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Risk-Based Assessment of Soil and Groundwater Quality in the Netherlands: Standards and Remediation Urgency

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To assess soil and groundwater quality two generic (i.e. multifunctional) risk-based standards, Target and Intervention Value, have been developed, in the framework of the Dutch Soil Protection Act. These standards allow soil and groundwater to be classified as clean, slightly contaminated or seriously contaminated. The Target Value is based on potential risks to ecosystems, while the Intervention Value is based on potential risks to humans and ecosystems. In the case of serious soil contamination the site has, in principle, to be remediated, making it necessary to determine the remediation urgency on the basis of actual (i.e. site-specific) risks to humans and ecosystems and, besides, actual risks due to contaminant migration.

KEY WORDS: Soil contamination; remediation urgency; standards; human exposure; ecotoxicological risks; risk due to contaminant migration.

1. INTRODUCTION

1.1. History

In 1983 the Dutch government published the Interim Soil Remediation Act and in support to this Act the *Soil Remediation Guideline.*[1] This *Guideline* outlines how to take action on soil contamination and included three soil and groundwater quality standards:

- the A-Value or Reference Value, based on the "background" concentration in the Netherlands: where the average soil concentration exceeded the A-Value soil contamination was present;
- the C-Value, derived using expert judgement: where the average soil concentration exceeded the C-Value there was a need for remediation;
- the B-Value, the average between A- and C-Values: where the soil concentration exceeded the B-Value there was a need to perform a further site investigation.

The main purpose of the Soil Protection Act, introduced in 1987, is to establish the accountability of individuals in contributing to soil pollution, and includes the question of financial responsibility for the consequences of soil contamination. An evaluation of the *Soil Remediation Guideline* of the Interim Soil Remediation Act was also started in 1987, resulting in a number of studies, which were to lead to a major revision of parts of this *Guideline.* The main goals of the revision were:

- to provide scientifically based criteria for deciding on whether to undertake remediation (this criterion has been redefined as "serious soil contamination").
- to link up with the general philosophy on risk-based standards in the Netherlands[2,3] and to use risk assessment and toxicological information to evaluate and if necessary adjust the former A-, B-, and C-Values. The C-Values

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were renamed *Intervention Values* in accordance with the "Framework of Definitions for Environmental Policy".[3]

Considering the interest on integrated soil quality standards and uniformity of definitions, it has been decided to develop Intervention Values applicable to soils and sediments. In 1994 the Intervention Values and the methodology to determine the urgency of remediation were formalized and the *Soil Protection Guideline* (formerly called the *Soil Remediation Guideline*) was incorporated into the Dutch Soil Protection Act; the Interim Soil Remediation Act was disposed of. In 1997 the *Soil Protection Guideline* was extended by incorporating standards for the second[4] and the third series[5] of contaminants and in 1999 by incorporating standards for the fourth series of contaminants[6] via Ministerial Circulars.[7,8]

In 1991–1992 the Ministry of Housing, Spatial Planning and the Environment (Ministry of VROM) initiated several working groups to evaluate the soil quality assessment procedures. Other relevant ministries participated in these groups, as well as representatives from the provinces, municipalities, research institutes, consultants and industry. The working groups, still operational, aim at evaluating and improving the procedures; they work in anticipation of rapid developments in environmental policy.

This paper describes the procedure for deriving the risk-based Target and Intervention Values and presents the procedures to determine the remediation urgency for contaminated sites. A differentiation is made between *potential* and *actual* risk assessment. Potential risk is the risk that would occur under "standardized" conditions and is independent of site-specific characteristics like land-use. Actual risk, on the contrary, is based on site-specific risks, e.g. site-specific human exposure and site-specific ecological effects. Actual risk is a function of land-use, human behavior, soil characteristics, et cetera.

1.2. Soil and Groundwater Quality Assessment

In the Netherlands site investigation starts with an Orientating Investigation, in which the first step is an extended historical survey of the site and surrounding area, possibly leading to a hypothesis on the spatial variability of the contaminant. Based on this information a distinction is made between a homogeneous and a heterogeneous contamination in the protocol.[9] The heterogeneous contamination cases are divided into those for which the contamination core is known and those with an unknown core. The answer to the following three questions form the result of the Orientating Investigation:

- Is the soil contaminated?
- Was the hypothesis on spatial variability right?
- Does the degree of contamination require further investigation?

Site investigation related to this last question is to be continued by the Further Investigation.[10] The purpose of this investigation is to quantify the type and extent of the contamination. Both investigations have to be carried out according to standardized procedures for sampling strategy.

Two soil quality standards have been derived to assess soil and groundwater quality: i.e. the Target Value and Intervention Value (Fig. 1). Both standards are based on *potential* risks, i.e. the risk that would occur under "standardized" conditions: the Target Values on potential risks to ecosystems and the Intervention Values on potential risks to humans *and* ecosystems. Note that a different ecotoxicological risk *level* is used for derivation of Target vs. Intervention Values. A further criterion used is the non-risk-based Intermediate Value, which is simply the average of Target and Intervention Values. Target, Intermediate and Intervention Values are employed independent of soil use, e.g. for a residential or industrial site, nature reserve, et cetera. These are generic (i.e., *multifunctional*) criteria.

From the site investigation the following implications can result:

- Concentration < Target Value (*clean soil*) means no restrictions.
- Concentration > Target Value and < Intermediate Value (*slightly contaminated soil*) means no Further Investigation; (Minor) restrictions can be imposed on soil use.
- Concentration > Intermediate Value and <

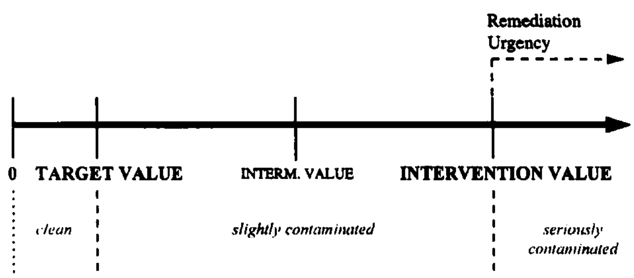

Fig. 1. Sol and groundwater quality standards and assessment.

Intervention Value means starting with the Further Investigation. If this still results in soil quality < Intervention Value, restrictions can be imposed on soil use. These are mainly based on other instruments than the Soil Protection Act (e.g., no growth of sensitive food crops, no direct use of groundwater as drinking water).
- An average soil volume concentration of at least 25 m^3 (for soil quality assessment) or an average concentration in the porewater of a water-saturated soil volume of at least 100 m^3 (for groundwater quality assessment) > Intervention Value (*seriously contaminated soil*) means that in principle remediation will be necessary; the urgency of remediation has to be determined.

The derivation of Target and Intervention Values is extensively described in Chapter 3.

The purpose of determining the urgency of remediation is distinguish between two urgency classes: urgent and non-urgent cases of serious soil contamination. Non-urgent cases are taken up in the provincial soil remediation program without a defined time for starting the remediation. For urgent cases remediation has to be initiated within one generation (circa 20 years). The determination of remediation urgency is based on *actual* (i.e., site-specific) risks to humans, ecosystems and risk due to contaminant migration. The procedure to determine the remediation urgency is extensively described in Chapter 4.

Because risk can show a large variation within one type of soil use, soil use-specific standards have not been derived. This means that the actual risks on the site have to be determined for each situation as a function of soil, soil use, building characteristics and infrastructure and, ultimately, human behavior. Urgent cases of remediation are categorized into three groups for which remediation has to be initiated within 4 years (category I), between 4 and 10 years (category II) and between 10 and 20 years (category III). This categorization is also based on risk scores derived from the actual risks to humans, ecosystems and risk due to contaminant migration. Finally, prioritization within one category is based on economic-financial, social and/or other environmental criteria.[11]

2. TOOLS FOR SOIL QUALITY ASSESSMENT

The risk tools needed to derive soil and groundwater quality standards (Chapter 3) and to determine the remediation urgency (Chapter 4) are described in this chapter.

2.1. Human Toxicological Risk Assessment

To assess the risk for humans, exposure and tolerable exposure will have to be determined. The tolerable exposure is based on human effects.

2.1.1. Human Exposure

Two human exposure models have been developed: CSOIL for exposure to contaminated terrestrial soils and SEDISOIL for exposure to contaminated sediments. Three elements are recognized in these models:

- contaminant distribution over the mobile phases of the soil and of the sediment;
- contaminant transfer from (the different mobile phases of) the soil and sediment into contact media;
- direct and indirect exposure to humans.

To enable assessment of exposure to contaminants in terrestrial soils the CSOIL calculation[12] uses as starting-point the total soil concentration as representative soil content (Fig. 2).
The distribution over the mobile soil phases (pore water and soil gas) is calculated according to the fugacity theory of Mackay and Paterson.[13] Formulae for the following exposure routes have been included in the model:

- soil ingestion;
- crop consumption;
- drinking-water intake;
- inhalation of air;
- inhalation of soil particles;
- inhalation of air during showering;
- dermal uptake via soil;
- dermal uptake during showering.

In the Netherlands there are many cases of groundwater contamination with volatile contaminants. The VOLASOIL model has been developed[14] because the processes that determine the indoor air concentration are difficult to quantify, and the spatial and temporal variability of the indoor air concentration hampers accurate measuring. This model enables one to assess an indication of the *site-specific* indoor air concentration via a

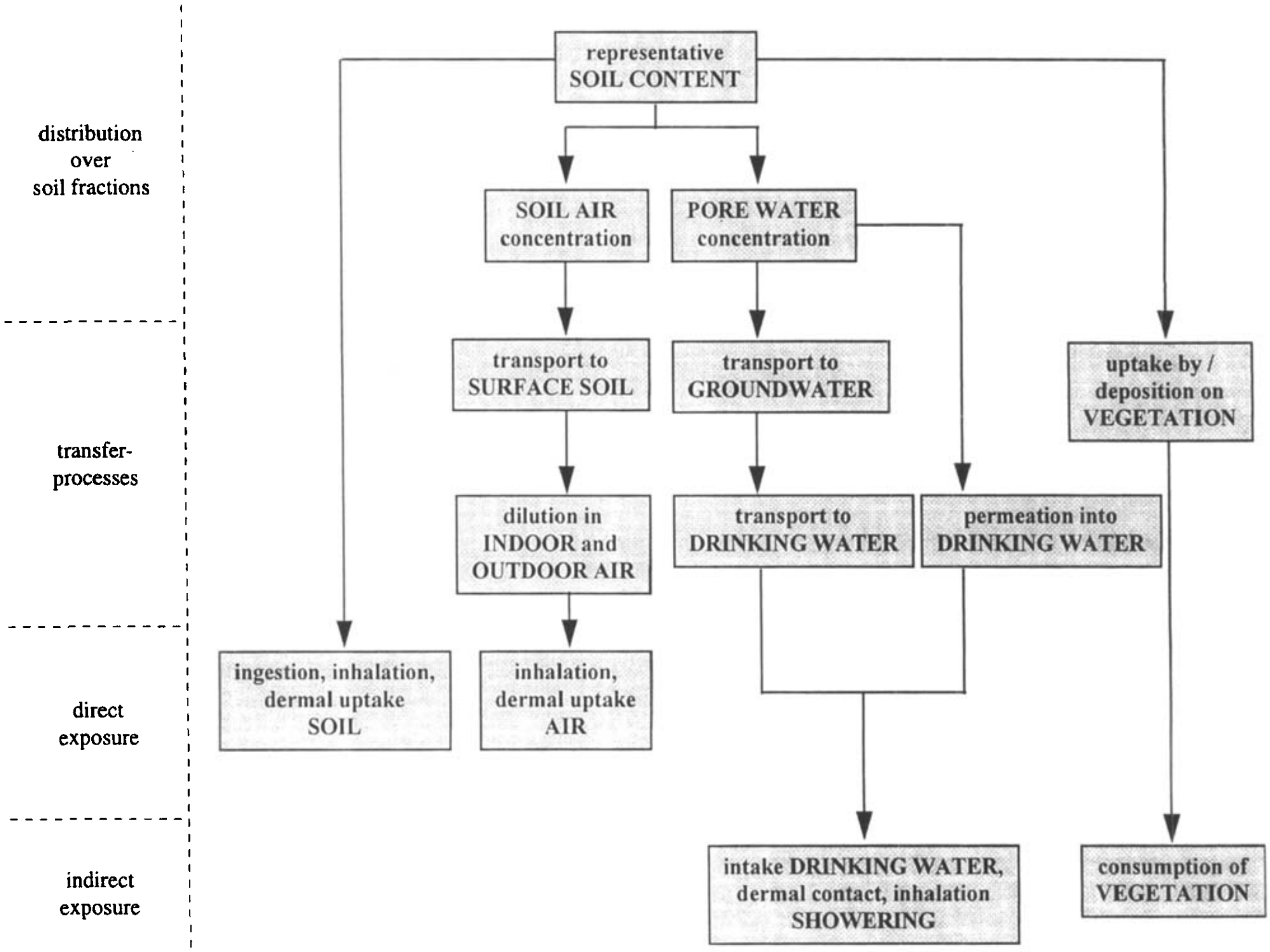

Fig. 2. CSOIL model to quantify exposure to contaminated terrestrial soils.

crawl space as a function of type and positioning of the contaminants, building and soil characteristics, and groundwater depth.

To enable assessment of exposure to sediments, the SEDISOIL calculation[15] uses as starting-point the total sediment concentration as representative sediment content (Fig. 3).

The distribution over the surface water and the suspended particles is calculated using average partition coefficients. Formulae for the following exposure routes have been included in the model:

- sediment ingestion;
- surface-water ingestion;
- suspended particles ingestion (together with surface water);
- fish consumption;
- dermal uptake via sediments;
- dermal uptake via surface water.

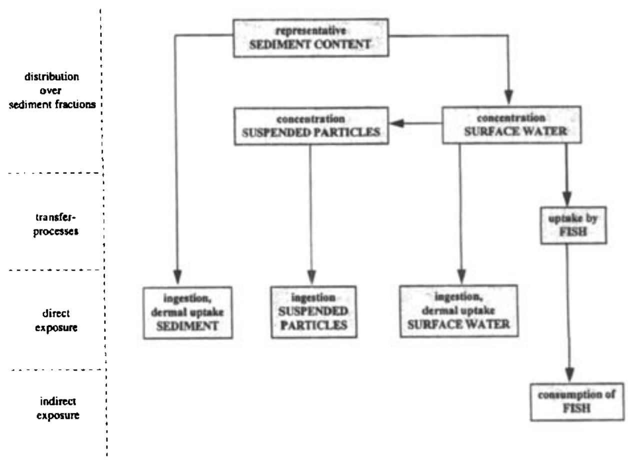

Fig. 3. SEDISOIL model to quantify exposure to contaminated sediments.

2.1.2. *Tolerable Exposure*

A distinction has been made between non-threshold contaminants (*genotoxic carcinogens*) and threshold contaminants (*non-carcinogens and non-genotoxic carcinogens*).[16] A tolerable exposure can be derived for the threshold contaminants for which no adverse effects for humans are likely to occur in cases where this exposure is not exceeded. For the non-threshold contaminants even the lowest exposure rate results in an increased chance of adverse effects for humans.

For non-genotoxic carcinogens and non-carcinogenic contaminants, the toxicological Tolerable Daily Intake (TDI), as derived by the WHO, is taken as the Maximum Permissible Risk for intake (MPR_{human}). If no TDI is available, an Acceptable Daily Intake (ADI) is derived using the same procedure as that used to derive a TDI. A TDI or ADI is the threshold exposure of a contaminant to which humans can be orally exposed to daily on the basis of body weight without experiencing adverse effects on health.

For genotoxic carcinogens, the MPR_{human} is defined as the dose of a contaminant (based on body weight for oral intake or air volume for inhalator intake) which forms a risk of one additional case of lethal tumor in 10,000 lifelong exposed individuals; this definition is based on a political decision.[2] The toxicity data have been profiled for all selected contaminants of the first series,[17,18] the second series,[4] the third series[19] and the fourth series.[20] The values for MPR_{human} are given in Appendix A.

2.2. Ecotoxicological Risk Assessment

Two relationships for each contaminant have been derived to quantify the ecotoxicological effects on ecosystems, i.e.:

- the relationship between soil concentration and irreparable damage to terrestrial species composition.[21,22]
- the relationship between soil concentration and adverse effects on microbial and enzymatic processes.[23]

The respective relationships are represented by the HCp-terrestrial species and HCp-processes (Hazardous Concentration functions, where 'p' represents the threatened percentage of the ecosystem). The relationships are derived on an empirical basis by statistical interpretation of observed NOECs (No Observed Effect Concentrations) and LOECs (Lowest Observed Effect Concentrations),[24] assuming that the sensitivity of species in an ecosystem can be described by a statistical frequency distribution. If NOECs are insufficiently available, L(E)Cs (Lethal Effect Concentrations) are used. In this case the L(E)Cs are divided by a factor of 10 to account for uncertainty. The ecotoxicological data are selected according to predefined criteria[23] and normalized for the influence of soil characteristics on the bioavailability, using the organic matter and clay content according to empirically derived formulae.[25] If not enough data on terrestrial species and microbial processes are available to derive a reliable relationship, aquatic data are also used, in which case the aquatic effect levels are translated to terrestrial effect levels using the partition coefficient of the contaminant between solid phase and pore water, and the fraction pore water in soils.[23] In this case an extra uncertainty factor of 10 is also used.

In addition, if a contaminant has a potential for secondary poisoning, the relationships between soil concentration and adverse effects on birds and mammals due to secondary poisoning, the HCp-birds and HCp-mammals, will be derived.[26,27]

2.3. Assessment of Risks due to Contaminant Migration

The assessment of contaminant migration in risk assessment has a special status because procedures to assess contaminant migration have, in contrast to assessment of risks to humans and ecosystems, been in use for many decades. To assess contaminant migration the following processes might play a role of importance:

- transport of water through (subsurface) soil or aquifers;
- transport of gas through soil;
- retardation of the contaminants due to sorption onto solid-phase particles;
- (microbiological) degradation of contaminants;
- precipitation/solution reactions;
- diffusion and dispersion in the (subsurface) soil and aquifer;
- fluid transport driven by density differences;
- preferential flow;
- contaminant uptake by crops, which reduces the contaminant load.

A (numerical) model can be used to assess the contaminant concentration at the location of a threatened target, combining (part of) the processes mentioned above. A number of these numerical models have become available during the last few decades.[28] The disadvantage of these models is that a large number of parameters have to be determined and expert knowledge on model application is required.

A simple equation to indicate the risk due to contaminant migration might be used to enable application for a wide range of environmental scientists. An example of such an equation is based on the combination of the groundwater flow velocity of the water and contaminant retardation:

$$F = v/R \tag{1}$$

where F = migration velocity of the contaminant (m/yr)
v = groundwater flow velocity (m/yr) (Darcy flux divided by effective porosity)
R = retardation factor (−).

Several methods exist to assess the soil/aquifer specific groundwater flow velocity, varying from monitoring to making a rough guess (expert judgement). The retardation factor can be determined by calculations based on the contaminant-specific sorption characteristics and the (subsurface) soil or aquifer. Using this simple equation results in a limited accuracy. For this reason it is wise to use more sophisticated procedures (models and/or monitoring systems) when in doubt about acceptable risks.

Besides, the concentration of the contaminant is also an important factor controlling the risks due to contaminant migration: higher contaminant loads may result in more severe effects. In addition, specifying the direction of contaminant migration, horizontally and vertically, in relation to the endangered targets is essential.

3. SOIL AND GROUNDWATER QUALITY STANDARDS

3.1. Target Values

The Target Values *for soil* are related to the Negligible Risk for ecosystems. This Negligible Risk level is assumed to be 1% of the Maximal Permissible Risk level for ecosystems (MPR_{eco}).[2] This MPR_{eco} is defined as the HC5 (Hazardous Concentration for 5% of the species in the ecosystem), i.e., 95% protection. Using the relations described in section 2.2, the Target Value can be calculated as 1% of the HC5. At this low soil concentration, no exposure to humans has been considered in the derivation of the Target Values. For metals the added risk approach was followed in the derivation of Target Values. This means that the "background" concentration in soils was added to the risk-based concentration as described above.[29] This procedure implies that soil quality is assessed on the basis of the *additional* metal fraction, i.e., caused by anthropogenic activity, only. Besides, the "background" metals might hardly be bioavailable due to aging. For most metals the risk-based concentration is negligible in comparison to the "background" concentration, which means that the Target Value is almost similar to this "background" concentration. This implies that under "natural" soil conditions prevailing in the Netherlands, there are (minor) effects on ecosystems, which was shown in a validation study.[30]

The Target Values *for groundwater* are based on the Negligible Risk for aquatic ecosystems. For metals the added risk approach was followed. Because the "background" concentration varies with depth, a differentiation is made between Target Values for "undeep" (<10 m below groundwater table) and "deep" (>10 m) groundwater.

When aquatic effect data for organic contaminants are lacking, the Target Value for groundwater for organic contaminants are based on other water quality standards or the detection limit.

The Target Values for soil and groundwater are given in Appendix A.

3.2. Intervention Values

The human toxicological (section 3.2.1) and the ecotoxicological intervention values (section 3.2.2) (formally: human toxicological and ecotoxicological serious soil contamination concentration; HUM-TOX SCC and ECOTOX SCC, respectively) have to be derived on the grounds of the criterion for human toxicological and the ecotoxicological serious soil contamination, respectively. Both values are integrated to yield the final Intervention Values (section 3.2.3).

3.2.1. Human Toxicological Serious Soil Contamination

In agreement with "Premises for risk management",[2] the human toxicological definition for serious soil contamination is taken as the soil quality resulting in exceeding of the Maximum Permissible Risk for intake (MPR_{human}). For this reason, the human toxicological intervention value is defined as the concentration of a contaminant in the soil which would result in an exposure equal to the MPR_{human} under standardized conditions (*potential* exposure), see Fig. 4.

The potential exposure is calculated using the CSOIL model. A standard exposure scenario has been defined to describe the standardized conditions.[12] In this scenario, all exposure pathways in CSOIL (section 2.1.1) are assumed to be operational on the basis of exposure to contaminants in a residential situation. In case that the calculated indoor air concentration (an intermediate result) exceeds the TCA, the human toxicological intervention value for soil is corrected in such a way that the calculated indoor air concentration equals the TCA. In the next step the exposure from all pathways is calculated for children and adults separately. Finally, the mean lifelong exposure is calculated by summing up exposure of children and adults with a relative weight of 6/70 (child during six years) and 64/70 (adult during 64 years), respectively.

Soil ingestion, crop consumption and inhalation of air generally contribute at least 90% to the total exposure for all contaminants considered in the *Soil Protection Guideline.*[12,4,5,6] The human toxicological intervention values are listed in Appendix A.

3.2.2. Ecotoxicological Serious Soil Contamination

The ecotoxicological intervention value has been defined as the HC50 (Hazardous Concentration 50,

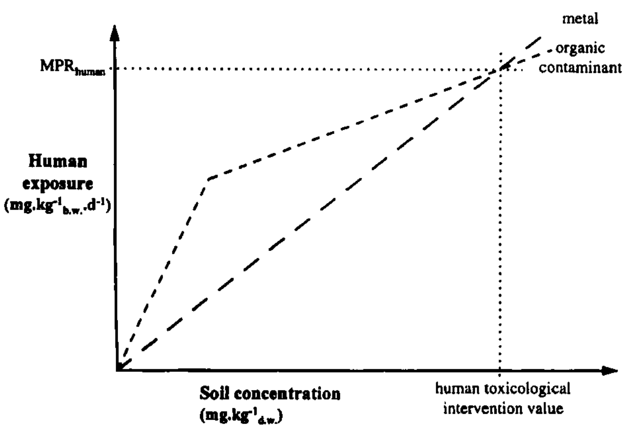

Fig. 4. Derivation of the human toxicological intervention value.

i.e. 50% of the ecosystem threatened) using the relations described in section 2.2. This risk level is much less stringent than the MPR_{eco}, which is defined as the HC5. The reason for this is a compromise between ecological acceptance (if 50% is protected the chance for recovery is acceptable) and practical use (the resulting contaminant concentrations in soil are high enough to avoid a huge part of the Netherlands being tagged as seriously contaminated). The extent of the adverse effects will vary among species and range from negligible to severe. An implication of this is that sensitive species are not protected at the level of the (ecotoxicological) intervention value. The ecotoxicological intervention values are listed in Appendix A.

3.2.3. Intervention Value for Soil

An uncertainty score has been assigned to the human toxicological and ecotoxicological intervention values to be used during the integration of the first series,[31] the second series,[4] the third series[5] and the fourth series.[6] The same weight is given to human as to ecotoxicological protection. This means that the most stringent (i.e. the lowest) value of the human toxicological and the ecotoxicological intervention values is taken as 'the' Intervention Value. An exception is made if the lower value is much more uncertain, in which case, the higher, but more reliable value, is taken as the final Intervention Value. It has been assumed that this is the case when one value is classified as "low" and the other as "high".

Risk for ecosystems and processes, as well as human risks are more-or-less related to the pore water concentration, rather than to the total soil concentration.[32] For this reason, the Intervention Values are corrected for organic matter and clay content,[33] and in doing so, indicate a correction for (bio-)availability.

3.2.4. Intervention Value for Groundwater

Direct human exposure to contaminants in groundwater in the Netherlands is unlikely. For this reason, the Intervention Values for groundwater have been derived from the Intervention Values for soil. The Intervention Value for groundwater is defined as the concentration in groundwater that is related to a soil concentration that equals the Intervention Value. This Intervention Value for groundwater is calculated on the basis of both the partitioning between the solid phase and pore water, and leaching into the groundwater. In a first step the equilibrium concentration in the pore water is calculated by dividing the Intervention Values for soil by an average partition coefficient.[31] The equilibrium concentration in the groundwater is calculated by simply dividing the pore water concentration by a factor of 10, taking into account the uncertainty in the partition coefficient, lack of partitioning equilibrium, dilution processes and the heterogeneity of the leaching process. Degradation has not been taken into account.

However, the possible consumption of contaminated groundwater as drinking water has also been considered in a final step. When using groundwater that is contaminated to the level of the Intervention Value directly as drinking water results in unacceptable human exposure (i.e. exposure exceeds the MPR_{human}), the Intervention Value for groundwater is corrected in such a way that drinking this contaminated groundwater would result in an exposure exactly equal to the MPR_{human}. Finally, the Intervention Values for groundwater were compared to existing quality objectives for soil and groundwater,[34] and with data generally representative for the groundwater in the Netherlands (data for relatively "clean" groundwater from the Dutch National Groundwater Quality Monitoring Network).

The Intervention Values for soil and groundwater are given in Appendix A.

Finally, here are some remarks on the derivation of the Intervention Values:

- No background exposure is taken into account in deriving the Intervention Values.
- Intervention Values are valid for terrestrial soils and sediments. To account for the typical physico-chemical characteristics of sediments, several proposed Intervention Values have been rejected in favor of the former target values for sediments[35]; this was a political decision.
- In 1997 some adaptations were proposed to the contaminant-specific input parameters in the derivation of six Intervention Values.[36] The six adjusted Intervention Values have officially been incorporated by a Ministerial Circular[37] (these adjustments has been included in Appendix A).
- In some cases no accurate proposal for an Intervention Value could be derived. In this case these proposals have been incorporated in the Ministerial Circulars as "Indicative Levels for serious soil contamination." These values can be used as Intervention Values, but have a lower status.

4. PROCEDURE TO DETERMINE REMEDIATION URGENCY

4.1. Procedure

One main difference with the procedure used to derive generic soil and groundwater quality guidelines is that determination of the remediation urgency is based on *actual* risks. The actual risk focuses on the site-specific risks, now and in the (near) future. For assessing the remediation urgency, risk analysis is also based on risk to humans and to the ecosystem on the contaminated site. However, the risk due to contaminant migration, i.e. migration of the contaminants from a contaminated site to other targets, is also considered.

The methodology for assessing the remediation urgency is based on the following conditions:

- the methodology should be based on risks;
- application of the methodology should be "easy", i.e., applicable for a wide range of users;
- the results should be scientifically "sound", i.e., represent the real risks as much as possible;
- the results should be uniform;
- application of the methodology should be in line with the results from site investigation as prescribed in the Dutch guidelines.

The methodology is conservative. This means that actual risks are assumed for humans, ecosystems *and* the risk due to contaminant migration, unless it can be proved otherwise. The methodology has been incorporated in the computer package *SUS* (Urgency of Remediation Methodology). This computer package (in Windows) presents:

- a description of the methodology;
- tab-pages for performing a step-by-step determination of the actual risks to humans, ecosystems and contaminant migration;
- defaults (and lower and upper limits) for input parameters;
- help-desk functions;
- a report option.

4.2. Actual Risk for Humans

At the contaminated site, the actual exposure of humans has to be quantified. To this end, the exposure models CSOIL (and VOLASOIL to calculate the site-specific indoor air quality) and SEDISOIL (section 2.1.1) can be used for contaminated terrestrial soils and sediments, respectively. However, because of large uncertainties, calculations have, in most cases, to be combined with measurements in contact media (contaminant concentration in indoor air and in crops for exposure to terrestrial soils, and contaminant concentration in fish for exposure to sediments). Contrary to the calculation of the potential risks, based on a standard exposure scenario, no fixed exposure scenarios have been defined. Because exposure might show extreme variation within one type of soil use (just as exposure through inhalation of contaminated air at an industrial site may vary by several orders of magnitude e.g. depending on the state of pavement of the site), standard soil-use-specific standards could imply a misleading accuracy. For this reason these soil-use-specific standards are not used.

The standardized methodology on determining the actual human risk is a three-step procedure. If one step does not lead to a clear assessment of the actual risk for humans, the next step will have to be performed. The steps are:

1. evaluation of the *possibilities* for exposure through the major exposure routes;
2. comparison with soil-use-specific standards for specific contaminants only (non-volatile contaminants)[(38)];
3. calculation of exposure using CSOIL (and VOLASOIL) or SEDISOIL, in combination with measurements in contact media; it has been assumed that there is an actual risk for humans if the exposure exceeds the MPR_{human} or the indoor air concentration exceeds the Tolerable Concentration Air (TCA).

As a support for the calculation of the exposure in step 3, a guideline for use of the input parameters has been derived for determining both the actual exposure of humans to terrestrial soils[(39)] and the indoor air concentration.[(14)]

4.3. Actual Risk for Ecosystems

Because there are no exposure models in use for assessing the risk for ecosystems, a pragmatic procedure has been developed to account for actual risks to ecosystems.[(40)] In this procedure a matrix has been defined (Fig. 5) on the basis of two elements:

- Degree of contamination: soil concentration $< 10 \times$ HC50 or soil concentration $> 10 \times$ HC50 (two classes);
- Ecological "sensitivity" of the area (three classes).

Depending on the position in the matrix, an actual risk for ecosystems is assumed to occur if the extent of the contaminated site exceeds a specified surface area. This limit value for surface area is based on the number of species protected as a function of surface area, as was found for some pesticides.[41] Although this relationship was only found for pesticides, surface area has been assumed here to represent biodiversity for all contaminants. If this simple procedure does not result in a clear decision on the actual risk for ecosystems, performing measurements (bio-assays) is recommended. However, no standard bio-assays are incorporated in the methodology.

4.4. Actual Risk due to Contaminant Migration

To enable uniform assessment applicable for a wide range of environmental scientists, a rather simple procedure has been adapted to determine the actual risk due to contaminant migration.[(42)] This pro-

ECOLOGICAL SENSITIVITY	SOIL CONCENTRATION < (10xHC50)	SOIL CONCENTRATION > (10xHC50)
High: Nature reserves 'Ecological Network' areas	50 m²	50 m²
Moderate: Pasture Residential area, including gardens Residential green space Recreation areas	5000 m²	50 m²
Low: City areas without gardens Arable land Flower bulb cultivation Horticulture Industry Fallow land Infrastructure	0.5 km²	5000 m²

Fig. 5. Limit value for surface area as a function of degree of contamination and ecological "sensitivity" of the area.

cedure is based on the stand-still principle: contaminants should not move independently of the targets that may be threatened. For this purpose the simple equation (Eq. 1) given in section 2.3 is used to quantify the migration velocity of the contaminant. Multiplication of this migration velocity by the largest cross-section of the contaminant plume in the saturated zone gives the flux of the contaminant, Fd (m^3/yr):

$$Fd = v \times A/R \tag{2}$$

where A = largest cross-section of the contaminant plume (m^2).

The contaminant flux represents the increase in the volume of contaminated groundwater. The following criterion, increase of a volume of contaminated water-saturated soil of more than 100 m^3 within the period of one year, is used for actual risk due to contaminant migration. Besides, the total contaminant load within a year should be sufficient to contaminate the groundwater in a volume of 100 m^3 water-saturated soil up to the level of the Intervention Value for groundwater. In other words, no extra cases of serious soil contamination (see section 1.2) should develop within a year. If this simple procedure does not result in a clear decision on the actual risk due to contaminant migration, application of (numerical) models and/or monitoring is recommended.

If there is simultaneous exposure to several contaminants, contamination can have serious effects, even if none of the individual contaminants exceeds the Intervention Value. The effect of simultaneous exposure has been investigated on a limited scale only. It has been proposed to account for the effects of simultaneous exposure for contaminants from the same group for which additive effects has been indicated, e.g. Cd, Pb and Hg,[43] chlorobenzenes,[44] polycyclic aromatic hydrocarbons,[45] and drins,[43] by using linear addition. No synergistic or antagonistic effects have been taken in account due to lack of knowledge on these.

5. SUMMARY

- A two-step procedure is used to assess soil and groundwater quality in the framework of the Dutch Soil Protection Act. In the first step soil and groundwater concentrations are compared with multifunctional contaminant-specific standards, i.e., Target and Intervention Values. These standards allow soil and groundwater to be classified as clean, slightly contaminated or seriously contaminated. Step 2, in which the actual, i.e. site-specific, risk is assessed with the purpose of determining the urgency of remediation, is only performed in case of a serious contamination. Because exposure might show extreme variation within one type of soil-use, soil-use-specific standards might imply a misleading accuracy. Therefore these soil-use-specific standards are not used.
- The Target Values are based on potential risks to ecosystems, while the Intervention Values are based on potential risks to humans and ecosystems. The human toxicological intervention value, formally known as human toxicological serious soil contamination concentration (HUM-TOX SCC), is defined as the contaminant concentration in the soil which would result in an exposure equal to the Maximum Permissible Risk for intake (MPR_{human}) using the CSOIL exposure model. A standard exposure scenario, based on a residential situation, has been defined to describe the standardized conditions (potential exposure). The ecotoxicological intervention value, formally known as ecotoxicological serious soil contamination concentration (ECOTOX SCC), has been defined as the HC50 (Hazardous Concentration 50), i.e., the soil concentration at which 50% of the ecosystem (species and processes) is threatened.
- The purpose of determining the urgency of remediation is distinguishing between two levels of urgency: urgent and non-urgent cases of serious soil contamination. The non-urgent cases are taken up in the provincial soil remediation program without a defined time for starting the remediation; treatment for the urgent cases has to be initiated within the period of one generation (circa 20 years). To assess the urgency of remediation use is made of a standardized methodology based on actual (i.e., site-specific) risks to humans and ecosystems, and risks due to contaminant migration.
- The actual exposure to humans is quantified using the exposure models CSOIL (and VOLASOIL to calculate the site-specific indoor air quality) and SEDISOIL for terrestrial soils and sediments, respectively. However, because of large uncertainties, calculations have, in most cases, to be combined with measurements in contact media (contaminant con-

centration in indoor air and crops for exposure to terrestrial soils and in fish for exposure to sediments).

- A pragmatic procedure has been developed to take into account actual risks to ecosystems. In this procedure a matrix was defined according to the degree of contamination and the ecological "sensitivity" of the area. Depending on the position in the matrix, actual risk for ecosystems is assumed to occur if the extent of the contaminated site exceeds a specified surface area. If this simple procedure does not result in a clear decision on the actual risk for ecosystems, performing measurements (bioassays) is recommended.

Actual risk due to contaminant migration is assumed if the increase of a contaminated water-saturated soil, calculated using a simple formula representing the contaminant flux, exceeds 100 m^3 within the period of one year.

If the procedure does not result in a clear decision on the actual risk, application of more sophisticated models and/or due to contaminant migration monitoring is recommended.

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During this period many scientists specialized in soil chemistry and contaminant behavior, human exposure and human or ecotoxicological effect assessment have participated. Thanks goes to Carl Denneman (Ministry of Housing, Spatial Planning and the Environment) and RIVM colleagues Reinier Van den Berg, Trudie Crommentuijn, Paul Janssen and Gerald Bockting for their important contributions in different stages of the project.

Appendix A. Maximal Permissible Risk for intake (MPR_{human}), Target Value for Soil and Groundwater (10% Organic Matter, 25% Clay), Ecotoxicological and Human Toxicological intervention value, Intervention Value for Soil and Groundwater (10% Organic Matter, 25% Clay)

Contaminant	MPR_{human} [$\mu g \cdot kg^{-1} \cdot d^{-1}$]	**Target Value soil** [$mg \cdot kg^{-1}$]	**Target Value groundwater** [$\mu g \cdot l^{-1}$]		Ecotoxicol. interv. value [$mg \cdot kg^{-1}$]	Human toxicological interv. value [$mg \cdot kg^{-1}$]	**Intervention Value soil** [$mg \cdot kg^{-1}$]	**Intervention Value groundwater** [$\mu g \cdot l^{-1}$]
I. Metals and trace elements			**<10m**	**>10m**				
Antimony	0.86	**3.0**	—	**0.15**	2900	15.7	**15**	**20**
Arsenic	2.1	**29**	**10**	**7.2**	40	678	**55**	**60**
Barium	20	**160**	**50**	**200**	625	4260	**625**	**625**
Beryllium	0.5	**1.1**	—	**0.05**	29	233	**(30)**[a]	**(15)**[a]
Cadmium	1.0	**0.8**	**0.4**	**0.06**	12	34.9	**12**	**6**
Chromium[b]	5.0	**100**	**1.0**	**2.4**	230	2250	**380**	**30**
Cobalt	1.4	**9.0**	**20**	**0.6**	240	452	**240**	**100**
Copper	140	**36**	**15**	**1.3**	190	15700	**190**	**75**
Mercury	0.61	**0.3**	**0.05**	**0.01**	10	197	**10**	**0.3**
Lead	3.6	**85**	**15**	**1.7**	290	300[c]	**530**	**75**
Molybdenum	10	**3.0**	**5.0**	**0.7**	480	911	**200**	**300**
Nickel	50	**35**	**15**	**2.1**	210	6580	**210**	**75**
Selenium	5.0	**0.7**	—	**0.07**	5.0	235	**(100)**[a]	**(160)**[a]
Silver	5.0	—	—	—	15	282	**(15)**[a]	**(40)**[a]
Tellurium	2.0	—	—	—	—	588	**(600)**[a]	**(70)**[a]
Thallium	0.2	**1.0**	—	**2.0**	14	118	**(15)**[a]	**(7.0)**[a]
Tin	2000	—	—	**2.2**	910	324000	**(900)**[a]	**(50)**[a]
Vanadium	2.0	**42**	—	**1.2**	250	1000	**(250)**[a]	**(70)**[a]
Zinc	1000	**140**	**65**	**2.4**	720	56500	**720**	**800**
II. Inorganic contaminants								
Cyanides (free)	50	**1.0**	**5.0**		—	16.8	**20**	**1500**
Cyanides (complex, pH < 5)	13	**5.0**	**10**		—	4.36	**650**	**1500**
Cyanides (complex, pH ≥ 5)	13	**5.0**	**10**		—	4.36	**50**	**1500**
Thiocyanates (sum)	11	**1.0**	—		—	3.69	**20**	**1500**

Appendix A. (*Continued*)

Contaminant	MPR_{human} $[\mu g \cdot kg^{-1} \cdot d^{-1}]$	**Target Value soil** $[mg \cdot kg^{-1}]$	**Target Value groundwater** $[\mu g \cdot l^{-1}]$	Ecotoxicol. interv. value $[mg \cdot kg^{-1}]$	Human toxicological interv. value $[mg \cdot kg^{-1}]$	**Intervention Value soil** $[mg \cdot kg^{-1}]$	**Intervention Value groundwater** $[\mu g \cdot l^{-1}]$
III. Aromatic contaminants							
Benzene	4.3	0.01	0.2	25	1.09	1	30
Ethyl benzene	136	0.03	4.0	—	244	50	150
Phenol	60	0.05	0.2	40	74.1	40	2000
Cresoles (sum)	50	0.05	0.2	50	117	5	200
Toluene	430	0.01	7.0	130	339	130	1000
Xylene	10	0.1	0.2	—	25.6	25	70
Catechol	40	0.05	0.2	—	22.9	20	1250
Resorcinol	20	0.05	0.2	—	10.4	10	600
Hydrochinon	25	0.05	0.2	—	10.8	10	800
Dodecylbenzene	5.0	—	—	—	1010	(1000)[a]	(0.02)[a]
Aromatic solvents	170	—	—	211	1450	(200)[a]	(150)[a]
Monochloroanilines	0.9	0.005	—	46	17.8	50	30
Dichloroanilines	—	0.005	—	43	—	(50)[a]	(100)[a]
Trichloroanilines	—	—	—	7.8	—	(7.8)[a]	(10)[a]
Tetrachloroanilines	—	—	—	27	—	(30)[a]	(10)[a]
Pentachloroanilines	—	—	—	5.9	—	(10)[a]	(1.0)[a]
4-chloro-2-methylphenol	20	—	—	15	39.3	(15)[a]	(350)[a]
4-chloro-3-methylphenol	300	—	—	15	589	(15)[a]	(350)[a]
IV. Polycyclic aromatic hydrocarbons							
Naphthaline	50	—	0.01	—	603	—	70
Anthracene	50	—	0.0007	—	29000	—	5.0
Phenantrene	20	—	0.003	—	661	—	5.0
Fluoranthene	20	—	0.003	—	1070	—	1.0
Benzo(a)anthracene	20	—	0.0001	—	11200	—	0.5
Chrysene	2.0	—	0.003	—	420	—	0.2
Benzo(a)pyrene	2.0	—	0.0005	—	1110	—	0.05
Benzo(*ghi*)perylene	20	—	0.0003	—	12000	—	0.05
Benzo(k)fluoranthene	20	—	0.0004	—	11600	—	0.05
Indeno(1,2,3-cd)pyrene	20	—	0.0004	—	11800	—	0.05
Total PAHs (10)	—	1	—	40	—	40	—
V. Chlorinated hydrocarbons							
1,1-dichloroethane	80	0.02	7.0	42	15.1	15	900
1,2-dichloroethane	14	0.02	7.0	60	3.86	4.0	400
1,1-dichloroethene	3.0	0.1	0.01	130	0.216	0.22[a]	5.8[a]
1,2-dichloroethene (cis)	6.0	—	—	238	0.51	—	—
1,2-dichloroethene (trans)	17	—	—	238	0.81	—	—
1,2-dichloroethene (sum)		0.2	0.01	238	—	1.0	20
Dichloromethane	60	0.4	0.01	60	18.9	10	1000
Tetrachloromethane	4.0	0.4	0.01	60	0.92	1.0	10
Tetrachloroethene	16	0.002	0.01	60	3.89	4.0	40
Trichloromethane	30	0.02	6.0	60	8.86	10	400
1,1,1-trichloroethane	80	0.07	0.01	88	14.6	15	300
1,1,2-trichloroethane	4.0	0.4	0.01	400	8.38	10[a]	130[a]
Trichloroethene	540	0.1	24	60	303	60	500
Vinylchloride	3.5	0.01	0.01	60	0.077	0.1	5.0
Dichloropropanes	60	0.002	0.8	125	1.81[d]	2.0[a]	80[a]
Chlorobenzenes:							
Monochlorobenzene	300	—	7.0	—	520	—	180
Dichlorobenzenes (sum)	190	—	3.0	—	1154	—	50
Trichlorobenzenes (sum)	0.5	—	0.01	—	9.04	—	10
Tetrachlorobenzenes (sum)	0.5	—	0.01	—	18	—	2.5

Appendix A. (*Continued*)

Contaminant	MPR_{human} [$\mu g \cdot kg^{-1} \cdot d^{-1}$]	**Target Value soil [$mg \cdot kg^{-1}$]**	**Target Value groundwater [$\mu g \cdot l^{-1}$]**	Ecotoxicol. interv. value [$mg \cdot kg^{-1}$]	Human toxicological interv. value [$mg \cdot kg^{-1}$]	**Intervention Value soil [$mg \cdot kg^{-1}$]**	**Intervention Value groundwater [$\mu g \cdot l^{-1}$]**
Pentachlorobenzene	0.5	—	**0.003**	—	23.7	—	**1.0**
Hexachlorobenzene	0.5	—	**0.00009**	—	26.8	—	**0.5**
Total chlorobenzenes	—	**0.03**	—	30	—	**30**	—
Chlorophenols:							
Monochlorophenols (sum)	3.0	—	**0.3**	10	14.0	—	**100**
Dichlorophenols (sum)	3.0	—	**0.2**	10	32.5	—	**30**
Trichlorophenols (sum)	3.0	—	**0.03**	10	56.3	—	**10**
Tetrachlorophenols (sum)	3.0	—	**0.01**	10	18.3	—	**10**
Pentachlorophenol	30	—	**0.04**	5.0	79.8	—	**3.0**
Total chlorophenols	—	**0.01**	—	10	—	**10**	—
Chloronaphthalene	0.5	—	—	—	9.12	**10**	**6.0**
Polychlorobiphenyls:							
Trichlorobiphenyl	0.09	—	—	—	5.52	—	—
Hexachlorobiphenyl	0.09	—	—	—	8.72	—	—
Total polychlorobiphenyls	—	**0.02**	**0.01**	1.0	—	**1.0**	**0.01**
Dioxins[c]	0.00001	—	—	0.046	0.001	**(0.001)[e]**	**(0.000001)[e]**
VI. Pesticides							
Organochlorine pesticides:							
DDT	20	—	—	—	11300	—	—
DDE	20	—	—	—	7830	—	—
Total DDT/DDD/DDE	—	**0.01**	**0.004 ng.l^{-1}**	4.0	—	**4.0**	**0.01**
Aldrin	0.1	—	**0.009 ng.l^{-1}**	0.35	13.8	—	—
Dieldrin	0.1	—	**0.1 ng.l^{-1}**	4.0	5.45	—	—
Endrin	0.1	—	**0.04 ng.l^{-1}**	0.06	4.36	—	—
Total drins	—	**0.005**	—	4.0	—	**4.0**	**0.1**
α-HCH	1	—	—	2.0	21.1	—	—
β-HCH	0.02	—	—	—	0.42	—	—
γ-HCH	1	—	—	2.0	21.1	—	—
Total HCHs	—	**0.01**	**0.05**	2.0	—	**2.0**	**1.0**
Other pesticides:							
Carbaryl	10	**0.03 μg.kg^{-1}**	**2.0 ng.l^{-1}**	5.0	461	**5.0**	**50**
Carbofuran	10	**0.02 μg.kg^{-1}**	**9.0 ng.l^{-1}**	1.5	435	**2.0**	**100**
Maneb	50	**2.0 μg.kg^{-1}**	**0.05 ng.l^{-1}**	35	29800	**35**	**0.1**
Atrazin	5	**0.2 μg.kg^{-1}**	**29 ng.l^{-1}**	6.0	21	**6.0**	**150**
Azinphosmethyl	5	**0.009 μg.kg^{-1}**	**0.1 ng.l^{-1}**	1.5	25.9[d]	**(2)[e]**	**(2)[e]**
Chlordane	0.5	**0.03 μg.kg^{-1}**	**0.02 ng.l^{-1}**	5.4	5.76	**4.0**	**0.2**
Heptachlor	0.1	**0.7 μg.kg^{-1}**	**0.005 ng.l^{-1}**	1.0	1.51	**4.0**	**0.3**
Heptachoro epoxide	0.1	**0.0002 μg.kg^{-1}**	**0.005 ng.l^{-1}**	—	0.90	**4.0**	**3.0**
Endosulfan	6	**0.01 μg.kg^{-1}**	**0.2 ng.l^{-1}**	7.1	2470	**4.0**	**5.0**
Tributyltinoxide	0.3	—	—	0.48	21.5[d]	—	—
Triphenyltin compounds	0.5	—	—	5.1	110	—	—
Total organotin compounds (sum)	—	**1.0 μg.kg^{-1}**	**0.05 ng.l^{-1}**	2.5	—	**2.5**	**0.7**
MCPA	1.5	**0.05 μg.kg^{-1}**	**0.02**	95	3.59	**4.0**	**50**
VII. Other pollutants							
Mineral oil	—	**50**	**50**	—	—	**5000**	**600**
Cyclohexanone	4600	**0.1**	**0.5**	—	270[d]	**45**	**15000**
Butyl benzylphthalate	25	—	—	—	776	—	—
Di(2-ethylthexyl)phthalate	25	—	—	—	4628	—	—
Total phthalates	25	**0.1**	**0.5**	60	—	**60**	**5.0**
Pyridine	1	**0.1**	**0.5**	150	1.06	**0.5**	**30**
Styrene	77	**0.3**	**6.0**	—	249	**100**	**300**
Tetrahydrofuran	10	**0.1**	**0.5**	—	0.40	**2.0**	**300**
Tetrahydrothiophene	180	**0.1**	**0.5**	4.1	94.0	**90**	**5000**
Ethylene-glycol	400	—	—	90	209	**(100)[e]**	**(5500)[e]**

Appendix A. (*Continued*)

Contaminant	MPR_{human} [μg·kg^{-1}·d^{-1}]	**Target Value soil [mg·kg^{-1}]**	**Target Value groundwater [μg·l^{-1}]**	Ecotoxicol. interv. value [mg·kg^{-1}]	Human toxicological interv. value [mg·kg^{-1}]	**Intervention Value soil [mg·kg^{-1}]**	**Intervention Value groundwater [μg·l^{-1}]**
Diethylene-glycol	400	—	—	480	0.09	**(270)**[a]	**(13000)**[a]
Acrylonitrile	0.1	**0.000007**	**0.08**	1.3	0.09	**(0.1)**[a]	**(5.0)**[a]
Formaldehyde	150	—	—	0.30	0.08[d]	**(0.1)**[a]	**(50)**[a]
Methanol	500	—	—	33	164	**(30)**[a]	**(24000)**[a]
Butanol	125	—	—	26	103	**(30)**[a]	**(5600)**[a]
Ethylacetate	900	—	—	68	546	**75**	**15000**
Butylacetate	200	—	—	196	469	**(200)**[a]	**(6300)**[a]
Methyl-*tert*-butyl ether (MTBE)	900	—	—	125	83[d]	**(100)**[a]	**(9200)**[a]
Methyllethylketone	190	—	—	175	37.2	**(35)**[a]	**(6000)**[a]
Tribromomethane	20	—	—	300	74.7	**75**	**630**
Isopropanol	1000	—	—	220	714	**220**	**31000**

— Not available.

[a] No reliable value could be derived; in the Ministerial Circulars this value (between brackets) is called Indicative Level for serious soil contamination.

[b] Based on chromium (III) only.

[c] Based on exposure and Maximal Permissible Risk for intake for a child (instead of averaged lifelong exposure and Maximal Permissible Risk for Intake).

[d] Corrected for exceeding of Tolerable Concentration Air (TCA).

[e] Toxicity equivalents, based on the most toxic compound.

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