State of the art of contaminated site management:
Policy framework and human health risk assessment tools
List of abbreviations

BASIAS : base de données des anciens sites industriels et activités de service, old industrials
Sites and service activities database
BASOL : (potentially) contaminated soil database
CEV: Critical Exposure Value
CVOCs: chlorinated volatile organic compounds
EPA: Environmental Protection Agency
HHRA: Human Health Risk Assessment
OQAI: Observatoire de la qualité de l’air intérieur, indoor air quality observatory
OVAM: Openbare Vlaamse Afvalstoffenmaatschappij, Public Waste Agency of Flanders
RI: Risk Index
RIVM: Rijksinstituut voor Volksgezondheid en Milieu, the National Institute for Public Health and the environment
SQSs: Soil Quality Standards
SVs: Soil screening value
UMS: Umwelt (Environment), Mensch (Human), Schadstoff (pollutant)
Summary

Human health risk assessment (HHRA) can be conducted in different ways and in order to meet different objectives. This approach can be used for:

- derivation of Soil Quality Standards: soil screening value (trigger values, target values...),
- site-specific risk assessment,
- development of remediation objectives,
- ranking of contaminated sites.

Soil Screening Values (SVs) are generic quality standards (based on generic exposure pathways and scenario, e.g. inhalation of vapours for residential areas, industry...) adopted in many countries to regulate the management of contaminated land. SVs are related to the use of the respective Site. The decision whether the soil contamination implies a hazard has to take into account the current uses but also the future uses of the Site. The actions to be conducted when exceeding the soil SVs vary according to national regulatory frameworks. They range from the need for further investigations to the need for remedial actions. These soil screening values are called differently according to the different European regions/countries: trigger values, reference values, target values, intervention values, clean-up values, cut-off values and many others names can be found.

Each country developed its own system, i.e. methodology or software package to quantify the risk posed by a contaminant in evaluating a source-pathway-receptor linkage: ‘Risc Human’ for The Netherlands, ‘UMS’ for Germany and ‘Vlier Humaan’ for Flanders. In France commercial software packages, like RBCA Toolkit or RISC are usually used. A project is currently running to develop a risk assessment tool which will be compulsory used.

That is why, in the frame of the CityChlor project, we proposed an overview of concepts and tools used by the different European regions/countries involved in this project for human health risk assessment (Flanders, France, Germany and the Netherlands).

General concept on HHRA is given. For each country, the contaminated site management and the tools used in HHRA and more specifically in the case of chlorinated solvent in urban areas are presented.

In general, it was observed that a consensus on the methodology was found between the different partner countries; indeed the management of contaminated sites is based on the same HHRA concept following the use of the site. The human health risk characterization is preceded by two steps: exposure assessment (‘probability’ in Risk Assessment terms) and the hazard assessment (‘effect’ in risk assessment terms). HHRA is all about linking exposure to effects, oral, inhalation and dermal exposures, relevant timeframes for exposure as regards to the occurrence of effects, and the compatibility of estimated Exposure and critical exposure (Toxicological Reference Value). It leads to quantify the risk of a contaminated site on human health.
In the specific case of chlorinated solvents in urban areas, the conceptual model allows identifying the primary contamination sources and the potential exposure pathways as usual (e.g., ingestion of contaminated water, inhalation of chemical in air, etc. ...). In this context, the different exposure pathways and transfer models that are taking into account in the HHRA tools used by the different partners to quantify the specific risk of a Site contaminated by chlorinated solvent were compared in the frame of this project. Large differences in the predicted concentration doses in the exposure environment given by the models were pointed out when models default exposure parameters were used. When parameters are unknown, the use of default data can impact significantly the conclusions in a site's risk management. A reliable characterization of the site is necessary.
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1 Introduction

1.1 CityChlor and the integrated approach

Space is scarce in Europe. Even in the subsurface it is getting busier. Large-scale soil and groundwater contamination with chlorinated solvents are often an obstruction for urban developments. The traditional way of dealing with polluted soil and groundwater does not work in all cases and is not economically and sustainable feasible. In urban environments multiple contaminations with chlorinated solvents are often mixed with each other and spread underneath buildings. This not only leads to technical problems for remediation, but also to liability and financial discussions and hence has an impact on society. An integrated approach and area-oriented approach is needed to tackle the problems. The CityChlor project has demonstrated that remediation and sustainable development can evolve on a parallel timescale.

An integrated approach combines all aspects that are relevant to tackle the problems that pollution with VOC in urban environment causes. Depending on area, site and context different aspects together or parallel to each other can be used. Not only technical solutions are included, but also socio-economical aspects as urban development, communication, financial and legal aspects, time, space, environment and actors (active & passive) have to be handled.

CityChlor did not remain at single case remediation, but looked at the area as a whole in a bigger context: the area-oriented approach. A technical approach that makes it possible to remediate, monitor and control multiple groundwater sources and plumes within a fixed area.

1.2 CityChlor and technical innovations

The managing of knowledge and technical innovations are one of the key to achieve a sustainable city development. A development project has to cope with loads of information coming from different disciplines in different (technical) languages and with different uncertainties. With chlorinated solvents, the knowledge about the pollution will always have a certain uncertainty that can have an impact on the course and the costs of the remediation. An efficient ‘managing of knowledge’ will try to decrease this degree of uncertainty.

CityChlor therefore also worked on the technical aspects of characterization and remediation. The conventional techniques that are applied for investigation and remediation have their limitations dealing with chlorinated solvents. Promising innovative techniques exist, but do not easily find their way to current application. This barrier is often caused by lack of knowledge on different levels. Experts and contractors do not always have the means to invest in experiments with new techniques, authorities are reluctant to accept techniques of which the results may be uncertain and clients aren’t eager to pay for experimental techniques.

Dissemination of knowledge can break this deadlock. CityChlor therefore collected experiences from field application of innovative techniques and implemented itself a number of techniques in pilot projects. For the detailed outcomes, the reader is referred to the specific reports.

CityChlor - “new solutions for complex pollutions”  http://www.citychlor.eu/
2  Aim of this report

This report aims to give an overview of contaminated site management and concepts used in human health risk assessment by the different European regions/countries involved in this project. In the context of chlorinated solvents pollution in urban areas, the ecological risk assessment will not be reviewed.

After this introduction, the report is composed of the following sections:

- The first section gives the general concept of Human Health Risk Assessment (HHRA). This general concept is used in many countries in Europe and by the different partners of the project (Flanders, Germany, The Netherlands and France) for the management of contaminated site;

- The second section gives the general management of contaminated site for each partner of Citychlor project and tools used to derive soil quality standard and used for site specific risk assessment are listed.

- In the specific context of CVOCs in urban areas, a comparison of the different models used in the partner countries is given in the third and last part of this report.
Human Health Risk Assessment

Human health risk assessment (HHRA) seeks to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, nowadays or in the future (US EPA).

The human health risk assessment may have many objectives:

- Derivation of Soil Quality Standards: Soil screening value (trigger values, target values...);
- Site-specific risk assessment;
- Development of remediation levels;
- Ranking of contaminated sites.

Only the derivation of Soil Quality Standards and site-specific risk assessment will be developed in this report for each partner.

The human health risk characterisation is composed of two steps: Exposure Assessment (‘probability’ in risk assessment terms) and the hazard assessment (‘effect’ in risk assessment terms). HHRA is all about linking exposure to effects, oral, inhalation and dermal exposures; relevant timeframes for exposure in regards to the occurrence of effects; and the compatibility of estimated Exposure and critical exposure (Toxicological Reference Value).

3.1 Site Conceptual model

The site conceptual model is a schematic diagram which identifies the primary sources of contamination and the different potential exposure pathways by which different type of population (e.g. residents, workers, etc.) might come into contact with contaminated media.

The first step consists in Site characterisation (nature and concentration of pollutants in soil and groundwater + background levels).

3.2 Exposure Assessment

The exposure assessment is defined as the concentration or amount of a particular agent that reaches the body in a specific frequency for a defined duration (International Programme on Chemical Safety 1999, 2004).

Exposure assessment provides a (quantitative) evaluation of exposure, including intensity, frequency and duration of exposure, route of exposure (oral, inhalation, dermal), rates (intake or uptake rates), the amount that may cross the body boundary (external exposure) and the amount absorbed (internal dose) (International Programme on Chemical Safety 1999).

Measurement and models can be used in exposure assessment. Human exposure can be assessed by measurements (biomonitoring: sampling and analyse of blood, urine, or measurements in contact media (parts of vegetables, indoor air)) or/and by using modelling tools. Measurements give the exposure at a given time while calculated exposure may be more useful to represent long term exposures and expected exposure scenarios (Swartjes et Cornelis, 2011).
3.3 Hazard Assessment

Hazard assessment leads to determine the possible adverse effects in the human body of the different contaminants studied. It is based on toxicological assessment of compounds. The hazard of a contaminant is its inherent potential to cause adverse effects when humans are exposed to that contaminant at any level. These adverse effects depend on the nature of the contaminant, the degree of exposure, and the performance of the human body. (Swartjes et Cornelis, 2011)

There are two steps in hazard assessment:
- Hazard identification: defines the type and nature of the adverse effects of the contaminant considered (threshold and non-threshold contaminants);
- Hazard characterisation: adverse effects are quantified and this process ideally results in a dose-response assessment (toxicological reference value, this assessment forms the basis for derivation of critical exposure values which are used in HHRA for risk appraisal).

3.4 Risk characterisation and management

Risk characterisation leads to combine results of the exposure and hazard assessments and give a conclusion with regard to human health risk on a contaminated Site.

The derivation of Soil Quality Standards

Soil Screening Values are generic quality standards adopted in many countries to regulate the management of contaminated land. They are usually within the form of concentration thresholds (mg kg\(^{-1}\) soil-dry weight) of contaminants in soil above which certain actions are recommended or enforced.

Site specific risk assessment

The Site specific human risk assessment of soil contamination is based on exposure and transport modelling of contaminants in soil, groundwater and contact media.

In general, it was observed that a consensus on the methodology was found between the different partner countries of the Citychlor project. Indeed the management of contaminated sites is based on the same HHRA concept, according to the current or future use of the Site.
4 Management of contaminated Sites and risk assessment tools in the different partners

4.1 Site management and risk assessment tools in France

4.1.1 Contaminated sites management: History, innovations and legal framework

History
At the beginning and without any referential and work management tools, contaminated sites management were based on authorities and Site’s responsible discussion. The French policy of contaminated sites' management was carried out in 1993. The objective was to register, select and remediate any potentially contaminated sites. A baseline investigation and a simplified risk assessment allowed filtering out three different classes of sites (to be considered as “banal”, “needing monitoring”, or “needing further assessment”). This first baseline investigation could be followed by further investigations and a detailed risk assessment.

In the simplified risk assessment, generic soil concentrations were used to set a score for the soil source (“soil source definition value”) and a score for the impact on the surface soil (“impact statement value”). Two classes of “impact statement value” were available: one for the sensitive site use (e.g. playground, garden, drinking water...) and another one for the non-sensitive site use (e.g. industrial and commercial use). This framework did not propose any soil screening value for assessment of risk or for remediation goals. Generic concentrations were used only in the frame of a scoring system which helps classifying the contaminated sites, but no reflexion about the future use of the Site was carried out. Furthermore, some pathways, such as the inhalation of dust and vapours, and some types of sources, were not taken into account.

For detailed risk assessment, no recommendation were made on which model should be used, each actor choosing its own tools according to its needs and possibilities. This framework presented a lot of uncertainties at each step (from historic investigation until transfer and risk assessment). For these reasons, a new contaminated land management was established in 2007. Indeed, two different approaches were defined: environmental media quality assessment (or Interpretation of environmental conditions) and management plan.

Regulation
In France, there is no specific regulation on contaminated sites. The main legal framework is based on 1976 law related to Classified Installations (Loi n°76-663; industrial or semi-industrial facilities listed in a national classification), which is a transposition of the IPPC directive (2008/1/EC, currently integrated in the directive on industrial emissions 2010/75/EU (IED)), and on many current circulars on contaminated soil management (Circulars of 08/02/2007, ...). For others activities (mining, military activities...) which are not related to
classified installations, specific regulations, like wastes regulation, are used (Law n°75-633 of 15/07/1975).

In France, two databases allow identifying potentially and contaminated site; the first one called BASOL which lists all contaminated or potentially contaminated Sites for which an action of the authorities is needed; and, the second one, BASIAS which lists, former or current, industrial or services sites with a potentially polluting activity. In 2007, 180 000 sites were identified in BASIAS. In 2013, 4 564 sites, for which an action of the authorities is needed, were identified in BASOL.

With regards to CVOCs contaminated Sites, the French Ministry of environment counts 652 contaminated sites with 521 of them showing an impact on groundwater (Ademe, 2009).

In February 2007, a new contaminated site management was established by the French Ministry of environment. It will be developed in the next part.

4.1.2 Management of contaminated sites

The French contaminated sites management policy aims to:

- prevent future pollutions;
- secure new industrial sites;
- identify, monitor and control pollution impacts;
- remediate in accordance with the land use and make it sustainable;
- insure memory of past activities and involve stakeholders (regulators, operators, tenants, municipalities ...).

Two different approaches of management are defined according to the site use (settled use or adapted/chosen use):

- Media quality assessment: make sure that the site environmental setting is compatible with current uses;
- Management plan: define actions to be implemented so that the site could be suitable for its future purposes. This procedure is performed when a classified installation closes its activity or when the interpretation of environmental conditions concludes that current uses are not compatible with media quality and that management measures should be implemented.

These two approaches can be independently, simultaneously or successively operated. For example, at the end of an environmental media quality assessment approach, and since simple management measures are not sufficient, a management plan will be necessary to restore the compatibility between the environmental settings (or environmental media quality) and uses (“suitable for use”). In another example, a management plan can lead to discover off-site pollutions (in a hydrological or aeolian down-gradient position). Consequently, an environmental media quality assessment approach will allow examining the compatibility between the current uses and the environmental setting.

For the two approaches, the first step in human health risk assessment is the on-site specific exposure conceptual model. This is a set of source-pathway-receptor scenarios showing human health exposure pathways at any impacted sources on and/or off-site.
4.1.2.1 Environmental Media Quality Assessment

The environmental media quality assessment is carried out when the uses are settled. It leads to appreciate the compatibility of each media according to its use. This approach which is based on measurement (and not modeling) consists on comparison of concentrations in exposition media with initial media quality when values exist, with local background values or with management legal values (excepted for soil for which no standard value was settled) (Fig. 1). For instance, for groundwater, to complete basic comparison between upstream and downstream, drinking water quality values can be used to appreciate contamination levels. For indoor air, guidance values are proposed by ANSES for some compounds like perchlorethylene. For others compounds in air, comparison can be done with OQAI data, which regroup concentrations currently measured in French houses. It allows identifying potential anomaly.

When there are no guidance values or references, as it can be the case for many compounds, and if degradation of environment is observed, a simplified risk management tool (Excel sheet) and/or a quantitative health risk assessment can be performed.

Fig. 1: Risk management criteria of Environmental Media Quality Assessment

- **Simplified risk management tool:**

When management legal value (from quality standard for drinking water, food, indoor air ...) and initial media quality measures do not exist, this simplified risk management tool allows, based on the different scenario and exposure pathway of the conceptual model, to give risk management interval for the judgment (see Table 1).
Different exposure pathways are studied in this calculation grid: soil ingestion, vapours inhalation (indoor or outdoor) as well as vegetable consumption. For each exposure pathway and each pollutant, and based on the environmental media quality characterization, this grid allow to calculate the oral and inhalation dose of pollutants (theoretical expositions). Then, individual excess risk for nonthreshold contaminants and hazard quotient for threshold contaminants are calculated. The hazard quotient is calculated, for threshold contaminants, as a ratio between an exposure daily intake (mg.kg$^{-1}$.j$^{-1}$) or an inhaled average concentration (mg.m$^{-3}$) and a toxicological reference value (mg.kg$^{-1}$.j$^{-1}$ or mg.m$^{-3}$). This last one is chosen following the circular 30/05/2006 DGS published by the French Ministry of Health. The individual excess risk is calculated, for non threshold contaminants, as a multiplication between an exposure daily intake (mg.kg$^{-1}$.j$^{-1}$) or an inhaled average concentration (mg.m$^{-3}$) and a toxicological reference value (mg.kg$^{-1}$ or mg.m$^{-3}$).

Following the Table 1, if the hazard quotient is between 0.2 and 5 or if the individual excess risk is between $10^{-4}$ and $10^{-6}$, further study is needed. A quantitative risk assessment can be performed to eliminate the doubt.

**Table 1:** Risk management intervals in environmental media quality assessment framework

<table>
<thead>
<tr>
<th>Risk management intervals</th>
<th>Results interpretation</th>
<th>Actions to lead</th>
<th>On environmental media quality</th>
<th>On the uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>For threshold contaminants</td>
<td>For nonthreshold contaminants</td>
<td>Environmental settings are compatible with the current settled uses</td>
<td>Insure that the pollution sources are handled *</td>
<td>Insure memory of environmental media quality</td>
</tr>
<tr>
<td>&lt; 0.2</td>
<td>&lt; $10^{-6}$</td>
<td>Environmental settings are compatible with the current settled uses</td>
<td>Simple remediation measures must be realized (containment, excavation of &quot;hot spot&quot;...)*</td>
<td>Restiction on the use can be performed to guarantee the compatibility between the use and environmental media quality</td>
</tr>
<tr>
<td>between 0.2 and 5</td>
<td>between $10^{-4}$ and $10^{-6}$</td>
<td>Further study is needed</td>
<td>Quantitative risk assessment can be performed</td>
<td></td>
</tr>
<tr>
<td>&gt; 5</td>
<td>&gt; $10^{-4}$</td>
<td>Environmental settings are not compatible with the current use of the site</td>
<td>A management plan has to be carried out</td>
<td></td>
</tr>
</tbody>
</table>

*For each case, the pollution sources have to be handled

**Quantitative health risk assessment**

A quantitative health risk assessment can be performed using additional parameters that those using in the calculation grid. Individual excess risk (for nonthreshold contaminants) and hazard quotient (for threshold contaminants) are calculated as the same way that in the IEM model/grid but the risk index are calculated using risk additivity for all compounds. The most critical value is retained. Either the hazard quotient is greater than 1 or if the individual excess risk is greater than $10^{-5}$, risks have to be considered as worrisome.
At the end of an environmental media quality assessment or a quantitative risk assessment, there are two types of actions:

- no action is needed for the site (environmental settings are compatible with the current use of the site), there are no restrictions to site use;
- actions are needed as environmental settings are not compatible with the current settled uses; adverse impacts were observed / predicted and simple remediation measures must be realized (simple remediation measures, containment measures…) otherwise, a management plan has to be carried out.

### 4.1.2.2 Management plan

Management plan similar to a remedial plan acts on the environmental media quality (action on pollution sources and/or their impact) as well as on the final use of the contaminated site (appropriate land development to reduce the exposure). Acceptable maximal concentrations are calculated and are the targets for the remediation of the management plan. Among the different choices on management option, a cost-effectiveness approach is performed to approve the management plan. When exposures cannot be entirely deleted with the management plan, a residual risks assessment has to be carried out. It leads to assessing risks due to the residual exposures which take into account all management actions and scenarios of future uses. Residual risks assessment aims to prove that the project is safe for people health. Restriction on the use of the contaminated Site, which is called public easement, can be performed.

### 4.1.3 Risk assessment tools used in France

In France, no recommendation is made, at the moment, on which models should be used to perform risk assessment. A project is currently running in France to develop a risk assessment tool, MODUL’ERS, which will be obligatory used. MODUL’ERS will be released for the first semester 2013. Guidance reports on methodology are available for Site visit and investigations in the appendices of 2007 Circular.

The following exposure pathways are currently studied in France: soil ingestion, water ingestion, dust and vapours inhalation as well as vegetable consumption. Dermal uptake pathway is no longer considered; as only very few specific toxicological reference value related to this pathway exist. Transposition from ingestion or inhalation toxicological reference value to dermal contact ones cannot be performed (circular 30/05/2006 DGS) but dermal contact is not considered as a main way of exposure for the general population. Note that only chronic exposures are considered in part of contaminated sites management.

Regarding to the vapours transfer and the specific case of chlorinated solvent, both VOLASOIL and Johnson and Ettinger equations (through a free Excel sheet with its user’s guide published by US-EPA), respectively a Dutch and an American model, are commonly used for human health risk assessment in France. VOLASOIL model is used for infinite pollution source (for transfer through crawl space, basement and slab-on-grade), for mono-layer and multi-layer soil (Hazebrouck et al. 2005), whereas Johnson and Ettinger model is used for both infinite and finite source for a multi-layer soil (initially for a slab-on-grade scenario).
4.2 Site management and risk assessment tools in The Netherlands

The main Dutch actors in defining the risk assessment framework and its specific tools and guidelines are the RIVM (National Institute for Public Health and the Environment) and the Dutch Ministry of Environment (VROM).

Swartjes et al. (2012) introduced the policy framework of contaminated site management in The Netherlands and the corresponding risk assessment tools. This publication was used in this chapter.

4.2.1 Contaminated sites management: history, innovations and legal framework

The Netherlands was among the earliest countries in the world to develop a policy for contaminated land management. In 1983, the Interim Soil Remediation Act was published by the Dutch government. This act included the first generation of SQSs (Soil Quality Standards namely the A, B and C Values), based on background concentrations and expert judgement. In 1987, the Soil Protection Act was introduced (Ministry of VROM, 2006). This act aimed mainly to establish the accountability of individuals, which means that parties are fully liable for each case of soil contamination created since 1987. The first series of risk-based Soil and Groundwater Quality Standards and the methodology to determine the urgency of remediation were formalized in a Ministerial Circular in 1994.

The legislation was extended in subsequent years based on scientific evaluations. A major evaluation and update of the first series of SQSs was concluded in 2001 (Lijzen et al., 2001; Otte et al., 2001; Rikken et al., 2001; Baars et al., 2001; Verbruggen et al., 2001).

Originally, the policy aimed towards multifunctionality of soil after remediation. The principle appeared to be too expensive and, from a risk assessment perspective, unnecessary. The ‘multifunctional’ approach was replaced by a ‘fitness-for-use’ approach.

A more recent piece of legislation is the Soil Quality Decree of 2008, in which sustainable soil management was introduced. This decree offers a balance between the protection of human health and the environment, and the opportunity to reuse (slightly) contaminated soil material for use as secondary building materials, to address economic and social developments and to judge the application of dredged sediment on land. The basic principles of this decree are the ‘stand still principle’ and the principle of ‘fitness for use’. The latest update of the framework for assessment of historically contaminated sites, including the revised SQSs, was published in 2009 (Ministry of VROM, 2009).
4.2.2 Management of contaminated sites

The Dutch Soil protection Act focuses both on prevention of new cases of soil contamination and on dealing with historically contaminated land.

In 2009, 258,000 potential sites, which are highly contaminated, are thus considered candidates for remediation (Swartjes et al., 2012).

The ministerial circular on soil remediation described the framework of contaminated sites management. According to this procedure, measured concentrations in soil and groundwater are compared with generic SQSs (human health based Soil Quality Standard): “Background Values” (for soil) or “Target Value” (for groundwater) and the “Intervention Values” (for soil and groundwater). The result of this comparison allowed classifying the site into “clean soil”, “slightly contaminated soil” or “seriously contaminated soil” (see. Fig. 2: “The contaminated sites management framework in The Netherlands”).

A serious soil contamination is defined as a volume of soil (unsaturated upper soil layer) of at least 25 m$^3$ showing concentrations above the Intervention Value (Swartjes et al., 2012). A serious case of groundwater contamination is defined as a volume of groundwater-satured soil (satured zone) of at least 100 m$^3$ that is contaminated at levels exceeding the Intervention Value (Swartjes et al., 2012).

**Fig. 2:** The contaminated sites management framework in The Netherlands: Background values are used for the unsaturated soil compartment (‘soil’); target Values are used for the saturated soil (‘groundwater’) compartment (Swartjes et al., 2012).

The Background Values are based on a nationwide investigation of relatively undisturbed soils in agricultural areas and natural areas randomly distributed over The Netherlands. They are considered as “no risk”. The “Intervention Values” for soil are based on both human health and ecotoxicological risks.

4.2.2.1 Sustainable soil management

A sustainable land management was developed to deal with the large areas classified as slightly contaminated site. In relation with the land uses, National Maximal Values, based on risks for human health, the ecosystem and agricultural production, were introduced:

- Maximal value for residential land use (MVresidential);
- Maximal value for industrial land use (MVindustrial).
They are used to manage the off-site reuse of soil material after transport and to set land use-specific remediation objectives for soil in case of soil remediation. Regarding these maximal values, four quality classes of contaminated site, related to the land use categories, are defined (see. Fig. 3): soils ‘always suitable’, ‘suitable for residential land use’, ‘suitable for industrial land use’ and ‘not applicable’.

Local maximal values can be used by the local authorities, for example, if the local natural background concentrations are higher than the national level or in case of diffuse contamination.

### 4.2.2.2 Urgency of remediation (for serious soil contamination)

The determination of the urgency of remediation consists of a three-step, tiered approach:

- **TIER 1** (describe above): soil and groundwater concentration measurement, these concentrations are compared with generic SQSs for soil and groundwater (in order to determine the class of contamination: clean, slightly or seriously contaminated site). The site-specific risks have to be assessed in case of serious soil contamination (TIER 2);
- **TIER 2**: A standard site-specific risk assessment for human health, the ecosystem and groundwater is conducted related to the specific land use;
- **TIER 3**: If the result of the tier 2 is not satisfactory, a detailed site-specific risk assessment has to be carried out (Tier 3 is often needed in case of complex sites, complex groundwater systems and/or contamination patterns).

Whether this procedure leads to ‘acceptable risks’, control measures can be taken to reduce or eliminate exposure. In case of ‘unacceptable risks’, a remediation plan has to be carried out and submit to the competent authorities. The remediation goals are different between mobile and immobile contaminants. Indeed, for immobile contaminants, the remediation should result in a soil quality that is fit for use whereas for mobile contaminants the remediation goal is to remove human health risks and reduce other risks in a cost-effective way.
Site specific risk assessment

The ratio between the site-specific exposure and the Critical Exposure Value (CEV), called the Risk Index (RI) allows to conclude on the site specific human health risk assessment (RI≤1: acceptable human health risk or RI>1: unacceptable human health risk).

- Groundwater-related risk assessment

For standard site-specific risk assessment (Tier 2), urgent remediation is needed if the following elements are met:

- A Light or Dense Non-Aqueous Phase Liquid (LNAPL or DNAPL);
- A nearby sensitive resources, like water catchment areas or ecologically important surface waters;
- Volume of water-satured soil with a concentration above the Intervention Value that exceeds 6000 m$^3$.

The detailed site-specific risk assessment (Tier 3) requires more site-specific data. There is no urgency for remediation of the groundwater contamination when the increase in volume of groundwater, in which the Intervention Value exceeded, is lower than 1000 m$^3$y$^{-1}$.

4.2.3 Risk assessment tools used in The Netherlands

CSOIL model and for the specific context of chlorinated solvent in urban areas the VOLASOIL model are used.

The CSOIL exposure model (for the latest update, Brand et al., 2007) was developed in the Netherlands by the RIVM and used to derive Soil Quality Standards. A commercial version is available as a Risk-Human model which allows the user to perform Site-specific risk assessments.

The model is a static and analytic model, which assumes a balanced situation between all compartments (solid, gas and liquid).

Three elements are taken into account in exposure models:

- Contaminant distribution over the soil phases;
- Contaminant transfer from the soil into contact media; and
- Direct and indirect exposure to humans.

The major exposure pathways which contribute to total human exposure are soil ingestion, vegetable consumption, inhalation of indoor air and soil particles and dermal uptake pathways (e.g. shower exposure). Risk-Human model takes into account all of these exposure pathways for soil and groundwater but also the inhalation of outdoor air and the direct human contact with contaminated groundwater (See appendix).

Regarding the inhalation of indoor air pathway, the VOLASOIL model (Waitz et al., 1996, Bakker et al., 2008) includes the calculation of the concentration in soil gas:

- at the depth of contamination,
- of contaminant transport to a crawl space by diffusion and convection,
- of the concentration in the crawl space air,
- of transport from the crawl space into indoor air and,
- of the concentration in indoor air.

The air permeability and porosity of the soil and building floor, the average air pressure differences between soil and crawl space, the depth of the groundwater table, the water
solubility of a contaminant and the ventilation rate (Bakker et al., 2008) are the most important parameters used under Dutch conditions. Note that the most used model in the Netherlands considers a crawl space in the building as a default parameter. Nevertheless, in the second version of VOLASOIL (Bakker et al., 2008) three foundation types (Slab-on-grade floor, concrete basement and crawl space) were added.

The dose-response assessment, which results in the Critical Exposure Value (CEV) for a contaminant, is included in the hazard assessment. CEV are compared to the exposure (generic or site-specific), as obtained using CSOIL for various scenarios, possibly in combination with measurements in contact media. The CEV covers various chronic limit values, i.e. those for the oral route (Tolerable Daily Intake (TDI) or for non-threshold genotoxic carcinogenic chemicals, the $10^{-4}$/lifetime Cancer Risk ($CR_{oral}$)) as well as the inhalation route (Tolerable Concentration in Air ($CR_{inhal}$) or for non-threshold genotoxic carcinogenic chemicals, the $10^{-4}$/lifetime Cancer Risk ($CR_{inhal}$)).
4.3 Site management and risk assessment tools in Belgium (Flanders)

In Belgium, the environmental legal framework and consequently the contaminated soil management, is managed differently in regards to the three regions (Flanders, Wallonia and Brussels Region). Only the legal framework in Flanders will be depicted in this report. OVAM stands for Openbare Afvalstoffenmaatschappij voor het Vlaams Gewest (Public Waste Agency of Flanders) and is responsible for waste management and soil remediation in Flanders.

4.3.1 Contaminated sites management: history, innovations and legal framework

In 2006, the Flemish government ratified the Decree for soil remediation and soil protection. This new Soil Decree replaced the Decree of 1995. The main objectives are to prevent new contamination and remediate historical contamination.

The Soil Decree contains some key-issues which reveal ways to handle soil contamination:
- the ground information register and the possibility to request a soil certificate, an extract of this register;
- the difference between historical and new/current soil pollution; and
- the difference between obligation and liability for remediation.

4.3.2 Management of contaminated sites

Distinction between “historical” and “new” contamination is made. Historical contaminations are defined by the contamination originated before the first Decree (29th October 1995). On the contrary, the “new” soil contamination originates after this Decree came into force.

According to the Decree, remediation of a new pollution is required as soon as the soil remediation values are exceeded. With respect to historical contamination, the decision to remediate will depend on the current hazard to humans and the environment (non quantified general criteria). Consequently, a risk-assessment approach is realised after the descriptive soil investigation. But the first step of the contaminated site management consists in soil investigation.

In Flanders, the decree on soil remediation gives two different screening values for some contaminants:
- Background value: reflected the normal values found in unpolluted soils. They correspond with the 90-percentile of concentrations measured in Flemish top soils for metals and metalloids. For most organic contaminants, the background level equals the limit of detection, except if they show diffuse enrichment and in that case, the 90-percentile of measured value is used.
- Soil clean-up standards (risk based approach): above this value, contamination could cause significant harmful effects for human health and environment, soil properties and soil function are taken into account. Five land use classes (nature, agriculture, residences, recreation and industry) with pre-defined exposure scenarios (e.g. inhalation of vapours, consumption of vegetable...) are used to derive the soil clean-up standards.
Critical values for concentration in soil are calculated based on human toxicology and on ecotoxicology. The most critical value is retained as soil remediation standard. Vlier-Humaan risk assessment model is used to derive soil remediation standards (see 3.3.3).

**Soil investigation: exploratory and descriptive soil survey**

As part of a property transfer or on a periodical basis or following a closure of certain installations which can or could damage soil, there is an obligation of soil investigation. The exploratory investigations include limited investigation (historical study, as well as restricted sampling operations).

If these investigations show the presence of contaminants, the need for further soil investigation depends on comparison of concentrations with soil clean-up standards. During a descriptive soil investigation the contamination will be characterized in detail and the risk for humans and ecosystems will be defined. The aim of this investigation is to give a description of the nature, quantity, concentration and origin of the contaminants, the possibility that these might spread, and the hazard that human beings, plants and animals, as well as surface and groundwater, might be exposed to.

**Site specific risk assessment**

Risk assessments must be conducted for the current use and for any potential future uses. The methodology for Site specific risk assessment is based on the approach followed to derive soil remediation standards and leads to screening values.

**Derivation of screening values**

Exposure of the population on the Site is calculated for each compound and expressed as an external dose, except for the dermal contact for which the absorbed dose is calculated.

Background exposure is added to the calculated exposure from the Site. This total exposure is divided by the tolerable daily intake (TDI) in case of non-carcinogenic effects and results in a risk index (RI). Children and adults are considered separately. If the RI of adults or children is greater than 1, serious threats have to be considered.

For carcinogenic effects, a lifetime exposure is calculated and divided by the dose corresponding with an additional cancer risk over a lifetime of $10^{-5}$ exposed persons.

Calculated concentrations should not exceed legal or toxicological values (e.g. maximal levels in food agriculture, in indoor air, drinking water limits).

**Groundwater screening values**

Background values are derived from levels found in unpolluted groundwater. For metals and metalloids, background values correspond to the natural levels, whereas laboratory limits detection values are taken as background level for organic contaminants.

Soil remediation standards for groundwater refer to drinking water quality for the threshold contaminants; they are derived from a toxicological basis or by WHO methodology (a fraction of TDI to drinking water is assigned) if no legal limits are available. For nonthreshold contaminants, excess lifetime cancer risks of $10^{-5}$ are taken.

Risk for spreading must also take into account the transport by air and towards surface water.
Remedial operations

The remediation actions are detailed and prescribed in a soil remediation study. The Public Flemish Waste Agency (OVAM) supervises the remediation operations. An approval expert in soil remediation follows operations and draws up a report and a final evaluation to OVAM which delivers a final declaration of soil remediation project. Restriction on uses can be performed if risks on the human health remain.

4.3.3 Risk assessment tools used in Belgium (Flanders)

Vlier-Humaan risk assessment model is used to derive soil remediation standards and to perform site specific human health risk assessment. This model is similar to the HESP and C-SOIL concept, but accounts for the typical Flemish conditions and policy decision. Other models can be used, but need a validation by OVAM.

The Vlier-Humaan model used is a static and analytic model, which assumes a balanced situation between all compartments (solid, gas and liquid). Preservation of mass is assumed: the total amount of substance in the soil remains constant; there is no depletion (infinite source). Disappearing of the substance through leaching, evaporation or breakdown is not taken into account.

In case of volatile compounds, the model calculates a dose and an indoor air concentration due to the presence of contaminants in soil or groundwater and compares the dose and indoor concentration with a tolerable daily intake and a tolerable concentration in air, respectively. It only includes diffusive vapor transport in soil and in concrete. Building foundations that can be considered include slab-on-grade floor, concrete basement and crawl space.

Like Risk-Human model, the Vlier-Humaan model takes into account soil ingestion, vegetable consumption, inhalation of indoor and outdoor air and soil particles and dermal uptake pathways (See appendix).
4.4 Site management and risk assessment tools in Germany

4.4.1 Contaminated sites management: history, innovations and legal framework

**Legal framework**

The management of contaminated land and groundwater requested a federal law. In 1999, the Federal Government of Germany put into force the Federal Soil Protection Act and the Federal Soil Protection and Contaminated Sites Ordinance (Bundes-Bodenschutz- und Altlastenverordnung or BBodSchV), which established nationally standardized regulations for the registration and remediation of contaminated sites.

In the German Soil Protection Act, contaminated sites are closed waste recycling, disposal facilities (old deposits) and sites of closed facilities, as well as areas where environmentally hazardous substances have been handled (abandoned industrial sites) that cause harmful changes to the soil or other hazards for individuals or the general population.

The protection of the soil against harmful impacts on its functions, the prevention of soil contamination and the regulation of the abandoned contaminated sites remediation are the most important objectives of the Act. According to the Federal Soil Protection Act, harmful impacts on soil functions are defined as hazards implicating considerable disadvantages or nuisances for individuals or the general public. The Federal Soil Protection and Contaminated Sites Ordinance specifies requirement in respect of site investigation, sampling strategy and laboratory approach, evaluation and remediation.

According to the groundwater Ordinance, groundwater can be classified as uncontaminated if the concentration values meet the “insignificance threshold”, which means they meet the following conditions:

- no relevant ecotoxicological effects occur, and if
- the demands of Drinking Water Ordinance or values derived accordingly are met.

The insignificance thresholds are primarily used to assess the groundwater quality. The aim is not intended to set a quality goal for groundwater, but rather that a groundwater status be maintained that is largely unaffected by human activity.

**History and innovations**

Before the federal law, several inequalities were observed on the contaminated land remediation by the use of generic threshold lists for the different Germany’s Länder (regions). Indeed, a factor of 13 for children playground (Bachman, 1993) until 150 for others standards (Viereck-Götte et Ewers, 1994) was observed between the thresholds values of the different Länder’s lists. The main German lists were based on the background value in soil as a reference threshold value and on risk assessment declined by the land use for the “action values”. But only soil ingestion pathway or, in some Länder, few exposition pathways like consumption of food cultivated on contaminated land were considered.

Only generic standards were listed and used to decide opportunity and objective of remediation. As a consequence, the main remediation option was focused on soil decontamination whereas, from risk assessment perspective, it was unnecessary. Economical impacts of these decisions were high, more particularly on the new coming Länder (Rippen, 1994a, 1994b).
In 2000, more than 360,000 sites suspected to be contaminated were registered in Germany (ICSS, 2004). A stepwise risk assessment procedure was performed to filter out the sites where there is urgent call for action because of their risks for humans and environment. At the beginning, the main remediation strategy was to focus on soil remediation, but nowadays the approaches move to a broader concept. Indeed, land remediation not only involves clean-up of soil and groundwater but include the whole process of land development for its reuse.

### 4.4.2 Management of contaminated sites

The main principle of risk assessment and handling suspected contaminating sites in Germany is the graduated examination and evaluation strategy. In general, risk assessment is carried out case by case and decisions depend on the kind of land use as well as on pollution extension, on the relevant targets and exposure pathways.

According to the Act on soil protection, the site investigation ought to be carried out step by step (see fig. 4), guaranteeing a cost effective and comparable evaluation of sites. At each step, a higher level of knowledge allows selecting sites with low or no risks which can be excluded from the further investigation and the sites where acute hazards are identified and where immediate measures have to be taken.

#### Historical investigation

The first step consists in a historical study. All available data about the former industrial sector, the technologies implemented or wastes released through the manufacturing processes are collected. Such information may be found, for example, in manufacturing files, archives, documents of environmental authorities, state land registers and local chronicles or by interviewing population. At this step, no technical or chemical investigations are performed but a site visit has to be carried out.

#### Orientating investigation

On historical study basis and if contamination is suspected, an orientating investigation is triggered. First measurements and soil samples are taken to assess the hazard for the relevant transport pathways and the resources to be protected.

**Fig. 4:** Management of contaminated sites (ICSS, 2004)
Soil remediation standard

For some contaminants, the Act on soil protection provides three categories of soil screening value:

- "action levels": indicating as a rule a hazard which has to be warded off; further investigations to ascertain the hazard are usually not necessary;
- "trigger levels": triggering further investigations to ascertain whether the pollution of the soil implies hazard;
- "precaution levels": indicating a certain chance of future soil problems which need to be addressed in order to avert upcoming damages.

The action levels and the trigger levels are listed in the regulation act and are related to the use of the Site (playgrounds, residential areas, park and recreational facilities, land used for industrial and commercial purposes) and are generic risk based.

The figure 5 shows the contaminated sites management framework in Germany.

If action level is exceeded, remedial actions are necessary. If the trigger value is exceeded, further investigations are required to determine whether the site is contaminated and whether measures are necessary. If the measured contaminants are lower than the trigger values, a risk for human health and the environment can be excluded. The trigger values are based on toxicological data, exposure models and substance-specific considerations. The orientating investigation leads to an expert opinion including a hazard assessment and recommendations for further action.

- Detailed investigation

If the orientating investigation has confirmed the suspected contamination, a detailed investigation is initiated. A final hazard assessment and the setting of criteria for the choice of which treatment have to be used, are performed. In general, data are required relating to the contamination source, the pathways of spreading of the harmful substances and the resources to be protected. A remedial plan is proposed based on the results of this detailed investigation. The optimum remediation technology for the site and the target values of the remediation have to be applied.

- Remediation investigations and remediation plan

Remediation investigations aim to identify the measures that are suitable, necessary and appropriate.

There are three major options for the elimination/reduction of hazards:

1. **Decontamination measures**: The source of contamination or the contaminated material is eliminated or reduced;
2. **Securing/containment measures**: Prevention/reduction of spreading of the contaminants;
3. **Protection and restriction measures**: other measures to prevent or reduce hazards.
The remediation investigation study is conducted using available data (results of investigation studies). Additional investigations can be carried out if these informations are not sufficient, especially for allowing a reliable delimitation of polluted areas or for assessing the suitability of remediation methods.

The remediation plan has to contain the statement of the initial situation, a description of the measures to be carried out and provision of proof of their suitability, a description of the internal control measures to check the correct execution and effectiveness of the planned measures, a description of the internal control measures within the scope of aftercare including monitoring and to conclude a description of time schedule and costs.

4.4.3 Risk assessment tools used in Germany: UMS model

The initial development of a risk assessment model so called “UMS” (Umwelt (Environment), Mensch (Human), Schadstoff (pollutant)) was developed for a site specific risk assessment in the detail investigation phase. However UMS was not integrated in the regulation frame. The UMS-System is not really used in practice.

UMS quantifies the actual or potential exposure relevant for human health, based on physical chemical and toxicological data, site specific characteristics and population behavior. There are nine scenarios: playground areas, public areas, parks and green areas, gardens, living buildings, industry, sport areas, business areas and wells. This model describes the release and the distribution of contaminants in the environment as well as the exposure frequency, intakes rates, absorption and bioavailability of contaminants for the different exposure groups. Five exposure groups can be used for calculation: babies, small children, young people and adults. Removal processes (photolysis, volatilization, biodegradation) is not taking into account in the UMS model. The oral, inhalation, crop consumption and dermal exposure pathways can be used in UMS.

The model calculates a risk index, which is in turn used to calculate a risk value. Three ranges of risk value (table 2) are specified to determine whether action is required on the Site. Groundwater cannot be modeled as a receptor within the UMS module. However, there is a second module, which may be used in conjunction with UMS.

**Table 2: Risk management in Germany**

<table>
<thead>
<tr>
<th>Balance with background pollution BER=TRV/TBRV</th>
<th>BER&gt;1.1</th>
<th>BER&lt;1.1</th>
<th>Colour code</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV&lt;=1</td>
<td>Neglected brownfield risk</td>
<td>Relevant risk is deducible only from background pollution</td>
<td>Green</td>
</tr>
<tr>
<td>1&lt;RV&lt;10</td>
<td>A brownfield risk is not to be definitely excluded</td>
<td>The not excluded brownfield risk can be raised due to the existing background pollution</td>
<td>Yellow</td>
</tr>
<tr>
<td>RV&gt;=10</td>
<td>A significant brownfield risk is present</td>
<td>The significant brownfield risk can be further raised due to the existing background pollution</td>
<td>red</td>
</tr>
</tbody>
</table>

RV : Risk value ;
5 Case of Chlorinated solvents in urban areas

5.1 Conceptual model

Chlorinated solvents do not occur naturally and are only present in the environment as a consequence of anthropogenic activities (industrial, military or domestic uses). Chlorinated solvents have been used by industry since the early 20th century for a variety of purposes, including metal degreasing, as dry cleaning agents and in the manufacture of plastics and consumer products, such as propellant aerosols and paints.

Pollution by chlorinated solvents is in many cases caused by small-scale activities as dry-cleaners, garages and metal-using industry, which generated multiple contaminant sources for widespread groundwater pollution in urban areas.

Due to their physicochemical properties they produce large scale plumes of pollution in the groundwater (vertical infiltration and horizontal spreading of solvents). In the densely populated Northwestern-Europe, these plumes are located under residential and urban development areas and therefore difficultly accessible.

The fig. 6 represents a general conceptual model for the problematic of chlorinated solvents in urban areas. It allows to identify the different targets (population exposed), transfer and exposure pathways.

![Fig. 6: Human risk conceptual model](image)

The source can be detected in soils, above the saturated zone (e.g., non aqueous phase liquid (NAPL) floating on the water table or disseminated within the capillary fringe) or in the saturated zone (e.g., a soluble groundwater plume) (McAlary et al. 2011).

Exposure pathways might be inhalation of contaminated indoor or outdoor air (1), drinking water consumption (2) (contamination through pipes or direct groundwater consumption),
food consumption (3) via vegetables, oral intake of soil by children and adults (e.g. gardener) (4) and dermal contact from water and vapors in a shower (5).

However, due to the high volatility of these chemicals and the urban context, soil vapour migration into house (1), with subsequent inhalation, is often the main exposure pathway to humans. Many mechanisms lead to transfer vapours from underground to the surface soil layer and then from the surface soil to indoor and outdoor air. Models can provide at best an estimate of indoor air concentrations within an order of magnitude of measured values (Bradley, Patterson and Davis, 2009). The model accuracy is often reasonable. Indeed, one order of magnitude variability can also be observed in measured indoor air concentrations using 24-h samples (Kuehster et al. 2004).

As a result of the second part of this report, the different partner’s intrusion models and parameters taken into account in these models are listed in the following table (Table 3). For all models, source and depth contamination, soil moisture content, building ventilation rate are the parameters that most influence the predicted indoor air concentration (McAlary et al. 2011).

Table 3: Overview of vapor intrusion models used by the Citychlor partners (McAlary et al. 2011)

<table>
<thead>
<tr>
<th>Compartment/floor</th>
<th>CSOIL</th>
<th>Vlier-Humaan</th>
<th>Johnson et Ettinger model</th>
<th>VOLASOIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>slab-on-grade</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>concrete basement</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>crawl space</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transport</th>
<th></th>
<th>X</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>diffusive</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>diffusive plus convective</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th></th>
<th>X</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vadose zone</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>soil gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application</th>
<th></th>
<th>X</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site specific assessments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>derivation of screening levels</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The **CSOIL exposure model** (under the commercial version Risk-Human) includes only diffusive vapour transport. It calculates the indoor air concentration for a typical Dutch dwelling with a crawl space as a result of vapour intrusion from the groundwater or the vadose zone contamination. In some situations e.g. if a concrete basement, slab-on-grade or pure product is present, the CSoIL model was not sufficient (Huijsmans and Wezenbeek, 1995). In the mid-1990s the **VOLASOIL model** (Waitz et al., 1996) was developed by the RIVM including both diffusive transport and convective transport in soil. In the second version of VOLASOIL, three foundation types (Slab-on-grade floor, concrete basement and crawl space) were added (Bakker et al, 2008).
The Vlier-Humaan model, used in Flanders, takes into account only diffusive vapour transport and the following buildings foundations: slab-on-grade floor, concrete basement and crawl space.

The Johnson&Ettinger (1991) model (J&E Model) is a screening-level model that considers one-dimensional upward diffusion from a subsurface source through the water-unsaturated zone, convective flow into the building through a foundation crack due to underpressurization, and dilution in the building due to ventilation (McAlary et al. 2011). A user’s guide was published in 2004 (US EPA, 2004); this manual provides documentation and instructions for using the vapour intrusion model. In specific circumstances, it may not be applicable. Indeed, preferential pathways, fractured subsurface media or other processes that may be important are not taking into account.

A comparison of models used in the different countries has been performed on the NICOLE/ISG report (Geraghty and Miller Internation Inc., 2004) and are presented in the next paragraph. Capabilities of risk model are summarized in appendix.

5.2 Comparison of the Citychlor partners models

The NICOLE/ISG comparison study (Geraghty and Miller Internation Inc., 2004) was used for this part. The aim of this study was to critically appraise the human health risk assessment models/systems commonly used in the different european countries. It is focused on site-specific human health risk assessment. The comparison of risk assessment systems was performed in four phases:

- **Phase I**: identification of the risk assessment “systems” in European countries;
- **Phase II**: Pro-forma screening of systems to evaluate capabilities;
- **Phase III**: Use of hypothetical generic test site data set to produce comparable results;
- **Phase IV**: Use of 5 case study test sites to evaluate scenarios in non-idealised situations.

The last phase and more specifically the case study test site 4 (active chemical manufacturing site) allow to compare the different partners systems (Risc-Human, UMS, Vlier-Humaan, RCBA and RISC).

**Test Site’s description**

This test site comprises an active agro-chemicals production site. The site is located on the banks of a major river. Shallow and deep soil sources have been identified, impacted by tetrachloroethene (PCE), trichloroethene (TCE) and lindane (γ-HCH – gamma-Hexachlorocyclohexane). A dissolved plume of CVOCs extends over a lateral area of approximately 14,000m². Groundwater is encountered at approximately 9 m below ground level.

The test site allows comparison of direct contact pathways for commercial workers (dermal uptake and ingestion); firstly with the shallow soil source and secondly via the inhalation of indoor air impacted by vapors originating from the deep soil source.

It should note that only Risc-human has the capability to model a commercial worker receptor. In this case study, chemical properties and exposure parameters default values were used.

**Results and discussion**

The predicted receptor point concentrations in indoor air from a deep soil source are reported for all three contaminants of concern. Dose concentrations are presented for soil ingestion, dermal contact with soil and inhalation of indoor air.
Receptor point concentrations:
- Concentrations of all contaminants of concern in indoor air predicted by UMS are greater than those predicted by any of the other models.
- RBCA, RISC and Risc-Human predict results that are more similar for Lindane, than for TCE and PCE. This finding is explained by similarities and differences in the chemical properties of Lindane, TCE and PCE between models. Model defaults were generally retained for chemical properties, however, as a less common contaminant Lindane was not present in all of the databases, in this case, the properties of Lindane were taken from Risc-Human.
- Vlier-Humaan predicts lower concentrations than Risc-Human (difference in the definition of building parameters in Vlier-Humaan: the footprint of the building is hard-wired to be smaller than that in Risc-Human but the height is an input parameter, resulting in smaller indoor air concentrations).

Doses concentration:
Only the inhalation of indoor air dose will be described in this report.
- The dose predicted by the UMS system is higher than in others partners systems.
- Risc-Human predicts a greater dose than RISC (it is probably explained by the use of default exposure data).
- In the contrary, Vlier-Humaan predicts lower doses than Risc-Human.

For this test site, the predicted doses concentrations for soil, vegetable ingestion are similar. For dermal contact and indoor air exposures, predicted doses varied over two and three orders of magnitude, respectively. Groundwater migration models produced generally similar results.

Large difference in the predicted doses were pointed out when models default exposure parameters were used for the different test sites. When parameters are unknown, the use of default data can impact significantly the conclusions in a site’s risk management. The choice of parameters have to be justified and need to be in coherence with the specific Site. Evaluator experience is essential to identify the uncertainties and reduce them as far as possible.
6 Conclusion

In general, it was observed that a consensus on the methodology exists between the different partner countries. Indeed the management of contaminated sites is based on the same HHRA concept following the current or future use of the Site.

**Soil quality standards**

HHRA have many objectives whose the derivation of soil quality standards. They are based on exposure and toxicological modeling.

Soil Screening Values are generic quality standards adopted in many countries to regulate the management of contaminated land. They are usually within the form of concentration thresholds (mg.kg$^{-1}$ soil-dry weight) of contaminants in soil above which certain actions are recommended or enforced. The implications of exceeding this soil standard value vary according to national regulatory frameworks. They range from the need for further investigations to the need for remedial actions. Different names are met for these soil screening values, namely trigger values, reference values, target values, intervention values, clean up values, etc... The derived soil quality standard for Flanders, France, Germany and The Netherlands are presented in the table 4.

**Table 4:** Type of screening values and site specific risk assessment (RA) for each partner

<table>
<thead>
<tr>
<th>Countries</th>
<th>Negligible risk</th>
<th>Intermediate risk</th>
<th>Unacceptable risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Screening RA</td>
<td>Screening RA</td>
<td>Screening RA</td>
</tr>
<tr>
<td><strong>The Netherlands</strong></td>
<td>Target Value (long term objectives) or background value</td>
<td>Intervention values</td>
<td>Define urgency of remediation</td>
</tr>
<tr>
<td><strong>Belgium (Flanders)</strong></td>
<td>Background First target for remediation</td>
<td>Further investigation (for historical contaminants only)</td>
<td>Clean-up standards (for new contaminants only)</td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td>Trigger values</td>
<td>Action levels (in principle to be remediated)</td>
<td>Define the need for remediation and target</td>
</tr>
<tr>
<td><strong>France</strong></td>
<td>Background value, initial media quality (baseline concentration), management threshold (when available)</td>
<td></td>
<td>Acceptable maximal concentrations</td>
</tr>
</tbody>
</table>

Since 2007, in France, there are no longer soil standard. The concentration has to be compared with the initial media quality if available or with the local background values around the Site, and with the legal tresholds available for food and drinking water. In the case of Site
specific risk assessment, acceptable maximal concentrations have to be calculated, these values correspond to the remediation objectives.

In The Netherlands, background value (for soil) or target value (for groundwater) are given in the legal framework. Above these values, Site is considered as slightly contaminated. There is intervention values for seriously contaminated and site specific risk assessment has to be performed to define urgency of remediation.

In Flanders, difference between the historical and new contamination is made. The first target for remediation is the background value. Then for historical contamination only, beyond an intermediate value, further investigation is needed. Clean-up standards for new contamination only are given. The site specific risk assessment is used for historic pollution to identify the need of remediation.

And to conclude, in Germany two types of screening value are met, trigger value beyond further investigation is needed and actions levels. The site specific risk assessment is used to define the need for remediation and target.

**Risk assessment tools**

Each partner develops or uses different models. In the context of chlorinated solvents, the main route exposure is the inhalation of contaminated indoor air in buildings (dwellings, offices, schools...).

The NICOLE’s report concluded that in the generic test site, the predicted doses for soil, vegetable ingestion are similar. For dermal contact and indoor air exposures, predicted doses varying over two and three orders of magnitude, respectively. Groundwater migration models produced generally similar results.

Large difference in the predicted doses concentrations were pointed out when models default exposure parameters were used for the different test sites. When parameters are unknown, the use of default data can impact significantly the conclusions in a site’s risk management. This means that a good characterization of the contaminated zone is necessary and that the experience of the assessor in charge with the risk assessment is highly important to identify sensitive parameters used as input parameters in models and to assess uncertainties linked to these parameters. The assessor has to know all the advantages and limits of models used for his risk assessment.
7 Bibliography


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Circulaire du 8 février 2007 relative aux installations classées - Prévention de la pollution des sols - Gestion des sols pollués

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Loi n°75-633 du 15 juillet 1975 relative à l’élimination des déchets et à la récupération des matériaux

Loi n° 75-633 du 15 juillet 1975 relative à l’élimination des déchets et à la récupération des matériaux

The Netherland regulation


German regulation


Decree for soil remediation and soil protection (2006)
**Summary of risk system Capabilities (1/2) (NICOLE report (2004))**

<table>
<thead>
<tr>
<th>Model</th>
<th>Soil models</th>
<th>Groundwater models</th>
<th>Vapour transport models</th>
<th>Air mixing models</th>
<th>Surface water mixing models</th>
<th>Presence of NAPL</th>
<th>Probabilistic capability</th>
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</thead>
<tbody>
<tr>
<td>RBCA Toolkit (commercial)</td>
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</table>

**Soil Models** – Risk System models contamination from a soil source  
**Groundwater Models** – Risk System models contamination from a groundwater source  
**Vapor Transport Models** – Risk System considers transport of vapor within the risk system  
**Air mixing Models** - Risk System considers air mixing within the risk system  
**Surface water mixing models** - Risk System considers mixing of surface waters within the risk system  
**Presence of NAPL** - Risk System considers the presence of low and high density free phase product (model dependant)  
**Probabilistic capability** - Risk System allows the use of stochastic input concentrations and exposures parameters giving a resultant, statically evaluated risk.

**Summary of risk system Capabilities (2/2) (NICOLE report (2004))**
## Exposure Assessment Models:

<table>
<thead>
<tr>
<th>Model</th>
<th>Soil (Direct Contact)</th>
<th>Soil (Vegetable Uptake)</th>
<th>Soil (Inhalation of Particulates)</th>
<th>Inhalation indoor air</th>
<th>Inhalation outdoor air</th>
<th>Groundwater (Direct Contact)</th>
<th>Groundwater (Vegetable Uptake)</th>
<th>Groundwater (Shower model)</th>
<th>Groundwater (Irrigation model)</th>
<th>Surface Water</th>
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</table>

**Exposure Assessment Models:**

- **Soil (Direct Contact)** – Direct human contact with contaminated soil
- **Soil (Vegetable Uptake)** – Uptake of contaminants into vegetable grown on contaminated soil
- **Soil (Inhalation of Particulates)** – Human inhalation of contaminated soil particulates
- **Inhalation of Indoor Air** – Human inhalation of vapors in indoor air. Where the Risk System considers soil models vapor transport from soil to air is a pathway and/or where the Risk System considers groundwater models vapor transport from groundwater to air is a pathway
- **Inhalation of Outdoor Air** – Human inhalation of vapors in outdoor air. Where the Risk System considers soil models vapor transport from soil to air is a pathway and/or where the Risk System considers groundwater models vapor transport from groundwater to air is a pathway
- **Groundwater (Direct Contact)** – Direct human contact with contaminated groundwater
- **Groundwater (Vegetable Uptake)** – Uptake of contaminants into vegetable grown on contaminated groundwater
- **Groundwater (Shower model)** – Direct human contact with contaminated groundwater used for a shower
- **Groundwater (Irrigation model)** – Uptake of contaminants into vegetable grown irrigated with contaminated groundwater
- **Surface water** - transport of contamination from soil and/or groundwater to surface water