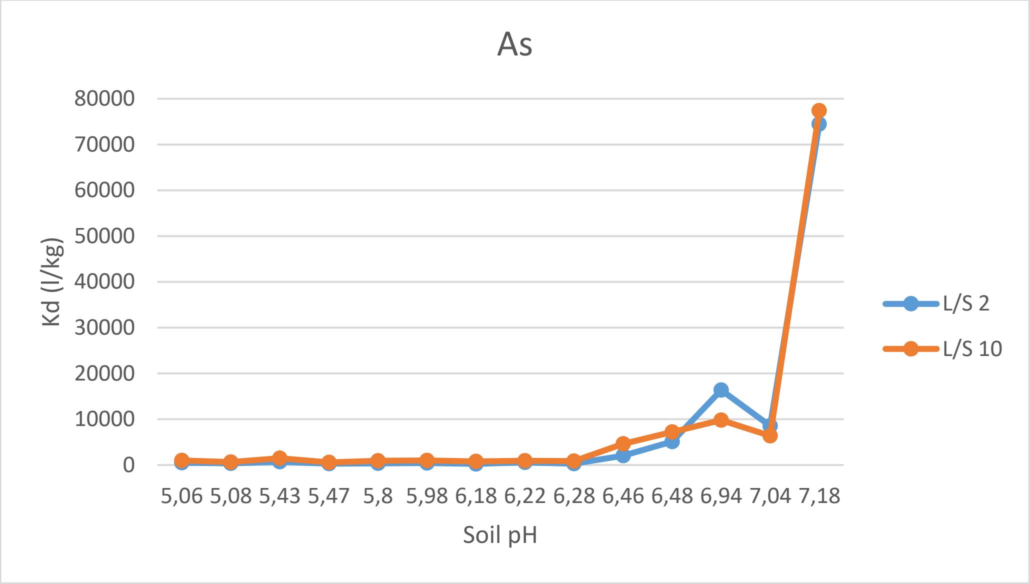


Figure 76: Variation in Kd values for As with pH at L/S 2 and 10.

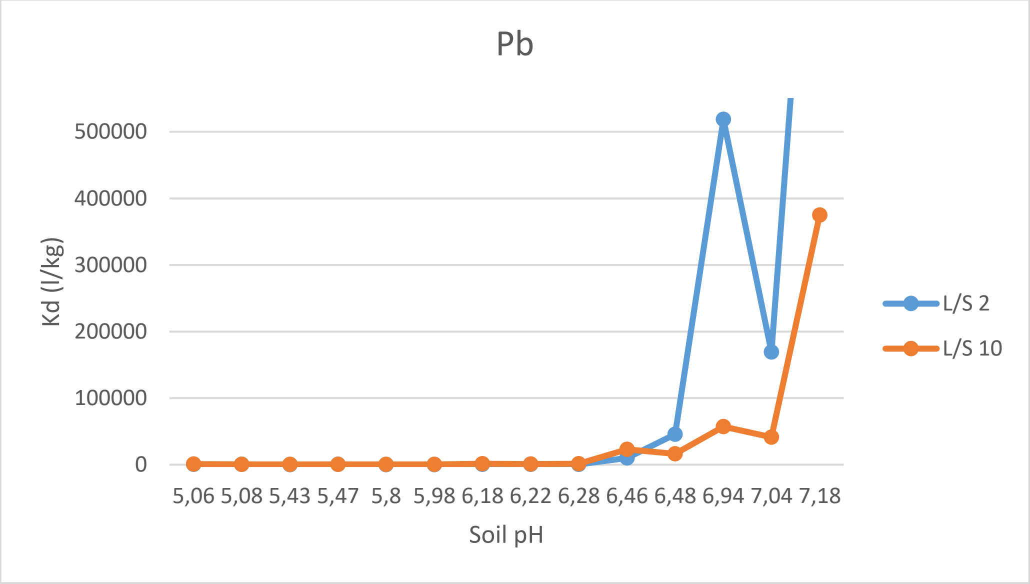


Figure 77: Variation in Kd values for Pb with pH at L/S 2 and 10.

All the four toxic metals analyzed showed an overall increasing K_d value at higher pH both at L/S ratio 2 and 10. This trend wass, however, not always satisfied. In sample 1522 – 0.35 M, with a soil pH of 7,04, the K_d significantly decreased for Cu, As and Pb at both L/S ratio 2 and 10 and for Zn but only at L/S ratio 10. A peak in the K_d of all the metals occurred at pH 6,94, in sample 1506 – 0.4 M, with the exception of Zn at L/S ratio 10 with an almost regularly increasing trend. Cu was the toxic metal for which the K_d variation with pH at L/S ratio 2 and 10 resulted the most similar.

2.10 Kd and LOI

The correlation between LOI of the soil samples and K_d for Cu, Zn, As and Pb are reported in Figure 78 to Figure 81.

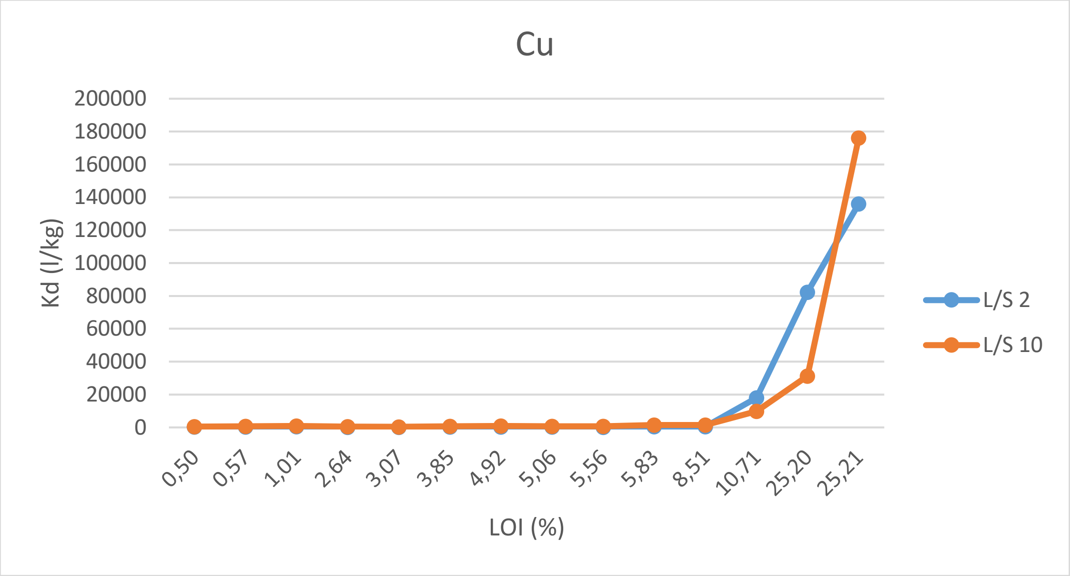


Figure 78: Variation in Kd values for Cu with LOI at L/S 2 and 10.

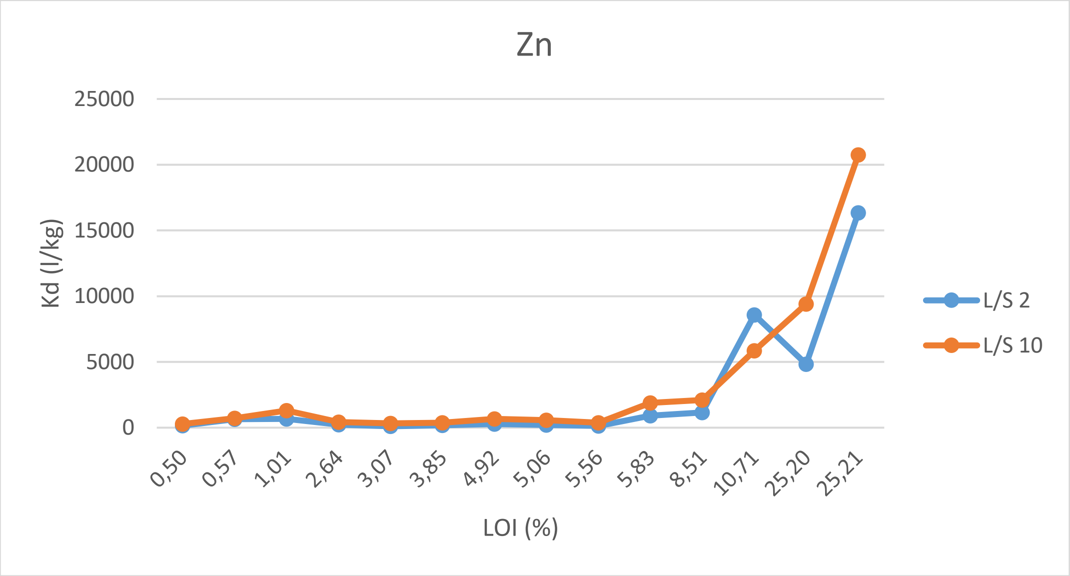


Figure 79: Variation in Kd values for Zn with LOI at L/S 2 and 10.

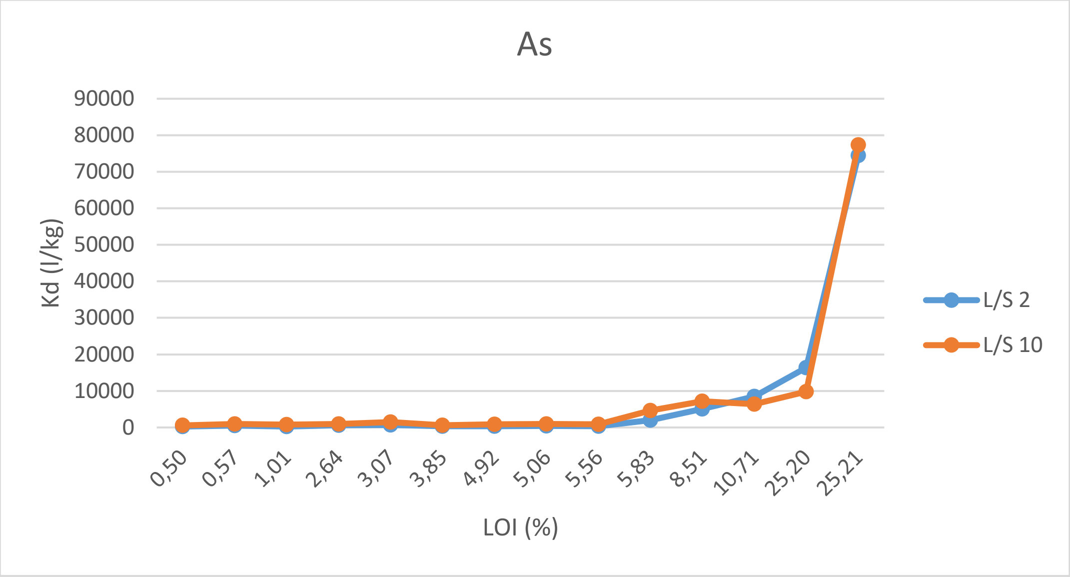


Figure 80: Variation in Kd values for As with LOI at L/S 2 and 10.

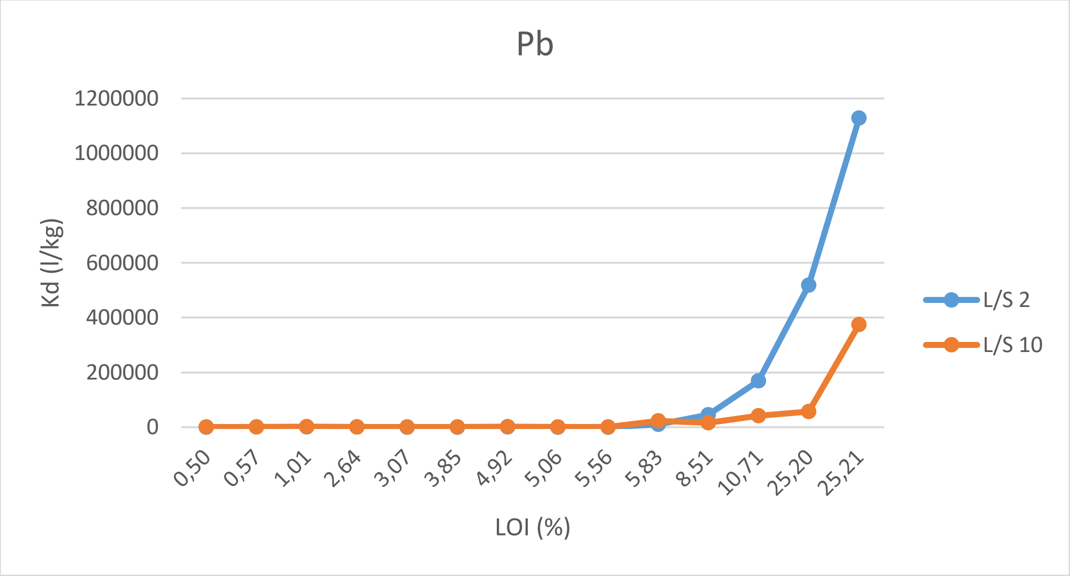


Figure 81: Variation in Kd values for Pb with LOI at L/S 2 and 10.

The K_d of all the toxic metals analyzed increased at greater SOM contents both at L/S ratio 2 and 10. In the case of As, in particular, the trend at different L/S ratios resulted pretty similar. Pb showed a more significant increase in K_d at L/S ratio 2 than at L/S ratio 10. In the case of Zn, the K_d at L/S ratio 2 decreased in correspondence of a LOI of 25,20%, in sample 1506 – 0.4 M, but then increased again. The greatest increment in K_d corresponds in all the metals to a LOI of 10,71%, measured in sample 1522 – 0.35 M.

3 Discussion

3.1 Soil properties

The large majority of the soil samples analyzed in laboratory showed a coarse texture, thus making a strong adsorption of metals on soil more unlikely. It must be noticed that, since the samples were all taken in the first meter of soil due to the relevant presence of metals detected in the previous surveys, there was a high probability that the soil material analyzed in laboratory would have been the one of the filling layer present at the site, as it happened. The sample 1513 – 1.10 M, composed by clay, was the one with the most suitable soil texture for a relevant sorption of metals.

The soil pH that, a fundamental soil parameter in the leaching of metals, varied in the four measurements for all the samples analyzed. Therefore, an increase or decrease in the soil pH could have affected the mobility of the toxic metals considered, changing their chemical form and influencing the interaction with soil texture. The use of $CaCl_2$ solution resulted in low pH if compared to the value obtained using distilled water. The presence of Ca^{2+} might, in fact, have caused in some measure the precipitation of $CaCO_3$ thus making the soil pH more acid. The variation in soil pH occurring in the two phases of the leaching test was not relevant and showed different trends in the soil samples. The only sample that had a pH above 8 in all the four measurements was 1522 – 0.35 M. In this case, the leaching of metals could have been significantly lower than in the other samples due to the “basic” conditions.

The SOM, expressed in terms of LOI, plays an important role in the leaching of metals in soil. The analyzed samples showed that the soil at the site of study was heterogeneous, with soil samples that could be classified as with “very rich” and others as “very poor” - considering the ranking provided by ARPAV (Agenzia Regionale Protezione Ambiente Veneto), soils with a SOM of less than 0.8% can be classified as “very poor”-. It is consequently realistic to assume that the sorption of metals on the organic fraction can’t be significant enough to prevent the leaching of the analyzed metals in samples 1517 Surf. and 1506 Surf. Again, according to ARPAV classification, samples Building Surf., 1522 – 0.35 M, 1522 – 0.65 M and 1506 – 0.4 M, can be classified as “very rich” in soil, with a SOM fraction above 8%. Therefore, in these samples, the relevant presence of humic substances might have played an important role in the prevention of toxic metals from leaching in soil water. As noticed in the chapter "Results", the SOM in the sampling points either increases or decreases with depth with the latter as, theoretically, the most common situation in soil. The fact that in some sampling point, e.g., 1506, the SOM at first increased and then decreased with depth could be explained by the filling layer present on the area of study. This material is likely to be not homogenously spread in the property with some "lens" of soil with higher organic content. The great difference in SOM between the analyzed soil samples and with depth, is a proof of the heterogeneity of the soil in the polluted area and the difficulty to draw a conceptual model that can realistically represent the soil properties. This great difference in the soil structure can be one reason of the heterogeneous contamination at the site of study.

3.2 Leaching test and total metals' concentration in soil

The two phases batch leaching test performed in this study showed generally higher concentrations of Cu, Zn, As and Pb at L/S ratio 2 than at L/S ratio 8, with Zn reaching the highest concentration of 1292 µg/l, in sample S7 – 0.5 M. However, these values must not be confused as indicators of the mobility of the metals themselves because they don't take into consideration the total concentration of the chemical on the soil sample. Therefore, a high metal's concentration in the leachate might correspond either to a great part of the contamination in the soil sample or only to a small percentage of it, due to the relevant level of pollution on the solid matrix. The information about the mobility of the metals is, in fact, given by the K_d value.

The total concentration of Cu, Zn, As and Pb on the analyzed soil samples, confirmed that the surface soil layer of the area of study is considerably polluted by these toxic metals. Cu and Pb were the metals found in the highest concentrations on the solid matrix, in sample 1522 – 0.65 M. This was however expected due to the significant presence of residues and pieces of metals in the surface soil, below the layer of asphalt. The sampling point 1522 was in fact the one in which the previous surveys detected the largest number of metals' concentrations above the MKM generic guidelines.

3.3 Comparison with drinking water guidelines

Even if no wells for drinking water purposes are located in the polluted area or in the surroundings, the comparison between the levels of Cu, Zn, As and Pb in the leachate and the drinking water guidelines for these toxic metals, showed that Pb was the one exceeding the most of the times the maximum acceptable concentration in water. The shallow groundwater level, that can be at only 0.5 M from ground level in the area, and the high permeability of the surface soil mainly constituted by filling material might pose an additional risk to the contamination of groundwater. Therefore, the possible presence of hazardous levels of toxic metals, mainly Pb, in groundwater should be checked if the water reservoir in the area had to be used for drinking water purposes by the community of Böllnas.

3.4 Comparison with generic KM and MKM guidelines

The comparison between the concentration of Cu, Zn, As and Pb on the soil samples analyzed in laboratory and the generic KM and MKM guidelines, confirmed the hypothesis of a heterogeneous pollution at the site of study.

The soil samples in which the calculated concentration of toxic metals resulted below both the KM and MKM generic benchmarks, were in fact found on surface (i.e. 1517 Surf., S7 Surf. and 1506 Surf.) but below the ground level as well (i.e. 1513 – 1.10 M, S7 – 0.8 M (I) and 1506 – 0.6 M). The sampling points 1513 and S7 showed an overall low presence of Cu, Zn, As and Pb, thus the presence of the toxic metals both above and below the generic guidelines was not surprising. A different situation was the one of sampling point 1506. In this case the pollution resulted below both the KM and MKM generic guidelines at ground level and at– 0.6 M, but above them at – 0.4 M. The heterogeneity that characterizes this sample in particular might be due to the age of the pollution and the soil organic matter. Due to the permeability of the soil texture, the metals might have penetrated the surface ground layer reaching the groundwater. The presence of higher levels of Cu, Zn, As and Pb at – 0.4 M could be due to the content of SOM, that may have captured a part of the metals that were headed downwards to groundwater.

The sampling points Building and 1522 resulted those in which the highest levels of Cu, Zn, As and Pb were found in the analyzed soil samples. In the first case this was expected due to the maintenance performed on the train coaches and the presence of a furnace where metals were treated. In the second sampling point a significant presence of toxic metals was not a surprise due to the data provided by previous studies on site. Cu was found in sample 1522 – 0.65 M at a concentration that was 25 times the MKM generic guideline thus showing a critical level of pollution in that sampling point that was suggested by the presence of rusty residues of metallic components.

The presence of Cu, Zn, As and Pb above the generic guidelines proved that these toxic metals might pose harm to human and environment and therefore it was reasonable to include them in the risk assessment to determine their site-specific guidelines.

3.5 Kd determination

As noticed in the "Results" chapter, the Kd value at L/S ratio 10 was between the one at L/S ratio 2 and the one at L/S ratio 8 for all the HMs considered. This can be attributed to the fact that the concentration in the leachate at L/S ratio 10 was calculated from both L/S 2 and 8 and not directly measured. Consequently, if the Kd value for L/S ratio 2 was lower than the one for L/S ratio 8 as in most the samples, the resulting Kd at L/S ratio 10 was lowered.

Considering the K_d values at different L/S ratios, it is possible to state that the mobility of Cu, Zn and As in soil water was enhanced at the lowest L/S ratio, i.e. 2, at which the leaching test was performed, in the large majority of the analyzed soil samples. Since the leaching test performed at L/S ratio 2 is broadly recognized as the one representative of the short-term leaching in the actual soil environment, the greatest fractions of Cu, Zn and As are more likely to pass from the solid to the liquid matrix in the short period. In the case of Pb the situation was not so clearly defined. In fact, four samples showed more mobility of Pb at L/S ratio 8 and 10 than at L/S ratio 2. Therefore, it is realistic to state that, given the K_d calculated for the fourteen soil samples analyzed, Pb becomes more mobile in soil water in the long term. Considering the aged contamination at the site of study, this also explains why Pb was the metal, of the four analyzed, that was detected the most above the drinking water guidelines in the previous surveys on groundwater (see Appendix 6).

All the four toxic metals showed peaks in the K_d, at all the L/S ratios, in two samples: 1522 – 0.65 M and 1506 – 0.4 M. This decrease in the mobility of the metals resulted to be the greatest at L/S ratio 2 for Pb and at L/S ratio 8 for Zn in both the samples. The K_d of Cu and As was higher at L/S ratio 8 in sample 1522 – 0.65 M and at L/S ratio 2 in sample 1506 – 0.4 M. In both the soil samples, the SOM content was high, 25,20% and 25,21% respectively, classifying the soil as “very rich”. Therefore, it is likely that the higher retention of metals on soil is due to the stronger sorption of the chemicals on the solid matrix, enhanced by the functional groups present on the surface of humic substances.

Moreover, the pH of the soil solution, that in both samples was among the highest values for each of the four measurements performed, could have enhanced the sorption of metals on soil with a possible change in the chemical form of the metal. A useful instrument in the assessment of this phenomenon is constituted by the Pourbaix diagram that shows the possible stables ionic forms of metals in an aqueous system. Cu, Zn, As and Pb all present a change in chemical form between pH 6 and 8, which is the range of pH values measured before and after the leaching test. However, to deeply assess if a change in the chemical form might have occurred in the analyzed samples and thus be addressed as the main cause of the strong bond between the metals and the soil in samples 1522 – 0.65 M and 1506 – 0.4 M, data about the voltage potential of the soil solution must be available, which is not the case of this study. Therefore, if the local authorities were interested in performing deeper studies on the mobility of the toxic metals at the property of Bollnas Bro 4:4, more detailed information should be gathered about the soil parameters that can affect the speciation of these chemicals.

The final site-specific K_d for Cu, Zn, As and Pb and the default ones provided by the Swedish software for site-specific guidelines are reported in Table 43.

Table 43: Kd value for Cu, Zn, As and Pb provided by the database of the Swedish software for site-specific guidelines and those calculated through the two phases batch leaching test.

Source	**K_d (l/kg)**			
Metal	**Cu**	**Zn**	**As**	**Pb**
Swedish software	600	600	300	1800
Leaching test	353	294	556	390

First of all, it must be specified that the site-specific K_d was chosen adopting a conservative approach selecting the lowest K_d, calculated using the harmonic mean, between the one at L/S ratio 2 and L/S ratio 10. Therefore, the leaching of the analyzed toxic metals will result overestimated.

The K_d proposed by the Swedish software's database resulted higher than the one determined performing a two phases batch leaching test in the case of Cu, Zn and Pb, whilst the opposite occurred for As. Therefore, it is likely that the impact on groundwater as resource and the possible exposure through ingestion of drinking water might result relevant in the determination of the site-specific guidelines for Cu, Zn and Pb. Pb, in particular, had a site-specific K_d almost 5 times smaller than the default one, thus its mobility might be an issue at the site of study. This information is consistent with the data collected in previous surveys, that showed presence of Pb in groundwater, and the observations done before. As, on the other hand, resulted less mobile at the site of study than in the default situation. Once again, this result is consistent with the analysis performed on groundwater samples in previous studies that detected As in concentrations below the drinking water guideline.

Due to the difference in Cu, Zn, As and Pb mobility between the site-specific conditions and the default scenario proposed by the Swedish software, the site-specific guidelines for the four analyzed toxic metals might result significantly different, with Pb as the most critical pollutant.

3.6 K_d and pH

Interpolating the pH and K_d values of the fourteen soil samples analyzed in laboratory, the theory regarding the influence of the soil pH on the mobility of metals in soil resulted generally respected. In fact, at acid soil pH the mobility of metals is enhanced due to their positive charge and the consequent competition with hydrogen ions for the sorption on the functional groups present on the solid matrix surface. Therefore, it is not unexpected that the leachability of Cu, Zn and Pb decreased when the soil pH increased. In particular, at pH greater than 6,5 the mobility of the analyzed metals significantly diminished. In the case of As, that can be found in basic solution as arsenate and form negatively charged groups, it was not so obvious the increase in sorption on soil at higher pH values.

However, As is usually present in soil environment in the +3 or +5 oxidation states and thus can be easily adsorbed on the negative charges present on soil surface. Due to the predisposition of As to form complexes with, above all, $Fe(OH)_3$ and PO_4^{3-} ions, the fact that the adsorption on soil increased at higher pH values indicates that these affine ions were not present in the soil solution in relevant concentrations.

The samples with the highest pH values detected, i.e. 1506 – 0.4 M, 1522 – 0.35 M and 1522 – 0.65 M, were also those with the greatest content of SOM, that has a fundamental role in the sorption of metals on soil. In sample 1522 – 0.35 M, an unexpected increase in mobility affected all the analyzed metals suggesting that in that case soil pH is not the parameter that most determine metals' fate in soil environment.

The trend of K_d with pH resulted approximately the same at both the L/S ratios adopted during the leaching test in almost all the samples. This was however expected due to the unimportant variation in the solution pH between the two steps of the performed leaching test. In the case of Pb, in particular, higher pH caused a much greater reduction in the mobility of the pollutant in the short period, i.e. at L/S ratio 2, than in the long one, i.e. at L/S ratio 10. On the other hand, considering Cu, Zn and As, an increase in the soil pH enhanced the sorption on the solid matrix more in the long term than in the short one.

In order to properly assess the correlation between soil pH and mobility of toxic metals in the area of study, it is necessary to perform further investigations on the soil properties. The possible presence of functional groups on the solid matrix and of ions that can form complexes with the metals must be determined because determinant in the fate of metals in soil.

3.7 K_d and LOI

The correlation between K_d and the SOM for Cu, Zn, As and Pb showed an increase in the sorption of the analyzed toxic metals in the soil samples with the highest amounts of SOM, i.e. 1522 – 0,35, 1506 -0.4 M and 1522 – 0.65 M. As explained before, these samples were also those in which the highest soil pH values were detected, thus it is reasonable to state that both the soil pH and the content of organic matter reduced the mobility of the metals in soil.

However, as it was visible in the graphs reporting the interpolation of the LOI and K_d values, the increase in the sorption of the analyzed metals resulted more regular than when considering the soil pH. In fact, Cu, Zn and Pb showed a gradual decrease in the mobility until a LOI of 8.51% and then a great enhancement of the sorption on the solid matter in correspondence of greater presence of SOM in soil. Whilst Cu and As fate in soil didn’t significantly differ in the long and in the short period, Pb showed again a much relevant decrease in mobility in the short term, i.e. L/S ratio 2, than in the long one. The only metal’s fate that was differently influenced by the SOM content was Zn. Whilst at L/S ratio 10 the trend resembled the ones of the other metals, at L/S ratio 2, an unexpected decrease in sorption was found for a LOI of 25.20%, corresponding to sample 1506 – 0.4 M. This value is difficult to be properly justified. In fact, the K_d resulted greater in the previous sample even if the SOM content was less than a half of the one in sample 1506 – 0.4 M (10.71%) and then the K_d increased again for an almost unchanged LOI (25.21%). Moreover, the pH of the soil solution after the leaching step at L/S ratio 2 (7.55) resulted not much different than the ones detected in the previous sample (8.04) and the following one (7.64). Therefore, it is unlikely that the variation in Zn mobility was determined by soil pH. A possible explanation is the already cited heterogeneity that characterizes the soil in the area of study. It might be possible that the fraction of soil used for the determination of the LOI of the sample significantly differed from the one used for the leaching test. This is, however, impossible to be verified.

If the local authorities were interested to determine which was the soil parameter mainly affecting the fate of Zn in soil, they should put great effort in the characterization of the soil samples before proceeding with the leaching test.

4 Conclusions

In this context of spread and heterogenous pollution in the area of study, the mobility of toxic metals is an important issue due to the adverse impact that they might cause on human health and environment. Considering the previous surveys performed at the site, the most critical sampling point concerning the levels of toxic metals detected were identified to take new soil samples to analyze in laboratory. The fourteen samples analyzed were all taken in the surface layer of the soil and the large majority of them showed a texture constituted by the filling material that covers the property of Bollnäs Bro 4:4. A two phase batch leaching test was performed at L/S ratio 2 and 8 to assess the mobility of Cu, Zn, As and Pb.

The concentrations of metals analyzed in the leachate resulted above the drinking water guidelines in many samples with Pb as the most critical one. Considering the levels of pollution on the solid matrix, Zn resulted the metal found at the highest concetration.

The site-specific K_d of Cu, Zn, As and Pb were calculated at L/S ratio 2,8 and 10 with the latter determined using the concentrations detected in the leachate at L/S ratios 2 and 8. The mobility of Cu, Zn and As was lower in the long period than in the short one whilst the opposite occurred for Pb. The representative K_d of the four analyzed metals were calculated using the harmonic mean to be inserted in the software for the risk assessment. Comparing the calculated K_d with those provided by the database of the Swedish software for site-specific guidelines, the mobility of As resulted lower than in the default scenario while higher for Cu, Zn and Pb, with the greatest difference in correspondence of Pb. Therefore, this variation in the mobility of the analyzed metals might influence the corresponding site-specific guidelines.

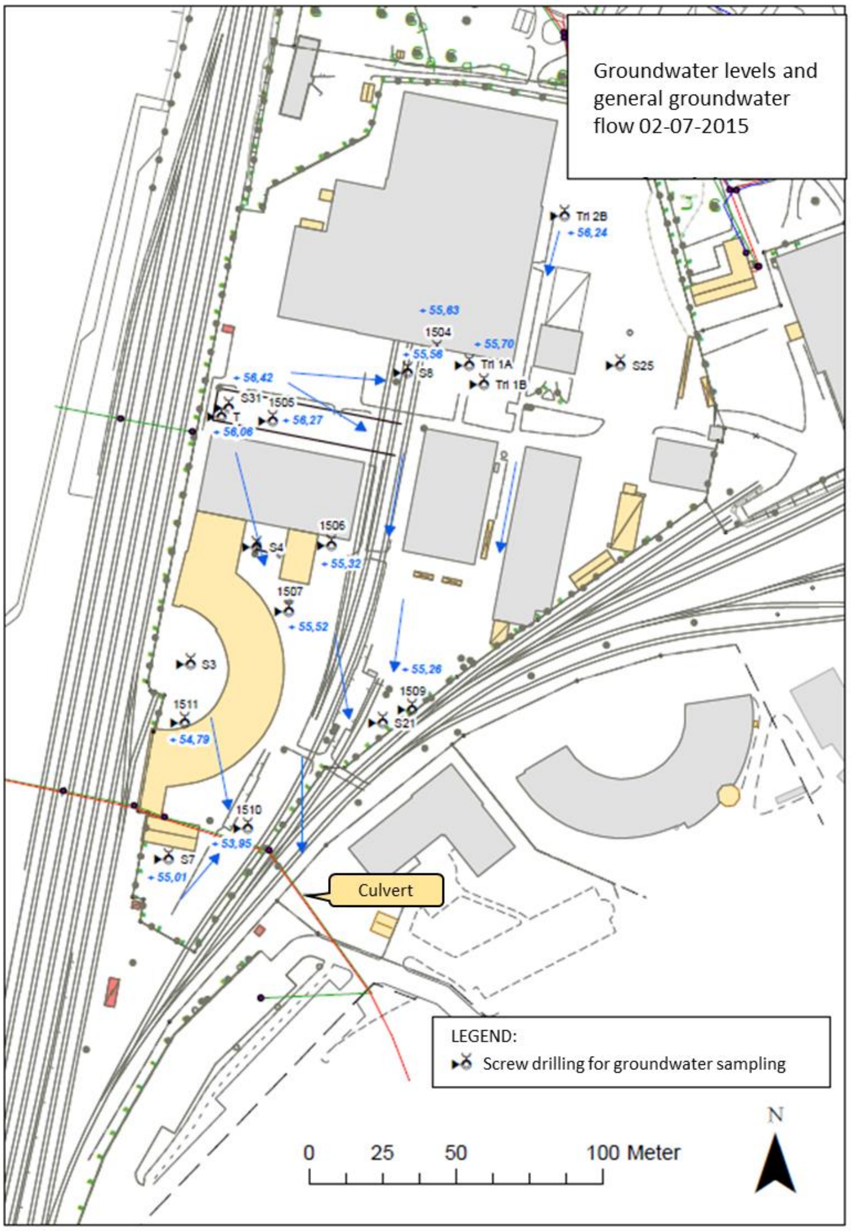
The fate of metals is determined both by the compound itself and the soil properties. In particular, the soil pH and the content of SOM are the most determinant factors. In the analyzed samples, the theoretical behavior of metals in soil was, in general, respected, with an increase in the sorption on soil matter with higher pH and SOM fractions.

The mobility of Cu, Zn and As was more significantly lowered by high soil pH values in the long period than in the short one, whilst the opposite occurred for Pb. However, the almost regular increasing sorption on soil showed by the metals when considering the SOM, expressed in terms of LOI, suggested that the fraction of organic matter of soil played the most important role in the fate of the analyzed metals.

The analysis performed on the soil samples showed that the impact due to the release of toxic metals from the solid matrix into the liquid one, can’t be overlooked since it might cause a significant adverse impact on human health and environment. Groundwater, in particular, might be significantly polluted by these hazardous compounds, also due to the shallow groundwater level and the permeability of the surface layer of soil, where the most relevant concentrations of metals were detected.

APPENDIX 3

Piezometric levels at the property of Böllnas Bro 4:4.



APPENDIX 4

Soil samples analyzed in the previous surveys for concentrations of inorganic pollutants. The cells with concentrations below the Swedish guideline are colored in green, the values above the guideline in yellow and those with concentrations 3 times or more the guideline are colored in red.

Sampling point	Depth (m)		As	As (XRF)	Pb	Pb (XRF)	Cd	Co	Cu	Cu (XRF)	Cr	Ni	Zn	Zink (XRF)	Hg	Hg (XRF)
	from	to	mg/kg TS	mg/kg	mg/kg TS	mg/kg	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg	mg/kg TS	mg/kg
MKM generic guideline			**25**	**25**	**400**	**400**	**15**	**35**	**200**	**200**	**150**	**120**	**500**	**500**	**2,5**	**2,5**
1501	0	0,2		<LOD		116				36				184		<LOD
1501	0,2	1		<LOD		30				20				96		<LOD
1501	1	2		<LOD		21				16				73		<LOD
1501	2	3	<2.5	<LOD	4,9	29	<0.2	2,9	7,6	20	4,8	3,2	19	64	0,011	<LOD
1501	3	3,5	<2.5	<LOD	2	12	<0.2	2,1	4,7	<LOD	3,5	2,3	14	56	<0.01	<LOD
1502	0	1	9,5	<LOD	290	202	0,48	13	200	55	37	32	350	375	0,32	<LOD
1502	1	1,8	6,3	<LOD	16	19	<0.2	13	28	28	33	21	98	98	0,016	<LOD
1503	0	1	3,4	<LOD	150	113	0,29	4,2	29	36	33	8,5	140	183	0,034	<LOD
1503	1	1,5	2,7	<LOD	76	85	0,31	4,4	28	32	20	9,3	130	148	0,026	<LOD
1504	0	1		<LOD		250				42				170		<LOD
1504	1	2	4,7	<LOD	150	91	2,8	4,4	45	30	12	8,1	180	145	0,19	<LOD
1504	2	3	<2.5	<LOD	29	34	0,32	2,4	12	13	23	6,2	42	75	0,031	<LOD
1504	3	3,5		<LOD		59				25				98		<LOD
1505	0	1	7	22	370	826	0,39	12	270	423	15	24	400	417	0,77	18
1505	1	1,5	9,1	<LOD	360	174	0,4	26	180	122	23	30	430	537	0,96	14
1505	1,5	2		<LOD		73				54				145		<LOD
1505	2	3		<LOD		16				17				79		<LOD
1506	0	1	21	<LOD	5600	646	1,1	12	4900	786	20	29	910	583	8,3	25
1506	1	1,8	6,8	<LOD	33	19	0,24	15	62	26	44	29	110	79	0,067	<LOD
1506	1,8	2,8		<LOD		26				24				57		<LOD

Sampling point	**Depth (m)**		**As**	**As (XRF)**	**Pb**	**Pb (XRF)**	**Cd**	**Co**	**Cu**	**Cu (XRF)**	**Cr**	**Ni**	**Zn**	**Zink (XRF)**	**Hg**	**Hg (XRF)**
	from	**to**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**
MKM generic guideline			**25**	**25**	**400**	**400**	**15**	**35**	**200**	**200**	**150**	**120**	**500**	**500**	**2,5**	**2,5**
1507	0	1		<LOD		14				16				50		<LOD
1507	1	2		<LOD		10				<LOD				50		<LOD
1507	2	3	<2.5	<LOD	8	14	<0.2	3	12	20	6,8	4	20	58	0,011	<LOD
1507	3	3,5	<2.5	<LOD	9	20	<0.2	3,1	13	<LOD	16	3,7	20	46	0,014	<LOD
1508	0	1	6,3	<LOD	110	67	1,3	6,2	63	24	24	9,4	520	342	0,07	<LOD
1508	1	2	<2.5	<LOD	2	15	0,24	4,5	15	15	18	5,4	47	77	<0.01	<LOD
1508	2	3	3	<LOD	20	56	0,38	4,8	28	32	14	8,2	140	126	0,023	<LOD
1509	0	1		<LOD		122				42				278		<LOD
1509	1	2	8,9	<LOD	84	2329	1,3	10	59	851	25	17	490	4458	0,076	<LOD
1509	2	2,5		<LOD		1236				472				2751		<LOD
1509	2,5	3	8,1	<LOD	380	514	2,1	8,3	340	287	21	13	980	1606	0,32	<LOD
1510	0	1	2,7	<LOD	40	63	0,26	3,7	26	45	8,8	6,1	69	141	0,092	<LOD
1510	1	1,8		<LOD		13				<LOD				46		<LOD
1510	1,8	2		<LOD		17				24				89		<LOD
1510	2	3		<LOD		16				22				90		<LOD
1511	0	1		<LOD		34				19				73		<LOD
1511	1	2		<LOD		17				36				94		<LOD
1511	2	3	<2.5	<LOD	19	16	<0.2	3,5	13	<LOD	9,7	4,8	29	47	0,014	<LOD
1511	3	3,6	<2.5	<LOD	51	33	<0.2	3,4	17	16	8,2	5,2	34	56	0,023	<LOD
1512	0	0,4	3,8	<LOD	25	32	<0.2	7,7	28	22	21	8,6	89	101	0,045	<LOD
1512	0,4	1		<LOD		23				<LOD				59		<LOD
1512	1	2		<LOD		21				17				95		<LOD
1512	2	2,5		<LOD		21				29				98		<LOD
1513	0	1	5,8	<LOD	97	63	<0.2	4,7	130	245	8,1	8,7	93	190	0,079	<LOD
1513	1	1,6	27	<LOD	27	33	<0.2	11	45	26	52	27	96	128	0,068	<LOD
1513	1,6	2	10	3,6	14	14	0,21	15	22	15	28	15	63	80	<0.01	<LOD
1513	2	3		<LOD		14				<LOD				79		<LOD
1514	0	0,5	2,9	<LOD	93	166	<0.2	6,1	59	111	15	8,5	49	247	0,041	<LOD
1514	0,5	1		<LOD		20				29				78		<LOD

Sampling point	**Depth (m)**		**As**	**As (XRF)**	**Pb**	**Pb (XRF)**	**Cd**	**Co**	**Cu**	**Cu (XRF)**	**Cr**	**Ni**	**Zn**	**Zink (XRF)**	**Hg**	**Hg (XRF)**
	from	**to**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**
MKM generic guideline			**25**	**25**	**400**	**400**	**15**	**35**	**200**	**200**	**150**	**120**	**500**	**500**	**2,5**	**2,5**
1514	1	2		<LOD		24				15				83		<LOD
1514	2	2,3		<LOD		15				16				100		<LOD
1515	0,04	0,6	7,7	<LOD	170	146	0,24	7,8	110	75	18	13	120	174	0,35	<LOD
1515	0,6	1		<LOD		34				29				69		<LOD
1515	1	2		<LOD		19				17				82		<LOD
1515	2	3		<LOD		21				31				105		<LOD
1516	0	1	3,1	<LOD	90	142	0,26	5	58	65	12	7,2	100	172	0,12	<LOD
1516	1	2	3,5	<LOD	98	179	0,28	5	67	96	13	8,3	110	192	0,15	<LOD
1517	0	1	18	<LOD	460	236	0,61	12	220	162	24	28	200	235	0,72	<LOD
1517	1	1,6	5,4	<LOD	72	43	<0.2	8,8	48	72	9,8	21	56	115	0,051	10
1518	0	0,6	19	<LOD	630	513	0,74	9,4	220	170	21	18	350	453	1,1	<LOD
1518	0,6	1	9,3	<LOD	26	308	0,3	16	43	69	38	37	100	221	0,019	<LOD
1518	1	2		<LOD		32				33				113		<LOD
1519	0	0,6	23	<LOD	200	191	0,66	6	90	75	12	10	230	310	0,46	<LOD
1519	0,6	1		<LOD		24				<LOD				65		<LOD
1519	1	1,7		<LOD		53				<LOD				79		<LOD
1519	1,7	2		<LOD		18				17				84		<LOD
1520	0,2	0,8	4,5	<LOD	28	33	<0.2	6,4	25	21	17	11	62	82	0,041	<LOD
1520	0,8	1,8	6,9	<LOD	28	32	<0.2	9	31	27	25	17	100	127	0,056	<LOD
1521	0	0,4	<2.5	<LOD	4	18	<0.2	2,6	7	<LOD	6,7	3,8	18	55	<0.01	<LOD
1521	0,4	0,8	8,8	<LOD	98	40	0,34	9,2	93	18	17	11	130	115	0,32	<LOD
1521	0,8	1		<LOD		17				18				75		<LOD
1521	1	2		<LOD		22				22				73		<LOD
1521	2	3		3,9		18				<LOD				76		<LOD
1522	0	0,3	5,1	<LOD	120	124	0,71	9,3	69	56	32	12	290	397	0,22	<LOD
1522	0,3	0,8	27	<LOD	4600	1746	1,6	14	10000	2497	24	35	2000	1705	4,3	<LOD
1522	0,8	1,5	<2.5	<LOD	34	37	<0.2	3,6	38	47	8,1	4,4	36	76	0,026	<LOD
1522	1,5	2,5		5,7		72				94				132		<LOD
1522	2,5	3		<LOD		25				20				92		<LOD

Sampling point	**Depth (m)**		**As**	**As (XRF)**	**Pb**	**Pb (XRF)**	**Cd**	**Co**	**Cu**	**Cu (XRF)**	**Cr**	**Ni**	**Zn**	**Zink (XRF)**	**Hg**	**Hg (XRF)**
	from	**to**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**
MKM generic guideline			**25**	**25**	**400**	**400**	**15**	**35**	**200**	**200**	**150**	**120**	**500**	**500**	**2,5**	**2,5**
1523	0	0,9		<LOD		78				80				67		<LOD
1523	0,9	1	7,4	<LOD	14	29	0,22	12	27	28	28	21	76	110	0,016	<LOD
1523	1	2	7,4	<LOD	15	27	0,22	12	22	28	27	17	79	104	0,024	<LOD
1541	0	0,7	5,9	<LOD	64	98	0,22	10	39	46	20	16	100	128	0,038	<LOD
1541	0,7	1		<LOD		15				<LOD				30		<LOD
1541	1	2		<LOD		13				<LOD				46		<LOD
1541	0,5	1	18	<LOD	310	82	0,7	18	96	67	11	49	190	181	0,06	<LOD
1542	0	0,4		32		68				47				144		<LOD
1542	0,4	1	<2.5	<LOD	4	14	<0.2	2,9	6,7	<LOD	4,7	2,9	23	48	<0.01	<LOD
1542	1	1,3	<2.5	<LOD	2,4	16	<0.2	2,5	5,5	15	4,3	2,6	17	48	<0.01	<LOD
1543	0	0,6	7,2	<LOD	93	118	0,6	9,8	110	94	13	12	110	156	0,1	<LOD
1543	0,6	1		<LOD		23				26				108		<LOD
1543	1	2	5,2	<LOD	19	28	0,3	15	34	25	41	29	99	124	0,018	<LOD
1544	0	0,6		<LOD		25				20				99		<LOD
1544	0,6	1	12	<LOD	24	19	0,35	15	46	<LOD	46	37	120	<LOD	0,019	<LOD
1544	1	2	14	<LOD	20	24	0,33	18	44	29	42	39	110	114	0,018	<LOD
1545	0	0,6		<LOD		400				326				259		<LOD
1545	0,6	1		<LOD		63				132				119		<LOD
1545	1	2	12	<LOD	14	23	<0.2	9,3	25	26	30	17	72	84	0,023	<LOD
1545	2	2,5	11	<LOD	17	18	0,38	15	36	30	33	26	100	110	0,014	<LOD
1546	0	0,4	9,3	<LOD	98	125	0,81	6,5	51	73	11	11	350	481	0,43	15
1546	0,4	0,6	16	<LOD	68	66	1	17	86	69	13	42	230	254	0,47	12
1546	0,6	1		<LOD		15				<LOD				41		<LOD
1546	1	2		<LOD		18				<LOD				75		<LOD
1546	2	3		<LOD		15				<LOD				113		<LOD
1546	3	3,5		<LOD		11				15				97		<LOD
1547	0	0,7	8,6	<LOD	130	149	0,57	7,3	130	94	10	12	200	278	1,3	<LOD
1547	0,7	1	<2.5	<LOD	3,6	17	<0.2	3,6	14	<LOD	6,1	3,8	34	52	0,013	<LOD
1547	1	1,5		<LOD		21				21				114		<LOD

Sampling point	Depth (m)		As	As (XRF)	Pb	Pb (XRF)	Cd	Co	Cu	Cu (XRF)	Cr	Ni	Zn	Zink (XRF)	Hg	Hg (XRF)
	from	**to**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg**	**mg/kg TS**	**mg/kg**
MKM generic guideline			**25**	**25**	**400**	**400**	**15**	**35**	**200**	**200**	**150**	**120**	**500**	**500**	**2,5**	**2,5**
1547	1,5	2		<LOD		21				<LOD				43		<LOD
1547	2	3		<LOD		20				16				94		<LOD
1548	0	0,5	7,5	<LOD	240	165	1,5	9,7	75	54	8,8	15	510	220	0,5	<LOD
1548	0,5	0,7	8,3	<LOD	87	89	0,99	9,7	78	84	9,6	17	310	333	0,22	12
1548	0,7	1	<2.5	<LOD	5,5	20	<0.2	6,3	13	22	12	9,5	38	55	<0.01	<LOD
1548	1	2		<LOD		64				49				177		<LOD
1548	2	2,5		<LOD		19				20				87		<LOD
1549	0	0,5		<LOD		77				34				122		<LOD
1549	0,5	1		<LOD		20				17				61		<LOD
1549	1	2		<LOD		18				<LOD				57		<LOD
1549	2	3		<LOD		15				<LOD				62		<LOD
S1	3	3,6	0,248		5,09		<0,01	1,59	4,26		3,5	2,2	15		<0,04	
S10	2	3,2	1,74		23,1		0,354	2,78	14,9		8,26	8,91	171		0,0635	
S12	2	3	0,589		3,57		<0,01	1,58	4,19		5,78	2,24	18,5		0,0566	
S13	0,8	1,4	8,24		62,3		0,153	9,38	38,8		18,8	21,9	143		0,0564	
S16	0,5	1	9,86		164		0,272	8,73	184		14,8	22,6	128		0,267	
S16	1	2	4,68		14,6		0,0151	6,07	20,3		24,7	13,1	75,6		0,0499	
S2	3	4	2,24		8,99		0,0536	5,13	14,8		14,3	10,1	51,2		0,0415	
S30	0	1	6,96		23,3		0,12	8,1	32,4		29,2	19,9	78,7		<0,04	
S40	0,5	1	5,15		3,6		<0,1	3,86	25,7		7,33	6,12	21,7		<1	
S41	0,7	2	13,3		56,8		0,739	7,82	72		8,29	21,8	191		<2	
S6	2	3	1,32		98,4		0,039	1,57	49,8		2,82	2,38	35,9		0,111	
S7	2	3	8,22		1110		0,083	11,8	32,4		21	13,4	94,4		0,281	
S7	2	3	12,7		79,9		<0,1	9,69	22,6		21,1	21,2	89,6		<1	
S7	0,5	1	4,5		120000		0,757	5,81	208		11,8	10,4	791		5,87	
S8	0	1	7,96		76,7		0,364	7,59	74,5		7,87	21,1	127		0,16	

APPENDIX 5

Soil samples analyzed in the previous surveys for concentrations of organic pollutants. The cells with concentrations below the Swedish guideline are colored in green, the values above the guideline in yellow and those with concentrations 3 times or more the guideline are colored in red.

Sampling point	**Depth (m)**		**Benzene**	**Toluene**	**Ethylbenzene**	**Xylene**	**Aliphatic >C5-C8**	**Aliphatic >C8-C10**	**Aliphatic >C10-C12**	**Aliphatic >C12-C16**	**Aliphatic >C16-C35**	**Aliphatic sum >C5-C16**	**Aromatic >C8-C10**	**Aromatic >C10-C16**	**Aromatic >C16-C35**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline			**0,04**	**40**	**50**	**50**	**80**	**120**	**500**	**500**	**1000**	**500**	**50**	**15**	**30**
1501	0	0,2	<0.003	<0.1	<0.1	<0.1	<1.2	6,3	65	270	100	340	<1	<1	<1
1501	0,2	1	<0.003	0,15	0,82	2,4	9,4	340	790	1400	240	2500	79	100	<1
1501	1	2	0,0053	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	19	<10	<1	<1	<1
1501	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1501	3	3,5	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	1200	<10	<1	2,4	5
1502	0	1	<0.003	<0.1	<0.1	<0.1	<1.2	2,9	<10	<10	2000	<10	<1	1,5	8,1
1503	0	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	13	64	93	77	<1	<1	1,3
1503	1	1,5	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	24	19	24	<1	<1	<1
1504	1	2	<0.003	<0.1	<0.1	0,24	<1.2	<2	<10	<10	14	<10	<1	<1	<1
1504	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	23	<10	<1	1,1	<1
1505	1	1,5	0,0036	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	89	<10	<1	2	3,2
1505	1,5	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	13	<10	<1	<1	<1

Sampling point	Depth (m)		Benzene	Toluene	Ethylbenzene	Xylene	Aliphatic >C5-C8	Aliphatic >C8-C10	Aliphatic >C10-C12	Aliphatic >C12-C16	Aliphatic >C16-C35	Aliphatic sum >C5-C16	Aromatic >C8-C10	Aromatic >C10-C16	Aromatic >C16-C35
	from	to	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
MKM generic guideline			**0,04**	**40**	**50**	**50**	**80**	**120**	**500**	**500**	**1000**	**500**	**50**	**15**	**30**
1506	1,8	2,8	<0.003	<0.1	<0.1	<0.1	<1.2	2,4	24	91	110	120	<1	3,1	<1
1507	0	1	<0.003	<0.1	<0.1	<0.1	<1.2	8,5	46	200	180	250	7,6	31	1,1
1507	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1507	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1507	3	3,5	<0.003	<0.1	<0.1	<0.1	<1.2	13	76	380	280	470	5	41	<1
1508	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1509	0	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	12	<10	<1	<1	<1
1509	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	19	<10	<1	<1	<1
1510	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	3,3	21	36	19	60	<1	<1	<1
1511	0	1	0,0087	<0.1	<0.1	<0.1	<1.2	9,7	62	69	24	140	<1	<1	<1
1511	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	11	<10	<1	<1	<1
1512	0,4	1	0,017	0,1	<0.1	0,12	<1.2	<2	<10	<10	13	<10	1,1	1,1	<1
1512	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	14	<10	<1	<1	<1
1512	2	2,5	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1513	1	1,6	0,0085	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1513	1,6	2													
1514	0,5	1	0,019	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	35	<10	<1	<1	1,5
1515	0,6	1	0,015	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	20	<10	<1	<1	<1
1515	1	2	0,025	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	15	<10	<1	<1	<1

Sampling point	Depth (m)		Benzene	Toluene	Ethylbenzene	Xylene	Aliphatic >C5-C8	Aliphatic >C8-C10	Aliphatic >C10-C12	Aliphatic >C12-C16	Aliphatic >C16-C35	Aliphatic sum >C5-C16	Aromatic >C8-C10	Aromatic >C10-C16	Aromatic >C16-C35
	from	to	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
MKM generic guideline			**0,04**	**40**	**50**	**50**	**80**	**120**	**500**	**500**	**1000**	**500**	**50**	**15**	**30**
1515	2	3	0,014	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	47	<10	<1	1,5	1,7
1516	0	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	14	<10	<1	<1	<1
1516	1	2	0,016	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	54	<10	<1	18	11
1517	0	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	12	<10	<1	<1	<1
1518	0	0,6	0,0064	<0.1	<0.1	<0.1	<1.2	<2	<10	15	58	15	<1	2,1	1,1
1519	0,6	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	19	<10	<1	<1	<1
1519	1	1,7	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	110	<10	<1	<1	<1
1519	1,7	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1520	0,2	0,8	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1521	0,8	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	28	<10	<1	<1	<1
1521	1	2	0,0088	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	89	<10	<1	4,1	1,7
1521	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	13	<10	<1	<1	<1
1522	1,5	2,5	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1522	2,5	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	12	<10	<1	<1	<1
1523	0	0,9	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	53	<10	<1	<1	1,6
1541	0	0,7	0,0033	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	34	<10	<1	1,8	<1
1541	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1

Sampling point	**Depth (m)**		**Benzene**	**Toluene**	**Ethylbenzene**	**Xylene**	**Aliphatic >C5-C8**	**Aliphatic >C8-C10**	**Aliphatic >C10-C12**	**Aliphatic >C12-C16**	**Aliphatic >C16-C35**	**Aliphatic sum >C5-C16**	**Aromatic >C8-C10**	**Aromatic >C10-C16**	**Aromatic >C16-C35**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline			**0,04**	**40**	**50**	**50**	**80**	**120**	**500**	**500**	**1000**	**500**	**50**	**15**	**30**
1541	0,5	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	16	<10	<1	<1	<1
1542	0	0,4	0,011	<0.1	<0.1	<0.1	<1.2	<2	<10	16	150	16	1,4	1,3	3,2
1542	1	1,3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1543	0,6	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1543	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1544	1	2	<0.003	<0.1	<0.1	0,38	<1.2	<2	<10	19	51	19	4,6	240	47
1545	0	0,6	0,0098	0,11	0,14	7,3	<1.2	2,9	<10	27	52	30	8	250	47
1545	0,6	1	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	29	<10	<1	<1	<1
1545	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	19	<10	<1	<1	<1
1546	1	2	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	100	<10	<1	2,2	3,6
1546	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	<10	<10	<1	<1	<1
1547	1	1,5	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	37	<10	<1	<1	2,3
1547	1,5	2	0,0057	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	39	<10	<1	4,1	6
1547	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	11	<10	<1	<1	<1
S16	0,5	1	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	<10	<20	<1,6	<1,2	
S16			<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	<10	<20	<1,6	2,3	
S23	2	3	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	<10	<20	<1,6	<1,2	
S27	0,5	1	0,27	0,35	<0,05	0,08	<10	<10	<10	<10	91	<20	1,2	2,7	

Sampling point	Depth (m)		Benzene	Toluene	Ethylbenzene	Xylene	Aliphatic >C5-C8	Aliphatic >C8-C10	Aliphatic >C10-C12	Aliphatic >C12-C16	Aliphatic >C16-C35	Aliphatic sum >C5-C16	Aromatic >C8-C10	Aromatic >C10-C16	Aromatic >C16-C35
	from	to	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
MKM generic guideline			**0,04**	**40**	**50**	**50**	**80**	**120**	**500**	**500**	**1000**	**500**	**50**	**15**	**30**
S28	0	1	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	<10	<20	<1,6	<1,2	
S30	0	1	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	14	<20	<1,6	<1,2	
S31	0	0,5	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	28	<20	<1,6	4,7	
S33	1	1,3	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	<10	<20	<1,6	<1,2	
S34	0	0,8	<0,01	<0,05	<0,05	<0,05	<10	<10	15	63	134	78	<1,6	<1,2	
S35	0,3	1	<0,05	<0,05	<0,05	<0,1	<10	<10					<2		
S38	1,3	2	<0,05	0,16	<0,05	0,33	<10	<10					<2		
S39	0	1	<0,01	<0,05	<0,05	<0,05	<10	<10	<10	<10	<10	<20	<1,6	0,4	
S44	3	3	<0,05	0,07	0,43	2	28	32					78		
S7	2	3	<0.003	<0.1	<0.1	<0.1	<1.2	6,3	65	270	100	340	<1	<1	<1
S7	0,5	1	<0.003	0,15	0,82	2,4	9,4	340	790	1400	240	2500	79	100	<1
S8	0	1	0,0053	<0.1	<0.1	<0.1	<1.2	<2	<10	<10	19	<10	<1	<1	<1

Sampling point	**Depth (m)**		**Dichloromethane**	**1,2-Dibromomethane**	**1,1-Dichloroethane**	**1,2-Dichloroethane**	**cis-1,2-Dichloroethene**	**trans-1,2-Dichloroethene**	**TriChloromethane**	**TriChloroethene**	**1,1,1-TriChloroethane**	**1,1,2-Trichloroethane**	**Tetrachloromethane**	**Tetrakloreten**	**BromoDichloromethane**	**Dibromochloromethane**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline			**0,25**	**0,025**		**0,060**			**1,2**	**0,60**	**30**		**0,35**	**1,2**	**1,0**	**1,8**
1504	1	2	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1504	2	3	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1505	0	1	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1505	1	1,5	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1506	0	1	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1506	1	1,8	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1512	0	0,4	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1513	0	1	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	0,28	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1513	1	1,6	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1514	0	0,5	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1515	0,04	0,6	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	0,25	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1516	0	1	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1516	1	2	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1517	0	1	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	0,12	<0.01	<0.01	<0.01	<0.05
1517	1	1,6	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1518	0	0,6	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1518	0,6	1	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1519	0	0,6	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05

Sampling point	**Depth (m)**		**Dichloromethane**	**1,2-Dibromomethane**	**1,1-Dichloroethane**	**1,2-Dichloroethane**	**cis-1,2-Dichloroethene**	**trans-1,2-Dichloroethene**	**TriChloromethane**	**TriChloroethene**	**1,1,1-TriChloroethane**	**1,1,2-Trichloroethane**	**Tetrachloromethane**	**Tetrakloreten**	**BromoDichloromethane**	**Dibromochloromethane**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline			**0,25**	**0,025**		**0,060**			**1,2**	**0,60**	**30**		**0,35**	**1,2**	**1,0**	**1,8**
1520	0,2	0,8	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1520	0,8	1,8	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1521	0	0,4	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1521	0,4	0,8	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1545	1	2	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
1545	2	2,5	<0.01	<0.003	<0.05	<0.01	<0.05	<0.05	<0.02	<0.02	<0.1	<0.03	<0.01	<0.01	<0.01	<0.05
S40	0,5	1	<0,05		<0,05	<0,05			<0,05	<0,05	<0,05	<0,05	<0,05	<0,05		
S41	0,7	2	<0,05		<0,05	<0,05			<0,05	<0,05	<0,05	<0,05	<0,05	<0,05		
S7	2	3	<0,05		<0,05	<0,05			<0,05	0,17	<0,05	<0,05	<0,05	<0,05		

Sampling point	**Depth**		**1,2,4-Trichlorobenzene**	**1,2-Dichlorobenzene**	**1,2,3-Trichlorobenzene**	**1,3-Dichlorobenzene**	**1,4-Dichlorobenzene**	**Monochlorobenzene**	**PAH-L sum**	**PAH-M sum**	**PAH-H sum**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline									**15**	**20**	**10**
1501	2	3							<0.03	<0.05	<0.08
1501	3	3,5							6,5	2,7	0,23
1502	0	1							0,055	0,46	0,27
1502	1	1,8							<0.03	<0.05	<0.08
1503	0	1							0,72	10	9,3
1503	1	1,5							0,52	6,6	8,6
1504	1	2	0,17	<0.1	<0.05	<0.1	<0.07	<0.03	0,33	6,5	7,9
1504	2	3	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,07	1,4	1,6
1505	0	1	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,071	1	0,87
1505	1	1,5	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,13	2,1	1,7
1506	0	1	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,47	9,4	11
1506	1	1,8	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	<0.03	<0.05	<0.08
1507	2	3							<0.03	0,12	<0.08
1507	3	3,5							0,36	2,6	1,7
1508	0	1							<0.03	0,49	0,36
1508	1	2							<0.03	<0.05	<0.08
1508	2	3							0,3	1,2	0,23
1509	1	2							<0.03	0,49	0,55
1509	2,5	3							<0.03	<0.05	<0.08
1510	0	1							0,034	1,9	2,7
1511	2	3							<0.03	0,31	0,46
1511	3	3,6							0,068	0,78	0,97
1512	0	0,4	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	<0.03	0,28	0,32
1513	0	1	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,13	1	1,5

Sampling point	**Depth**		**1,2,4-Trichlorobenzene**	**1,2-Dichlorobenzene**	**1,2,3-Trichlorobenzene**	**1,3-Dichlorobenzene**	**1,4-Dichlorobenzene**	**Monochlorobenzene**	**PAH-L sum**	**PAH-M sum**	**PAH-H sum**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline									**15**	**20**	**10**
1513	1	1,6	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	<0.03	<0.05	<0.08
1513	1,6	2							<0.03	<0.05	<0.08
1514	0	0,5	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,081	0,56	0,76
1515	0,04	0,6	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,16	2	4,6
1516	0	1	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,048	1,4	2,3
1516	1	2	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,035	1,3	2,4
1517	0	1	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,18	2,7	4
1517	1	1,6	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	<0.03	1,3	0,96
1518	0	0,6	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	4,5	38	28
1518	0,6	1	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	<0.03	<0.05	<0.08
1519	0	0,6	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,22	2,6	2,9
1520	0,2	0,8	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,15	2	2,1
1520	0,8	1,8	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,032	0,73	1,2
1521	0	0,4	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	<0.03	<0.05	<0.08
1521	0,4	0,8	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	0,09	1,1	1,3
1522	0	0,3							<0.03	0,26	0,38
1522	0,3	0,8							0,41	3,2	4,2
1522	0,8	1,5							<0.03	<0.05	<0.08
1523	0,9	1							<0.03	<0.05	<0.08
1523	1	2							<0.03	<0.05	<0.08
1541	0	0,7							0,1	3,3	4,4
1541	0,5	1							0,07	0,46	0,23
1542	0,4	1							<0.03	<0.05	<0.08
1542	1	1,3							<0.03	<0.05	<0.08

Sampling point	Depth		1,2,4-Trichlorobenzene	1,2-Dichlorobenzene	1,2,3-Trichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	Monochlorobenzene	PAH-L sum	PAH-M sum	PAH-H sum
	from	to	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
MKM generic guideline									**15**	**20**	**10**
1543	0	0,6							0,18	0,49	1,4
1543	1	2							<0.03	<0.05	<0.08
1544	0,6	1							<0.03	<0.05	<0.08
1544	1	2							<0.03	<0.05	<0.08
1545	1	2	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	29	92	31
1545	2	2,5	<0.05	<0.1	<0.05	<0.1	<0.07	<0.03	42	90	29
1546	0	0,4							0,071	1,3	1,6
1546	0,4	0,6							0,055	1,1	1,3
1547	0	0,7							0,21	6,9	11
1547	0,7	1							<0.03	<0.05	<0.08
1548	0	0,5							0,19	5,7	8,2
1548	0,5	0,7							0,47	12	16
1548	0,7	1							<0.03	0,1	0,15
S1	3	3,6							0,15	0,12	0,11
S10	2	3,2							0,15	0,1	0,11
S13	0,8	1,4							0,3	0,55	0,23
S16	0,5	1							0,34	1,38	0,69
S16									0,17	0,1	0,11
S2	3	4							0,15	0,06	0,28
S25	0	1							0,231	2,22	0,676
S26	0,5	1							0,15	0,25	0,4
S28	0	1							0,15	0,25	0,4
S30	0	1							0,05	0,75	0,64
S32	3	3,4								0,34	

Sampling point	**Depth**		**1,2,4-Trichlorobenzene**	**1,2-Dichlorobenzene**	**1,2,3-Trichlorobenzene**	**1,3-Dichlorobenzene**	**1,4-Dichlorobenzene**	**Monochlorobenzene**	**PAH-L sum**	**PAH-M sum**	**PAH-H sum**
	from	**to**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**	**mg/kg TS**
MKM generic guideline									**15**	**20**	**10**
S35	0,3	1							0,193	3,04	3,156
S41	0,7	2						<0,05	0,05		
S6	2	3							1,58	1,92	0,71
S7	2	3							1	0,19	0,12
S7	2	3						<0,05	0,61		
S7	0,5	1							0,28	4,57	3,01
S8	0	1							11,55	29,63	2,98

APPENDIX 6

Groundwater samples analyzed in the previous surveys for concentrations of inorganic pollutants. The cells with concentrations below the Swedish guideline are colored in green, the values above the guideline in yellow and those with concentrations 3 times or more the guideline are colored in red. If the Swedish guideline was not available, the cell was colorless.

Sampling point	**Hg**	**Al**	**As**	**Pb**	**Fe**	**Cd**	**Co**	**Cu**	**Cr**	**Ni**	**Zn**	**Ba**
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline	**1**	**500**	**10**	**50**	**1000**	**5**		**2000**	**50**	**20**	**1000**	
S3	<0,02		<1	0,2		<0,05		2,6	<0,5	19	71	
S4	<0,02		<1	<0,2		<0,05		<1	<0,5	54	16	
S4	<0.1		1,2	42	2.900	0,7	2,2	89	2,6	14	220	
S7	<0,02		2,3	224		0,1		3,8	<0,5	6,2	48	
	<0.1		1,2	310	2.800	0,1	0,5	70	0,59	5,7	58	
S8	<0,02		<1	0,3		<0,05		1,2	<0,5	16	12	
S21	<0,002	16	2,1	0,1		0,01	3,23	<0,5	0,2	3,9	18	108
S31	<0.1		4,5	40	8.300	0,03	1,8	56	0,9	4,8	53	
T	<0.1		2	20	1.000	0,07	1,8	39	0,7	3,5	55	
Tri 1A	<0.1		0,1	2,7	61	0,02	0,11	1,5	0,3	0,3	2,9	
Tri 2B	<0.1		0,4	3,5	580	0,05	0,98	6,9	0,7	2,3	15	
1504	<0.1		1,0	2,5	4.000	0,1	1,7	1,7	0,4	3,5	35	
1505	<0.1		3,9	320	4.400	0,3	31	150	5,1	11	330	
1506	<0.1		1,5	31	2.200	0,05	1,1	40	4,3	2,4	39	
1507	<0.1		3,9	29	4.300	0,2	4,5	65	6,1	5,6	100	
1509	<0.1		7,9	450	5.200	5,4	3,7	380	2,9	13	3.800	
1511	<0.1		1,5	47	3.000	0,04	1,5	31	2,7	3,2	61	
Cistern	<0.1		0,06	5,3	180	0,2	0,59	1,9	0,1	0,6	400	

Sampling point	**Mn**	**Mo**	**F**	**Sr**	**Ca**	**Fe**	**K**	**Mg**	**Na**	**S**	**Si**
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline	**400**										
S21	10.800	5,3	37	196	30,0	0,4	4,5	19	15	1,8	27

APPENDIX 7

Groundwater samples analyzed in the previous surveys for concentrations of organic pollutants. The cells with concentrations below the Swedish guideline are colored in green, the values above the guideline in yellow and those with concentrations 3 times or more the guideline are colored in red.

Sampling point	**Benzene**	**Toluene**	**Ethylbenzene**	**Xylene**	**Bromodi Chloro methane**	**Dibromo Chloro methane**	**Trichloro methane**	**1,2-Dichloro ethane**	**Trichloro ethylene**	**Monochloro ethene**
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline	**50**	**500**	**500**	**500**						
S3										
S4										
S4	<0.1	<1	<1	<1						
S7										
S7	<0.1	<1	<1	<1						
S8										
S21	<0,2		<0,2				<0,1	<0,5	<0,1	<0,5
S25										
S31	<0,2	<0,2	<0,2	<0,2						
S31	57	<1	<1	<1						
T										
T	0,13	<1	<1	<1						
Tri 1A							<0,2	<1		<1
Tri 1A	<0.1	<1	<1	<1						
Tri 1B							<0,2	<1	5,4	<1
Tri 2B							<0,2	<1	22	<1
Tri 2B	<0.1	<1	<1	<1	<1	<1	<1	<1	45	
1504	<0.1	<1	<1	<1	<1	<1	<1	<1	<1	
1505	<0.1	<1	<1	<1	<1	<1	<1	<1	<1	
1506	<0.1	<1	<1	<1	<1	<1	<1	<1	<1	

Sampling point	Benzene	Toluene	Ethylbenzene	Xylene	Bromodi Chloro methane	Dibromo Chloro methane	Trichloro methane	1,2-Dichloro ethane	Trichloro ethylene	Monochloro ethene
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline	**50**	**500**	**500**	**500**						
1507	<0.1	<1	<1	<1	<1	<1	<1	<1	<1	
1509	<0.1	<1	<1	<1						
1511	<0.1	<1	<1	<1						
Cistern	<0.1	<1	<1	<1						

Sampling point	1,2-Dibromo methane	Tetrachl oroethylene	Trichloroethene + tetrachlorethene	Dichl oromethane	1,1-Dichloroethane	cis-1,2-Dichlo roethene	trans-1,2-Dichlo roethene	1,1,1-Trichlo roethane	1,1,2-Trichlo roethane	1,1,2,2-tetrachlo roethane	Tetra chloro methane
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline			**10**								
S21		<0,1		<1	<0,5	<0,5	<0,5	<0,1	<0,1	<0,5	<0,1
Tri 1A		<0,1		<1	<1	<1	<1	<0,2	<0,5		<0,2
Tri 1B		<0,1		<1	<1	1,6	<1	<0,2	<0,5		<0,2
Tri 2B		<0,1		<1	<1	<1	<1	<0,2	<0,5		<0,2
Tri 2B	<0.1	<1	46	<1	<1	<1	<1	<1	<1		<0.2
1504	<0.1	<1	1	<1	<1	<1	<1	<1	<1		<0.2
1505	<0.1	<1	1	<1	<1	<1	<1	<1	<1		<0.2
1506	<0.1	<1	1	<1	<1	<1	<1	<1	<1		<0.2
1507	<0.1	<1	1	<1	<1	<1	<1	<1	<1		<0.2

Sampling point	**Monochlorobenzene**	**Dichlorobenzene**	**1,2-Dichlorobenzene**	**1,3-Dichlorobenzene**	**1,4-Dichlorobenzene**	**1,2,3-Trichlorobenzene**	**1,2,4-Trichlorobenzene**	**1,2-Dichloropropane**
	µg/l		**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline								
S21	<0,2	<0,5						<0,5
Tri 1A								<0,5
Tri 1B								<0,5
Tri 2B								<0,5
Tri 2B	<1		<1	<1	<1	<1	<1	
1504	<1		<1	<1	<1	<1	<1	
1505	<1		<1	<1	<1	<1	<1	
1506	<1		<1	<1	<1	<1	<1	
1507	<1		<1	<1	<1	<1	<1	

Sampling point	**Aliphatic >C5-C8**	**Aliphatic >C8-C10**	**Aliphatic >C10-C12**	**Aliphatic >C12-C16**	**Aliphatic >C5-C16**	**Aliphatic >C16-C35**	**Aliphatic sum >C5-C35**	**Aromatic >C8-C10**	**Aromatic >C10-C16**	**Aromatic:a C8-C16**	**Aromatic >C16-C35**
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline	**300**	**100**	**25**	**3.000**	**300**	**3.000**	**3.000**	**500**	**120**	**500**	**5**
S4	<10	<10	21	<10		180	200	<10	<10	<10	<2
S7	<10	<10	<10	<10		17	17	<10	<10	<10	<2
S21	<10	<10									
S31	<10	<10	406	1.620	2.030	3.680		3,7	22		
S31	<10	<10	23	40		96	160	<10	<10	<10	<2
T	<10	<10	<10	12		34	46	<10	<10	<10	<2
Tri 1A	<10	<10	<10	<10		<10	<10	<10	<10	<10	<2
Tri 2B	<10	<10	<10	<10		<10	<10	<10	<10	<10	<2
1504	<10	<10	<10	<10		17	17	<10	<10	<10	<2
1505	<10	<10	<10	<10		<10	<10	<10	<10	<10	<2
1506	<10	<10	<10	<10		<10	<10	<10	<10	<10	<2

Sampling point	Aliphatic >C5-C8	Aliphatic >C8-C10	Aliphatic >C10-C12	Aliphatic >C12-C16	Aliphatic >C5-C16	Aliphatic >C16-C35	Aliphatic sum >C5-C35	Aromatic >C8-C10	Aromatic >C10-C16	Aromatic:a C8-C16	Aromatic >C16-C35
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Drinking water guideline	**300**	**100**	**25**	**3.000**	**300**	**3.000**	**3.000**	**500**	**120**	**500**	**5**
1507	<10	<10	38	200		350	590	<10	<10	<10	<2
1509	<10	<10	<10	<10		<10	<10	<10	<10	<10	<2
1511	<10	<10	<10	17		<10	17	<10	<10	<10	<2
Cistern	<10	<10	<10	29		100	130	<10	<10	<10	<2

Sampling point	Acenaphthene	Acenaphthylene	Naphthalene	Anthracene	Phen anthrene	Fluor anthene	Fluorene	Pyrene	Benzo(a) Fluoranthene	Benzo(a) Anthracene	Benzo(a) pyrene	Benso(b) fluoranthene
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Drinking water guideline												
S3	0,3	<0,12	1,2	0,08	1,8	0,08	2	0,07	<0,2		<0,01	<0,03
S4	1,8	0,34	18	0,65	8,4	2,8	5,4	1,9	1,2		0,7	0,6
S4	<0.1	<0.1	0,2	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
S7	<0,17	<0,38	1,1	<0,05	0,11	0,15	<0,12	0,08	<0,07		0,1	<0,09
S7	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
S8	5,8	<0,54	2,8	0,29	3,3	0,88	2,4	0,42	0,05		0,03	0,04
S21			<0,2									
S25	5,8	<0,54	0,3									
S31	0,22	<0.1	0,3	<0.1	0,1	1,0	0,3	0,7		0,15	<0.1	0,12
T	<0.1	<0.1	0,1	<0.1	0,2	0,4	<0.1	0,3		<0.1	0,11	0,18
Tri 1A	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1

Sampling point	**Acenaphthene**	**Acenaphthylene**	**Naphthalene**	**Anthracene**	**Phen anthrene**	**Fluor anthene**	**Fluorene**	**Pyrene**	**Benzo(a) Fluoranthene**	**Benzo(a) Anthracene**	**Benzo(a) pyrene**	**Benso(b) fluoranthene**
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline												
Tri 2B	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
1504	<0.1	<0.1	0,2	<0.1	<0.1	0,1	<0.1	0,1		<0.1	<0.1	<0.1
1505	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
1506	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
1507	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
1509	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
1511	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1
Cistern	<0.1	<0.1	0,1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1

Sampling point	**Benzo(k) fluoranthene**	**Benzo(ghi)perylene**	**Chrysene**	**Dibenzo(a,h)anthracen**	**Indeno(1,2,3-cd)pyrene**	**PAH-H, sum**	**PAH-M, sum**	**PAH-L, sum**
	µg/l	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
Drinking water guideline						**0,5**	**5**	**120**
S3	<0,01	<0,04	0,1	<0,02	<0,12	0,6	4,0	1,6
S4	0,4	0,4	1,1	0,1	0,5	4,9	19	20
S4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,2
S7	0,04	<0,11	<0,05	<0,05	<0,22	0,7	0,5	1,7
S7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
S8	0,02	<0,04	0,1	<0,02	<0,07	0,3	7,3	9,1
S21								
S25								6,6
S31								
S31	<0.1	<0.1	0,18	<0.1	<0.1	0,45	2,1	0,5
T								
T	<0.1	<0.1	0,16	<0.1	<0.1	0,45	0,8	0,1
Tri 1A								
Tri 1A	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
Tri 1B								
Tri 2B								
Tri 2B	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
1504	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	0,3	0,2
1505	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
1506	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
1507	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
1509	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
1511	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1
Cistern	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.2	0,1

Sampling point	Oilindex	PCB 28	PCB 52	PCB 101	PCB 118	PCB 138	PCB 153	PCB 180	Sum PCB
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Drinking water guideline	**25**								
S3	7.500								
S4	2.200	<0,0011	<0,0011	<0,0008	<0,0011	<0,0012	<0,0011	<0,001	<0,004
S7	420								
S8	1.200	<0,0011	<0,0011	<0,0008	<0,0011	<0,0012	<0,0011	<0,001	<0,004
T		<0,0011	<0,011	<0,0008	<0,0011	<0,0012	<0,0011	<0,0010	<0,0037

Other organic contaminants detected in sample S25 only and without a drinking water guideline.

Compound	**Concentration (µg/l)**	**Compound**	**Concentration (µg/l)**
1-methylnaphtalene	0,5	3,5-dimethylphenol	0,7
2- methylnaphtalene	0,4	dibenzofuran	0,2
o-cresol	0,2	Quinolin	<0,10
m-cresol	<0,010	Isoquinolin	<0,10
p-cresol	<0,010	Dibenzothiophene	<0,030
Phenol	<0,10	Benzothiophene	<0,030
2,4-dimethylphenol	1,2		

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