BRITISH STANDARD

BS EN ISO
15175:2011

Soil quality — Characterization of soil related to groundwater protection

ICS 13.080.40

British Standards

National foreword

This British Standard is the UK implementation of EN ISO 15175:2011. It is identical to ISO 15175:2004. It supersedes BS ISO 15175:2004, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EH/4, Soil quality.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ICS 13.080.40

English Version

Soil quality - Characterization of soil related to groundwater protection (ISO 15175:2004)

Qualité du sol - Caractérisation des sols en relation avec la nappe phréatique (ISO 15175:2004)

Bodenbeschaffenheit - Ermittlung von Kennwerten des Bodens hinsichtlich des Wirkungspfads Boden - Grundwasser (ISO 15175:2004)

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Foreword

The text of ISO 15175:2004 has been prepared by Technical Committee ISO/TC 190 “Soil quality” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 15175:2011 by Technical Committee CEN/TC 345 “Characterization of soils” the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2011, and conflicting national standards shall be withdrawn at the latest by December 2011.

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Endorsement notice

The text of ISO 15175:2004 has been approved by CEN as a EN ISO 15175:2011 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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ISO 15175 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 7, *Soil and site assessment*.

Soil quality — Characterization of soil related to groundwater protection

1 Scope

This International Standard provides guidance on the principles behind, and main methods for, the evaluation of sites, soils, and soil materials in relation to their role as a source of contamination of groundwater and their function in transporting, degrading and transforming contaminants. It identifies and lists relevant monitoring strategies, methods for sampling, soil processing and analytical methods.

This International Standard is applicable to the evaluation of the impact of contaminants on groundwater in relation to

- drinking water quality,
- irrigation water quality,
- industrial use,
- natural base flow.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6341, *Water quality — Determination of the inhibition of the mobility of* Daphnia magna *Straus* (Cladocera, Crustacea) — *Acute toxicity test*

ISO 6468, *Water quality — Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes — Gas chromatographic method after liquid-liquid extraction*

ISO 6878, *Water quality — Spectrometric of phosphorus using ammonium molybdate*

ISO 7150-1, *Water quality — Determination of ammonium — Part 1: Manual spectrometric method*

ISO 7150-2, *Water quality — Determination of ammonium — Part 2: Automated spectrometric method*

ISO 7888, *Water quality — Determination of electrical conductivity*

ISO 7890-1, *Water quality — Determination of nitrate — Part 1: 2,6-Dimethylphenol spectrometric method*

ISO 7890-2, *Water quality — Determination of nitrate — Part 2: 4-Fluorophenol spectrometric method after distillation*

ISO 7890-3, *Water quality — Determination of nitrate — Part 3: Spectrometric method using sulfosalicylic acid*

ISO 7981-2, *Water quality — Determination of six specified polynuclear hydrocarbons* (PAH) — *Part 2: Determination of six PAH by high-performance liquid chromatography with fluorescence detection after liquid-liquid extraction*

ISO 8165-1, *Water quality — Determination of selected monovalent phenols — Part 1: Gas chromatographic method after enrichment by extraction*

ISO 8245, *Water quality — Guidelines for the determination of total organic carbon (TOC) and dissolved organic carbon (DOC)*

ISO 9001:2000, *Quality management systems — Requirements*

ISO 9562, *Water quality — Determination of adsorbable organically bound halogens (AOX)*

ISO 9964-1, *Water quality — Determination of sodium and potassium — Part 1: Determination of sodium by atomic absorption spectrometry*

ISO 9964-2, *Water quality — Determination of sodium and potassium — Part 2: Determination of potassium by atomic absorption spectormetry*

ISO 9964-3, *Water quality — Determination of sodium and potassium — Part 3: Determination of sodium and potassium by flame emission spectrometry*

ISO 10048, *Water quality — Determination of nitrogen — Catalytic digestion after reduction with Devarda's alloy*

ISO 10301, *Water quality — Determination of highly volatile halogenated hydrocarbons — Gas chromatographic methods*

ISO 10382, *Determination of organochlorine pesticides and polychlorinated biphenyls – gas chromatographic method with electron capture detection*

ISO 10390, *Soil quality — Determination of pH*

ISO 10523, *Water quality — Determination of pH*

ISO 10573, *Soil quality — Determination of water content in the unsaturated zone — Neutron depth probe method*

ISO 10693, *Soil quality — Determination of carbonate content — Volumetric method*

ISO 10694, *Soil quality — Determination of organic and total carbon after dry combustion (elementary analysis)*

ISO 11047, *Soil quality — Determination of cadmium, chromium, cobalt, copper, lead, manganese, nickel and zinc — Flame and electrothermal atomic absorption spectrometric methods*

ISO 11048, *Soil quality — Determination of water-soluble and acid-soluble sulfate*

ISO 11074-1, *Soil quality — Vocabulary — Part 1: Terms and definitions relating to the protection and pollution of the soil*

ISO 11074-4 *Soil quality — Vocabulary — Part 4: Terms and definitions relating to the rehabilitation of soils and sites*

ISO 11259, *Soil quality — Simplified soil description*

ISO 11260, *Soil quality — Determination of effective cation exchange capacity and base saturation level using barium chloride solution*

ISO 11261, *Soil quality — Determination of total nitrogen — Modified Kjeldahl method*

ISO 11263, *Soil quality — Determination of phosphorus — Spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution*

ISO 11264, *Soil quality — Determination of herbicides — Method using HPLC with UV detection*

ISO 11265, *Soil quality — Determination of the specific electrical conductivity*

ISO 11266, *Soil quality — Guidance on laboratory testing for biodegradation of organic chemicals in soil under aerobic conditions*

ISO 11271, *Soil quality — Determination of redox potential — Field method*

ISO 11272, *Soil quality — Determination of dry bulk density*

ISO 11274, *Soil quality — Determination of the water retention characteristic — Laboratory methods*

ISO 11275, *Soil quality — Determination of unsaturated hydraulic conductivity and water-retention characteristic — Wind's evaporation method*

ISO 11277, *Soil quality — Determination of particle size distribution in mineral soil material — Method by sieving and sedimentation*

ISO 11348-1, *Water quality — Determination of the inhibitory effect of water samples on the light emission of* Vibrio fischeri *(Luminescent bacteria test) — Part 1: Method using freshly prepared bacteria*

ISO 11348-2, *Water quality — Determination of the inhibitory effect of water samples on the light emission of* Vibrio fischeri *(Luminescent bacteria test) — Part 2: Method using liquid-dried bacteria*

ISO 11348-3 *Water quality — Determination of the inhibitory effect of water samples on the light emission of* Vibrio fischeri *(Luminescent bacteria test) — Part 3: Method using freeze-dried bacteria*

ISO 11369, *Water quality — Determination of selected plant treatment agents — Method using high performance liquid chromatography with UV detection after solid-liquid extraction*

ISO/TS 11370, *Water quality — Determination of selected organic plant treatment agents — Automated multiple development (AMD) technique*

ISO 11464, *Soil quality — Pretreatment of samples for physico-chemical analyses*

ISO 11423-1, *Water quality — Determination of benzene and some derivatives — Part 1: Head-space gas chromatographic method*

ISO 11423-2, *Water quality — Determination of benzene and some derivatives — Part 2: Method using extraction and gas chromatography*

ISO 11466, *Soil quality — Extraction of trace elements soluble in* aqua regia

ISO 11905-1, *Water quality — Determination of nitrogen — Part 1: Method using oxidative digestion with peroxodisulfate*

ISO/TR 11905-2, *Water quality — Determination of nitrogen — Part 2: Determination of bound nitrogen, after combustion and oxidation to nitrogen dioxide, using chemiluminescence detection*

ISO 13536, *Soil quality — Determination of the potential cation exchange capacity and exchangeable cations using barium chloride solution buffered at pH = 8,1*

ISO 13877, *Soil quality — Determination of polynuclear aromatic hydrocarbons — Method using high-performance liquid chromatography*

ISO 13878, *Soil quality — Determination of total nitrogen content by dry combustion (“elemental analysis”)*

ISO 14154, *Soil quality — Determination of selected phenols and chlorophenols — gas chromatographic method*

ISO 14235, *Soil quality — Determination of organic carbon by sulfochromic oxidation*

ISO 14238, *Soil quality — Biological methods — Determination of nitrogen mineralization and nitrification in soils and the influence of chemicals on these processes*

ISO 14239, *Soil quality — Laboratory incubation systems for measuring the mineralization of organic chemicals in soil under aerobic conditions*

ISO 14254, *Soil quality — Determination of exchangeable acidity in barium chloride extracts*

ISO 14255, *Soil quality — Determination of nitrate nitrogen, ammonium nitrogen and total soluble nitrogen in air-dry soils using calcium chloride solution as extractant*

ISO 14256-2, *Soil quality — Determination of nitrate, nitrite and ammonium in field-moist soils by extraction with potassium chloride solution — Part 2: Automated method*

ISO 14507, *Soil quality — Pretreatment of samples for determination of organic contaminants*

ISO 14869-1, *Soil quality — Dissolution for the determination of total element content — Part 1: Dissolution with hydrofluoric and perchloric acids*

ISO 14869-2, *Soil quality — Dissolution for the determination of total element content — Part 2: Dissolution by alkaline fusion*

ISO 14870, *Soil quality — Extraction of trace elements by buffered DTPA solution*

ISO 14911, *Water quality — Determination of dissolved* Li^+, Na^+, $NH_4{}^+$, K^+, Mn^{2+}, Ca^{2+}, Mg^{2+}, Sr^{2+} and Ba^{2+} *using ion chromatography — Method for water and waste water*

ISO 15009, *Soil quality — Gas chromatogrphic determination of the content of volatile aromatic hydrocarbons, naphthalene and volatile halogenated hydrocarbons — Purge-and-trap method with thermal desorption*

ISO 15089, *Water quality — Guidelines for selective immunoassays for the determination of plant treatment and pesticide agents*

ISO 15178, *Soil quality — Determination of total sulfur by dry combustion*

ISO 15473: 2002, *Soil quality — Guidance on laboratory testing for biodegradation of organic chemicals in soil under anaerobic conditions*

ISO 15799, *Soil quality — Guidance on the ecotoxicological characterization of soils and soil materials*

ISO 15913, *Water quality — Determination of selected phenoxyalkanoic herbicides, including bentazones and hydroxybenzonitriles by gas chromatography and mass spectrometry after solid phase extraction and derivatization*

ISO 16703, *Soil quality — Determination of content of hydrocarbon in the range* C_{10} *to* C_{40} *by gas chromatography*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 20279, *Soil quality — Extraction of thallium and determination by electrothermal atomic absorption spectrometry*

OIML R 112:1994, *High performance liquid chromatographs for measurement of pesticides and other toxic substances*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074-1 and ISO 11074-4 and the following apply.

3.1
soil
upper layer of the Earth's crust composed of mineral particles, organic matter, water, air and organisms

[ISO 11074-1]

3.2
contaminant
substance or agent present in the soil as a result of human activity

cf. **pollutant** (3.8).

NOTE There is no assumption in this definition that harm results from the presence of the contaminant.

3.3
diffuse-source input
non-point-source input
input of a substance emitted from moving sources, from sources with a large area or from many sources

NOTE 1 The sources can be for example cars, application of substances through agricultural practices, emissions from town or region, deposition through flooding of a river.

NOTE 2 Diffuse-source input usually leads to sites that are relatively uniformly contaminated. At some sites the input conditions may nevertheless cause a higher local input near the source or where atmospheric deposition/rain is increased.

3.4
groundwater
water which is being held in, and can usually be recovered from, an underground formation

3.5
hazard
property of a substance or material, or any action, which may cause an adverse effect on soil functions

3.6
percolating water
soil water that moves downward in the percolating space due to gravity, insofar as it is not groundwater

3.7
point-source input
input of a substance from a stationary discrete source of defined size

NOTE 1 The sources can be stack emissions, accidental spills, waste dumps, spills on industrial sites, major leaks from sewers and other pipelines.

NOTE 2 Point-source input can cause both locally contaminated sites and relatively uniformly contaminated sites.

[ISO 11074-1]

3.8
pollutant
substance or agent present in the soil (or groundwater) which due to its properties, amount or concentration causes adverse impacts on soil functions or soil use

NOTE Also described as those substances which due to their properties, amount or concentration cause impacts on soil functions or soil use.

3.9
residual contamination
amount or concentration of contaminants remaining in specific media following remediation

[ISO 11074-4]

3.10
risk
expression of the probability that an adverse effect on soil functions will occur under defined conditions, and the magnitude of the consequences of the effect occurring

3.11
saturated zone
zone of the underground, where the space of the lithosphere is filled uninterruptedly with water at the time under consideration

NOTE The saturated zone encompasses the groundwater zone including the zone of capillary water.

3.12
soil function
function of soil which is significant to man and the environment

NOTE Important soil functions are

- control of matter and energy cycles as compartments of an ecosystem,
- vital support for the life of plants, animals and man,
- basis for the stability of buildings and roads,
- basis for agricultural production,
- buffer inhibiting movement of water, contaminants or other agents into the groundwater,
- source of a gene pool,
- preservation of archaeological remains,
- preservation of paleoecological remains.

[ISO 11074-4]

3.13
soil material
excavated soil, dredged materials and soil treated to remove or destroy or reduce the environmental availability of contaminants

3.14
soil water
all water of the unsaturated and saturated zone

3.15
subsoil
partially decomposed layer of rock underlying the topsoil and overlying the solid parent rock beneath

3.16
topsoil
upper part of a natural soil which is generally dark-coloured and has a higher content of organic matter and nutrient when compared to the subsoil below

[ISO 11074-4]

3.17
unsaturated zone
zone of the soil and the underground, where the space of the lithosphere is not filled uninterruptedly with water at the time under consideration

NOTE The unsaturated zone encompasses the zone of percolating water with the zone of capillary water being excluded.

4 General

Soils are of central importance within the water cycle because their storage and filter functions have a lasting influence on the water balance and groundwater quality. In this context, particular attention shall be paid to the following functions:

- mechanical filter functions (retention of suspended sludge and pollutant particles);
- chemical filter functions (sorption and mobilization of substances);
- transformation functions (degradation or transformation of substances).

Soil is understood as a porous medium consisting of three phases: the solid phase, the liquid phase and the gaseous phase. The ratio of these phases and their respective compositions vary widely in time and space.

The assessment of contamination affecting groundwater quality requires a profound understanding of the governing processes and reactions of potentially toxic compounds in soils. Contaminants are translocated in all three phases of soils as a function of the properties of the chemicals and the soil. Hence strategies for assessing risks to groundwater due to soil contamination should vary with the contaminants considered, and should take into account those soil properties which mainly govern the soil's filter, retention, release and transformation functions.

In addition to considering the properties of the chemicals and the soil governing the behaviour of contaminants in soils, different ways for contaminants to enter soils shall also be evaluated when designing suitable risk assessment strategies, with respect to contamination of groundwater. Soil and groundwater contamination can be caused by different sources on different spatial scales, as indicated in Figure 1. On regional and larger scales, soil contamination is caused, for example, by wet and dry atmospheric deposition and has predominantly diffuse character on a moderate level of contamination. On a local scale, a variety of point sources can cause all kinds and magnitudes of soil and groundwater contamination. Most point sources of contamination may also be regarded as off-site diffuse sources of groundwater contamination. It is evident that different contamination scenarios as a function of contamination sources and scale demand different investigation strategies with respect to groundwater impact. At present there are no uniform principles for the investigation and evaluation of contaminated soils and contaminated sites in relation to the protection of water resources.

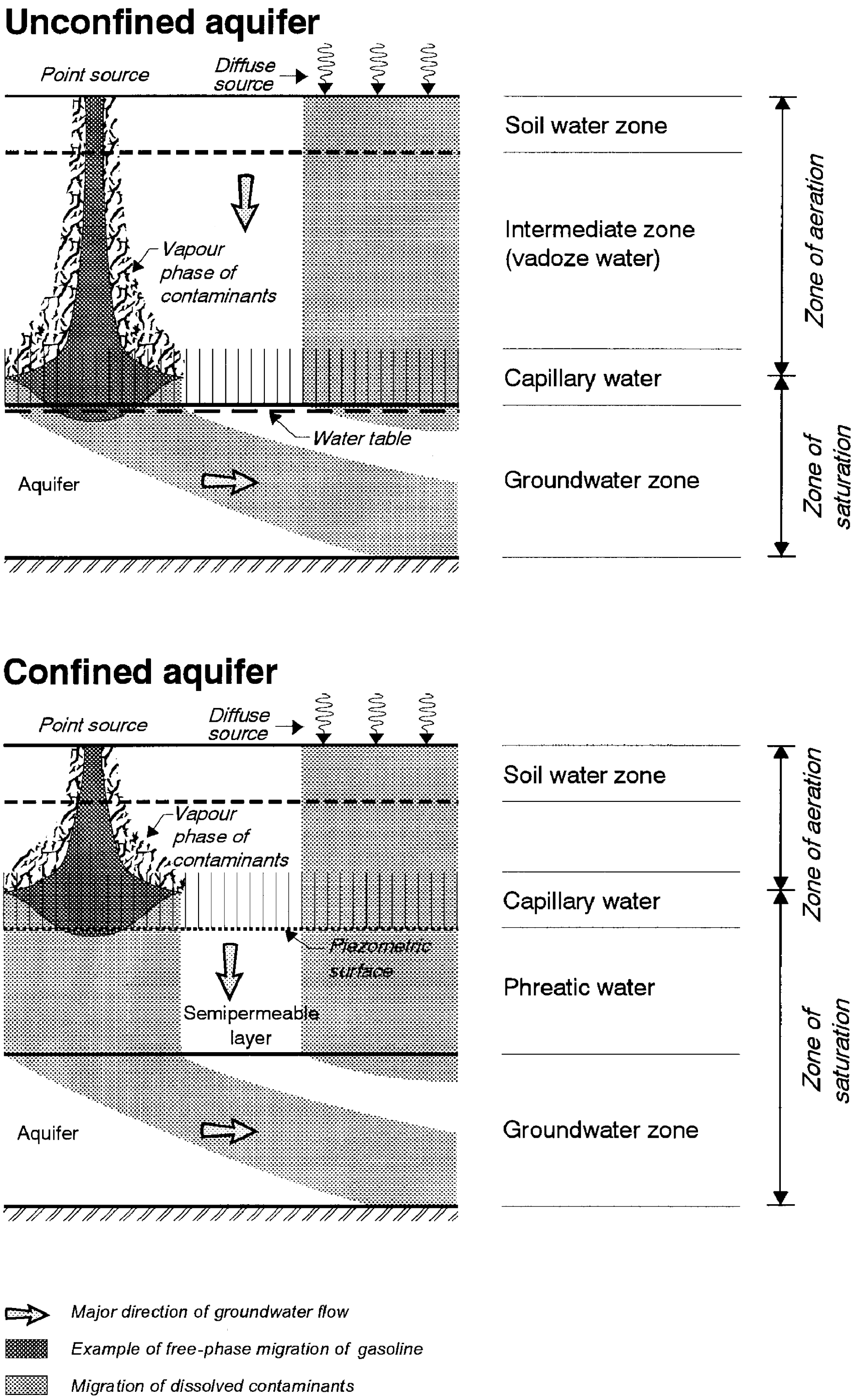

Figure 1 — Definition of groundwater zones and examples of sources of contamination

Investigation strategies may be qualitative or quantitative. Qualitative approaches mostly refer to assessment of, for example, the potential leaching risk of chemicals through the soil towards groundwater. In contrast to quantitative approaches, the level of actual soil contamination is not taken into account. Approaches of this type can also be utilized, e.g. to classify larger areas with respect to their capability of protecting groundwater resources against contamination, or as an introductory step in an assessment of an actual contaminated site.

To assess the on-site impact on groundwater resulting from specific soil contamination, quantitative approaches based on site-specific investigation procedures including laboratory and/or field measurements have to be carried out. Laboratory measurements can include physical, chemical and biological analysis, and leaching tests. Assessments of this kind also shall take into account natural background concentrations of a substance and other natural conditions affecting the impact on the groundwater. Assessments of impact on groundwater often include a temporal aspect, since the actual impact may not be measurable at the time of the investigation, but may happen some time in the future.

Assessments also depend on the purposes of investigations, for example:

- conservation of soil functions in order to prevent groundwater contamination;
- soil and groundwater monitoring;
- risk assessment;
- controlling remediation measures.

A listing of suitable methods are covered in the main part of this International Standard (see Clause 5). Some examples of assessment using principles of this International Standard are provided in Annexes A and B.

Since the impact on groundwater can lead to impact on surface waters, this aspect can in some cases be relevant in an overall impact assessment. This issue is not addressed explicitly in this International Standard.

5 Site assessment

5.1 General

A prerequisite for the evaluation of the soil-to-groundwater pathway is the determination of the relevant physical, chemical and biological characteristics of soils and the hydrological characteristics of the site. It is therefore normally necessary to collect data for the assessment of the contamination source with respect to the type and degree of contamination and extent of source(s).

It is also necessary to describe the soil compartment that is influenced by the source, and the factors in this compartment affecting the actual impact on the groundwater. Many processes influence the groundwater impact in this soil compartment, where a number of physical, chemical and biological processes can take place. In order to evaluate the importance of these processes in a specific assessment, it is necessary to describe the structure of the soil compartment, e.g. the geometry, hydraulic conditions and natural chemical and biologic processes. Input to the soil compartment includes the infiltration of water and specific contaminants. Output is the contaminant flux to the compartment of the groundwater zone investigated. A general description hereof is given in Figure 2 and a further description of the relevant parameters is given in 5.2.

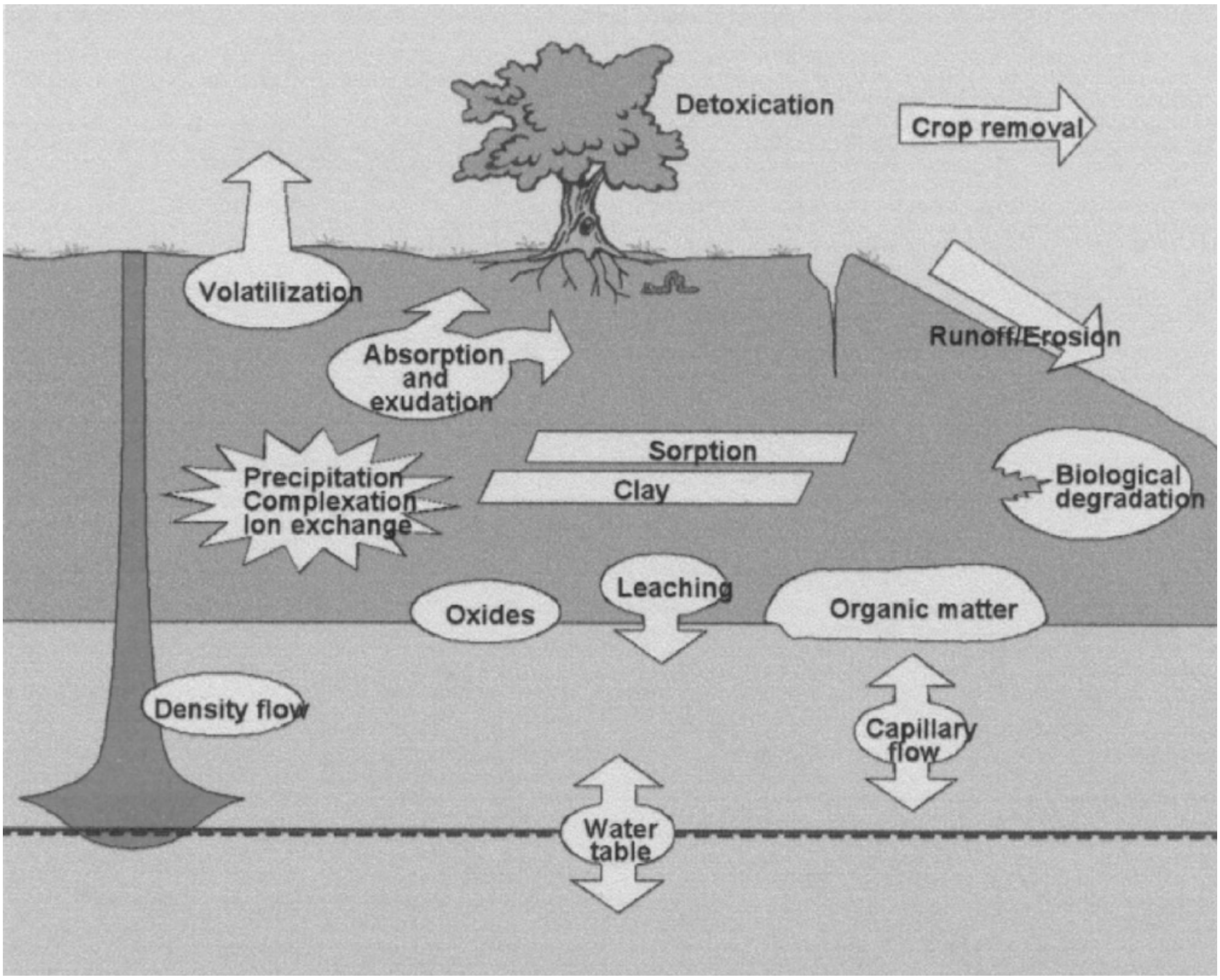

Figure 2 — Schematic diagram illustrating the soil compartment covered by the assessment procedure and processes affecting the impact of contamination on groundwater

The types of information needed to describe the relevant soil compartment include pedology, lithology of parent material, pedology (e.g. soil unit), hydrogeology (e.g. permeability), physico-chemical conditions (e.g. pH) and biological conditions (e.g. substrate availability). How large the actual soil compartment investigated should be (and thus the detail of the investigation) depends on the type of assessment chosen. For example, the volume is large if the assessment focuses on the general use of pesticides and fertilizers in an area covering a groundwater reservoir used as a drinking water source. The area and volume of the soil compartment investigated is considerably smaller if the assessment covers a “hot spot” on a contaminated site with a groundwater-pumping well located on a neighbouring site.

5.2 Relevant soil processes

Contaminant transport in the unsaturated zone is governed not only by the transport of percolating water but also by a number of biological and chemical processes. Which of these processes are to be considered important within a given context will depend on the type of contaminants and the actual soil conditions. An overview of soil and contaminant parameters related to contaminant transport is given in Table 1.

Table 1 — Soil and contaminant parameters related to different processes in soil

Process	Soil parameters	Contaminant parameters	Soil/contaminant interactions
Mass transport of contaminants	Hydraulic conductivity, degree of saturation, porosity, pore size distribution, soil water-retention functions	Solubility, volatility, density, viscosity	Relative permeability, residual saturation, wettability, surface tension, capillary pressure
Contaminant transport in water:			
Advection	Pressure gradient, hydraulic conductivity, porosity		Viscosity
Dispersion/diffusion	Dispersivity, pore water velocity	Diffusion coefficient	
Density transport	Pore water velocity, soil layering	Liquid density	Dispersion, change in density
Preferential flow	Pore size distribution, fissure size, macropore size, connectivity	Viscosity, density, diffusion coefficient	
Volatilization	Water content, temperature, chemical-phase content	Vapour pressure, Henry's constant	
Gas-phase transport	Water content, tortuosity, pressure differences	Diffusion coefficient	
Dissolution of organics	Hydraulic conductivity, tortuosity, water content	Solubility, composition of chemical phase	
Dissolution of inorganics	Hydraulic conductivity, tortuosity, water content	Solubility product	
Precipitation	pH, redox, other components	Solubility product, complexation constant	
Complexation	pH, ligand concentration, DOC	Complexation constant	
Ion exchange	Cation exchange capacity, ionic strength, other cations, pH	Valence, degree of hydratization	
Sorption of organics	pH, organic matter content, clay content and mineralogy, specific surface area	Octanol-water distribution coefficient, sorption constant	Ageing
Sorption of inorganics	pH, organic matter content, clay content and mineralogy, specific surface area, non-crystalline (short-range ordered) oxide and hydrous oxide gels	Sorption constant	Ageing
Degradation			
Abiotic	Redox, pH, temperature	Presence of primary substrate, degradability, toxicity to microorganisms	
Biotic	Microorganisms, redox, substrate, pH, temperature		

5.3 Impact assessment procedures

In order to complete a description of the source and the soil it is necessary to develop

- strategies for evaluation of site-specific parameters,
- sampling strategies, and
- analytical and testing strategies

for each site and/or media (soil, groundwater, soil air) that influences the impact on the groundwater.

These strategies should be determined on the basis of

- history of the site or area,
- available data and/or results of previous investigations,
- the nature of any process-based treatment methods that have been applied to the soil,
- the intended use of the site.

To optimize the actual need for information in relation to the costs and time demanded for the investigations in the field and laboratory, it is recommended to carry out the assessment in a stepwise procedure (see Table 2).

Table 2 — Stepwise procedure for impact assessment

Step 1	Preliminary investigation, including desktop investigation, site history, potential contaminants, available regional data on geology and hydrogeology
	Description of local geology and pedology in moderate detail and to verify the existence of contamination
	Chemical analyses to identify components and concentrations
	Primary impact assessment
	Definition of the importance of the problem, further action (e.g. site monitoring, immediate clean-up, further investigation or action is not necessary)
Step 2	Exploratory investigation, including supplemental field and laboratory investigations to estimate extent of source, specific hydraulic conditions, mobility, transformation and degradation and relevant reservoir conditions
	Secondary impact assessment
	Decision as to further action
Step 3	If necessary, main site investigations and testing in laboratory and field of specific details (e.g. leachability and/or degradation), computer modelling
	Tertiary impact assessment

The first step includes a preliminary study based on desktop investigations and limited field investigations with the aim to carry out an initial impact assessment. This step includes estimation of the soil geometry, soil unit and hydrological conditions on the basis of general knowledge of the area, possibly supplemented with some field data concerning local conditions. The presence of contaminants of interest and their likely concentrations are estimated on basis of site history and a few analyses of soil and water samples and/or soil-gas measurements. The relevant transport and decomposition processes are approximated from data related to the relevant soil conditions and contaminants retrieved from the literature. In step 1, qualitative methods as exemplified in Annex A can be useful, as can quantitative methods described as Level 1 in B.7.

If step 1 indicates need for a more detailed assessment, the next step is carried out. The relevant investigations consisting of supplementary sampling, chemical analysis and field tests are planned on the basis of step 1. Step 2 typically includes sampling to estimate the extent of the source(s), and the distribution of contaminants in the soil matrix between the different phases: the soil gas, which is bound to the soil particles and dissolved in the soil water. The transport of contaminants in various soil types and underlying lithologies (e.g. sand versus fractured rock) can be very different depending on their static and dynamic characteristics (e.g. cracking soils). It is very important in step 2 to determine the dominant mechanism of transport. For example if the transport is related to fractures in clay and rock, then the adsorption process can be of minor importance. Alternatively, in homogeneous sand with a high organic matter content, adsorption can be the most important process in the impact assessment. Information about the groundwater reservoir (e.g. extent, importance for the water supply situation) in question is also relevant in this phase, to be able to assess the severity of a potential problem. The seasonal pattern of climatic characteristics should be known in order to evaluate seasonal trends in potential and ongoing soil and groundwater contamination. Management practices should also be taken into account (e.g. irrigation type and quantities). In step 2, quantitative methods as exemplified as Level 2 in B.7 may be useful.

If the assessment still has to be improved after step 2, supplementary steps can be carried out. The content of these following steps can consist of some of the same elements as in step 2, but with improved accuracy of information available, e.g. by taking more samples to determine the influence of heterogeneity in the soil. Sorption, degradation and leaching test can be carried out in the laboratory. Leaching and extraction tests can be applied to assess the distribution of contaminants among the soil, water and geochemical phases, and to assess the environmental impact (on groundwater in this context) and possible remediation actions. Site-specific computer modelling of processes and groundwater flow can also be introduced as part of this step. In step 3, quantitative methods as exemplified as Level 3 in B.7 may be useful.

It can be seen that the assessment is often an iterative procedure, each step being a more refined version of the description of the problem and each leading to a more detailed basis for decision-making, as to the necessity of remedial action in the form of site clean-up, land-use restrictions, etc.

Characterization of soil, water and the target site will require measurement of physical, chemical and biological properties. Figure 3 indicates the broad areas in which measurement or description may be required.

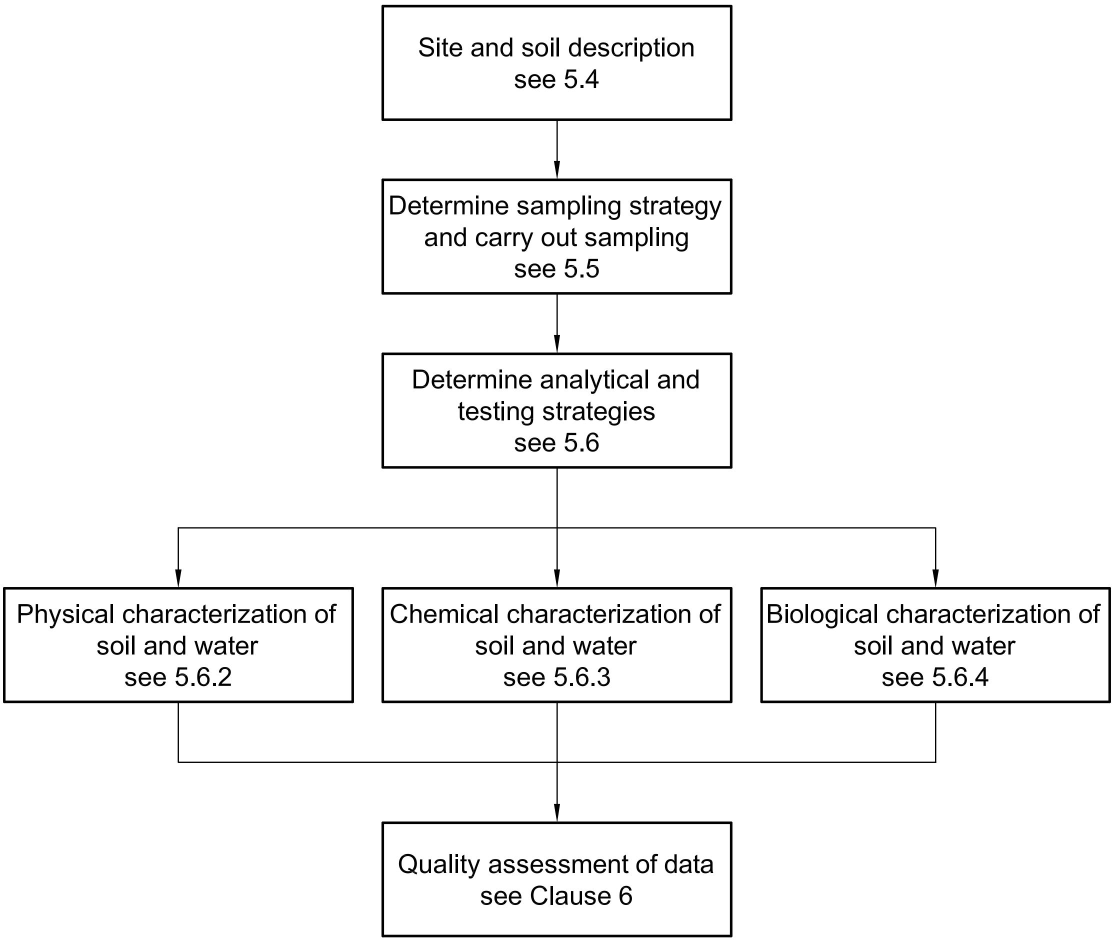

Figure 3 — Overall flow chart for assessment of soil and water

5.4 Site and soil description

The assessment of the potential impacts of contaminated soil on groundwater requires general information about the site under investigation. The most relevant parameters for a site-description are listed in Table 3. ISO 11259 cited in Table 3 shall be applied. The scale at which this information should be collected, and the degree of detail that is required, should be closely related to the objective of the investigation which primarily depends on the anticipated nature and distribution of a contamination (see ISO 10381-5). In the stage of desktop investigation (Step 1 according to Table 2), gathering information about the site does not include field work, whereas further investigation steps may necessitate more detailed field data collection. It is important to bear in mind that the reliability of data interpretation and risk assessment strongly depends on a profound knowledge of the site under consideration, hence collection of parameters indicated in Table 3 should be as comprehensive as possible.

Table 3 — Parameters for site and soil description

Parameters		Applicable International Standard
Landform and topography	Topography, landform, land element, position, slope, microtopography	ISO 11259
Land use and vegetation	Land use, human influence, vegetation	ISO 11259
Geology and lithology	Kind of parent material, effective soil depth	ISO 11259
Surface characteristics	Rock outcrops, surface coarse fragments, erosion phenomena, surface sealing, surface cracks, other characteristics	ISO 11259
Soil-water relationship	Surface water balance, rainfall, evapotranspiration, groundwater recharge, presence and depth of water table, site drainage, moisture conditions	ISO 11259
Soil type/soil profile description	Soil unit in regards of the classification system used Sequence and depth of diagnostic horizons, kind of boundaries Soil colour (matrix, mottling) Organic matter Texture, coarse elements, presence of non-soil material, pedofeatures Carbonates, field-pH, electrical conductivity Structure, voids, fracturing, inhomogeneities Compactness and consistence Total estimated porosity Roots, worm channels, biological activity	ISO 11259

5.5 Sampling

5.5.1 General

Before commencing any investigation, it is essential to define the objectives of the investigation and to prepare a sampling strategy consistent with those objectives (see Annex A to C). Reference should be made to relevant International Standards and to the guidance attached to any national criteria or standards relating to soil quality that are to be used in the assessment of the results of the investigation. In some jurisdictions, there may be a legal requirement to follow certain procedures if published criteria are to be used as the basis of the assessment.

For this International Standard, different sampling procedures may be required for pollution due to different sources, for example diffuse sources such as

- atmospheric deposition,
- inappropriate agricultural activity,
- inappropriate reuse of waste,
- flooding by contaminated water,

- road and urban runoff;

or point sources such as

- abandoned hazardous sites,
- abandoned industrial sites,
- abandoned waste disposal sites,
- abandoned potentially hazardous sites,
- abandoned mine workings,
- suspected hazardous sites,
- industrial sites,
- waste disposal sites,
- soil contamination caused by accidents and leakage (e.g. tank pipes).

International Standards are available for sampling of percolating water, groundwater and soil. Otherwise, appropriate national standards or equivalent regulations should be used.

5.5.2 Soil

If sufficient data are not already available, soil material and/or soil gas shall be sampled at the investigation site. The International Standards listed in Clause 2 on soil sampling in relation to soil quality shall be considered.

5.5.3 Water

It may be necessary to sample groundwater or percolating water at the site of investigation. The International Standards listed in Clause 2 shall be consulted and applied, where appropriate.

5.6 Characterization of soil and water

5.6.1 General

As can be seen in 5.1 to 5.5, the description and assessment of contaminated and uncontaminated sites require information on soil and water characteristics. In 5.6.2 to 5.6.4, relevant parameters required for the physical, chemical and biological characterization of soil and water are listed. Certain parameters require measurement in almost all situations; others only require measurement on a site- and contaminant-specific basis.

Principles of strategies for determination of relevant analysis and tests are provided in 5.2 and 5.3. Examples of the application of such procedures in the context of assessment methods are provided in Annexes A and B. Qualitative assessment approaches (Annex A) require, in addition to the general site and soil description (Table 3), selected physical (Table 4) and basic chemical parameters (Table 5) as input data. Quantitative assessment methods (Annex B) mostly require an extended and more specific data input, in particular with respect to the actual concentrations of potential contaminants in soils and water. Relevant inorganic and organic contaminants are listed in Tables 6, 7 and 8.

5.6.2 Physical parameters

A number of soil physical parameters are relevant in connection with the assessment of groundwater and contaminant transport in the unsaturated zone (Table 4). The actual choice of parameters measured should be based on a preliminary knowledge of site characteristics and the contaminant situation (Step 1). International Standards listed in Table 4 shall be applied.

In order to estimate hydraulic data for the saturated zone (e.g. hydraulic conductivity, transmissivity, leakage, etc.) pumping tests can be carried out. With this type of test, groundwater flow in the saturated zone can be described. Water migration in the unsaturated zone can be estimated on the basis of measurements of grain size distribution (e.g. by pedo-transfer functions/rules). However, inhomogeneities can dominate the distribution and velocity of the infiltration. If more accurate estimates are necessary, infiltration tests can be performed on site.

Table 4 — Physical parameters

Parameter	Methods	Soil[a]	Water[a]	Applicable International Standard[b]
Texture	sieving, sedimentation	X		ISO 11277 (s)
Coarse material	sieving	X		ISO 11277 (s)
Presence of non-soil material	sieving	X		ISO 11259 (s)
Hydraulic conductivity (unsaturated and/or saturated)	Wind´s evaporation method, field methods, e.g. Guelph constant-head permeameter	X		ISO 11275 (s)
Temperature	temperature sensors	X	X	
Water-retention characteristics	stepwise extraction of water by suction or tension	X		ISO 11274 (s)
Soil water content (*ex situ*)	neutron depth probe, TDR	X		ISO 10573 (s)
Pore size distribution	estimation from soil water-retention curves	X		ISO 11259 (s)
Field capacity	estimation from soil water-retention curves	X		ISO 11274 (s)
Bulk density	direct measurement on undisturbed soil samples, estimation from soil water retention curves	X		ISO 11272 (s)
Infiltration rate	constant head pressure infiltrometer	X		

[a] “X” indicates that the information or characteristic may be relevant. However, decisions about relevance should always be made on a case-specific basis.

[b] If available, (s) standard method for soil.

5.6.3 Chemical parameters

5.6.3.1 General

Conventionally, the chemical parameters to be measured are grouped as follows:

- basic characteristic parameters (Table 5),
- inorganic nutrients/contaminants/pollutants (Tables 6 and 7),
- organic contaminants/pollutants (Table 8).

In many cases, it can be useful to apply leaching/extraction tests to provide information about the release of specified contaminants/pollutants under reference conditions, or under conditions that more closely approximate or simulate the actual field situation under consideration. Leaching/extraction tests cover a range of experimental procedures and systems, from simple one-soil-sample/one-extractant systems (e.g. strong acid, weak extractant/complexing agents and water) to more sophisticated column-flow systems. Annex E gives an overview of the different leaching/extraction types, related assumptions and examples on how to evaluate the results of the tests. Commonly, all tests or extractions result in an eluate/leachant that may be chemically characterized or analysed for basic parameters, inorganic and/or organic contaminants with the analytical methods described in this subclause.

It is important that the contaminant situation in the soil, both in the source zone and at the groundwater table, be well described. The choice of parameters depends on the actual site history and the specific aim of the investigation. It should be noted that the choice of method influences the actual concentration measured, and the assessor should ascertain which methods are the most appropriate for different types of assessment.

Before any laboratory analysis, samples should be subjected to pretreatment (e.g. ground, sub-sampled) compatible with the method(s) of analysis to be employed. Methods for pretreatment shall be used according to ISO 11464 and ISO 14507. Some methods for extraction or analysis include their own requirements regarding pretreatment of samples and these shall always be followed unless there are sound technical reasons not to do so, in which case those reasons should be reported with the analytical results.

5.6.3.2 Basic characteristic parameters

A number of so-called basic characteristic parameters (see Table 5) influence soil processes that effect contaminant concentrations, e.g. adsorption, precipitation and complexation. The International Standards listed in Table 5 shall be applied.

Table 5 — Basic characteristic parameters

Parameter	Methods	Soil[a]	Water[a]	Applicable International Standard[b]
pH	pH-electrode	X		ISO 10390 (s)
			X	ISO 10523 (w)
Redox potential	Redox electrodes	X	X	ISO 11271 (s)
TOC	Combustion			ISO 10694 (s)
	Sulfochromic oxidation			ISO 14235 (s)
			X	ISO 8245 (w)
DOC	Combustion after filtering (0,45 µm)	X	X	
Organic carbon	Dry combustion, sulfochromic oxidation	X		ISO 14235 (s)
Cation exchange capacity	$BaCl_2$ unbuffered,	X		ISO 11260 (s)
	$BaCl_2$ buffered at pH 8,1	X		ISO 13536 (s)
Carbonate content	CO_2-evolution	X	X	ISO 10693 (s)
Specific electrical conductivity	EC-meter	X		ISO 11265 (s)
			X	ISO 7888 (w)
Exchangeable acidity	Titration	X		ISO 14254 (s)

[a] "X" indicates that the information or characteristic may be relevant. However, decisions about relevance should always be made on a case-specific basis.

[b] If available, (s) standard method for soil, (w) standard method for water.

5.6.3.3 Inorganic nutrients, contaminants and pollutants

Nutrients (see Table 6) can be of importance both in themselves and/or as necessary constituents for the biological degradation of organic compounds. The International Standards listed in Table 6 shall be applied.

Table 6 — Inorganic contaminants/pollutants — Nutrients

Nutrient, for example	Speciation/ Form	Extraction methods	Soil[a]	Water[a]	Applicable International Standard[b]
Calcium			X		
Magnesium			X		
Sodium			X		
Potassium	water soluble	H_2O		X	ISO 9964-1 (w)
				X	ISO 9964-2 (w)
				X	ISO 9964-3 (w)
	water soluble	H_2O	X	X	ISO 14911 (w)
Nitrogen	total	Dry combustion	X		ISO 13878 (s)
				X	ISO 11905-2 (w)
		(modified) Kjeldahl	X		ISO 11261 (s)
				X	ISO 10048 (w)
		Peroxodisulfate		X	ISO 11905-1 (w)
				X	ISO 11905-2 (w)
	nitrate	$CaCl_2$-extraction, dry soils	X		ISO 14255 (s)
		KCl-extraction, moist soils	X		ISO 14256-2 (s)
				X	ISO 7890-1 (w)
				X	ISO 7890-2 (w)
				X	ISO 7890-3 (w)
	ammonium	$CaCl_2$-extraction, dry soils	X		ISO 14255 (s)
		KCl-extraction, moist soils	X		ISO 14256-2 (s)
				X	ISO 7150-1 (w)
				X	ISO 7150-2 (w)
	water soluble	H_2O-extraction	X		ISO 14255 (s)
Phosphorus	total	Aqua regia	X	X	ISO 6878 (w)
	weak extractant	$Na(HCO_3)$-extraction	X		ISO 11263 (s)
Sulfur	total	Dry combustion, Aqua regia	X		ISO 15178 (s)
	weak extractant	Dilute HCl	X		ISO 11048 (s)
	water soluble	H_2O	X	X	ISO 11048 (s)

[a] "X" indicates that the information or characteristic may be relevant. However, decisions about relevance should always be made on a case-specific basis.

[b] If available, (s) standard for soil, (w) standard for water.

Metals and metalloids (see Table 7) can be contaminants or natural trace elements, that at higher concentrations may become pollutants. The International Standards listed in Table 7 shall be applied.

Table 7 — Inorganic contaminants/pollutants — Metals, metalloids, trace elements [a]

Metals, metalloids and trace elements[a], for example	Speciation/ form	Extraction/ preparation method	Soil[b]	Water[b]	Applicable International Standard[c]	
					Extraction/ preparation method	Determination method
arsenic, barium, cadmium, chromium, cobalt, copper, cyanides, iron, lead, manganese, mercury, molybdenum, nickel, selenium, thallium, zinc.	total	X-ray fluorescence	X		ISO 14869-2(s)	
		HF + $HClO_4$	X		ISO 14869-1(s)	ISO 11047 (s)
	pseudo-total	Aqua regia	X		ISO 11466 (s) ISO 20279 (s)	ISO 11047 (s) ISO 20279 (s)
	complexing	EDTA	X			
		DTPA	X		ISO 14870 (s)	ISO 11047 (s)
	weak extractant	Diluted acids (e.g. HNO_3)	X			
		$NaNO_3$	X			
		NH_4NO_3	X			
		$CaCl_2$	X			
		KCl	X			
		H_2O	X	X	See NOTE	See NOTE
		See leaching test (Annex E)				

NOTE There are a variety of extraction and analytical methods for soil and soil-water in the series of International Standards which may be applicable. However it is important to confirm that they will work with the extracts obtained from a particular (often contaminated) soil material.

[a] Can be pollutant at higher concentrations.

[b] "X" indicates that the information or characteristic may be relevant. However, decisions about relevance should always be made on a case-specific basis.

[c] If available, (s) standard for soil.

5.6.3.4 Organic contaminants/pollutants

Whereas the inorganic analyst is primarily concerned with the analysis of a defined number of elements and anions, the organic analyst is often interested in looking for any organic compound which may be present. In practice, organic analyses take two forms:

- determination of what is present (qualitative analysis), and
- determination of how much of a specific compound or class of compounds is present (quantitative analysis).

The detection of “adventitious” or unexpected substances, particularly when complex mixtures of organic chemical species are present, requires the use of analytical screening methods, such as gas chromatography/mass spectrometry. It is also customary to employ analytical methods that purport to give total concentrations of classes of compounds such as phenols, polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH) and chlorinated hydrocarbons. Care is required in both the use and interpretation of the results of such methods. Qualitative analysis is frequently carried out prior to quantitative analysis. Class analyses frequently precede specific compound analyses.

“Total” applied to organic compounds (e.g. phenols) usually means that an analytical technique has been employed that cannot distinguish between similar compounds: in the case of phenols, e.g. between monohydric, dihydric and trihydric compounds (i.e. compounds with one, two and three hydroxyl groups attached to the benzene ring). However, the term “total” may be misleading: perhaps not all phenols can be detected by the method employed (e.g. there may be limitations in terms of molar mass or the number and size of other functional groups present on the benzene ring) and different methods can give different results.

Many organic analyses involve extraction with an organic solvent. The solvent used and the conditions of extraction can influence the analytical results. For example, volatile PAHs (generally those of lower molar mass) may be lost during a hot Soxhlet-style extraction, whereas a cold extraction may be less effective in dissolving higher molar mass PAHs. This might be important: for example, when trying to determine residual concentrations of PAHs in a soil material subjected to thermal treatment, those remaining might be expected to be those less volatile.

Analyses of soil materials for volatile organic compounds (e.g. benzene, chlorinated solvents) presents particular analytical difficulties. Research suggests that even under ideal conditions of sampling, transport and sample preparation, substantial losses can occur (one study suggested that 50 % retention was the best that could be achieved). Under less than ideal conditions, almost all can be lost. Thus use of *in situ* methods, such as soil vapour analysis, are likely to give a more reliable indication of distribution and relative concentrations of the substances of concern. In addition, it should be noted that different laboratory methods (e.g. purge-and-trap and head-space analysis) can give substantially different results.

It is important to recognize that organic compounds can be extracted from naturally occurring organic materials (e.g. organic matter, decaying vegetation, peat, coal) and that non-specific analyses, in particular can, therefore, give misleading results.

The listed types of organic contaminants in Table 8 are some of the more commonly encountered, but the list is not exhaustive. The International Standards listed in Table 8 shall be applied.

Table 8 — Organic contaminants/pollutants

Substance/groups of substances	Speciation	Methods	Soil[a]	Water[a]	Applicable International Standard[b]
Mineral oil	gasoline	GC/FID	X	X	ISO 16703
	diesel		X	X X	ISO 11423-1 (w) ISO 11423-2 (w)
Water-miscible solvents				X	
PAHs	e.g. EPA-16	Soxhlet/HPLC/UV	X		ISO 13877 (s)
		RP C-18/HPLC		X	ISO 7981-2 (w)
Phthalates			X	X	
Phenols, chlorophenols		Acetone/GC/ECD	X	X	ISO 14154 (s) ISO 8165-1 (w)
Pesticides		RP C-18/HPLC/UV	X	X	ISO 11369 (w)
					ISO 11370 (w)
					ISO 15089 (w)
		immunoassay			OIML R 112 (s)
		HPLC			ISO 11264 (s)
	phenoxys	GC/MS			ISO 15913 (w)
PCB, chlorobenzenes, organochloro pesticides		GC/ECD	X	X	ISO 10382 (s) ISO 6468 (w)
Chlorinated aliphates	AOX	purge and trap	X	X	ISO 9562 (w) ISO 15009 (s) ISO 10301 (w)
Hydrocarbons		GC/FID or GC/MS, purge and trap thermodesorption			ISO 15009 (s) ISO 15009 (w)
Volatiles		GC/ECD purge and trap thermodesorption, GC/ECD or head space technique			ISO 15009 (s) ISO 10301 (w) ISO 10301 (w)
Trianzines, phenylurea herbicides		HPLC	X		

NOTE There are a variety of extraction and analytical methods for water in the series of International Standards which may be applicable. However it is important to confirm that they will work with the extracts obtained from a particular (contaminated) soil material.

[a] "X" indicates that the information or characteristic may be relevant. However, decisions about relevance should always be made on a case-specific basis.

[b] If available, (s) standard method for soil, (w) standard method for water.

5.6.4 Biological parameters

Biological parameters are often of specific interest for groundwater contamination risk assessment because they influence

- degradability of organic compounds in soils: The contaminant concentration at the groundwater table will depend not only on dilution and adsorption but also on the microbial influence on degradable components. To be able to assess this activity in both the present and future situation, information on the microbial activity (see Table 9) in the soil in question is important.
- (eco-)toxicological potential of organic compounds in the percolating soil water or groundwater: If the evaluation of soil contamination aims at determining the leachability and/or bioavailability of organic compounds, eco-toxicological investigations of the fluid phase (see Table 9) can be carried out to characterize the soil's inherent retention capacity analogously to physical and chemical extraction or leaching tests (see E.5).

The following biological parameters (see Table 9) are examples; the International Standards listed shall be applied. For comprehensive information, ISO 15799 shall be applied.

Table 9 — Biological parameters

General characteristic	Specific measurement/example	Soil[a]	Water[a]	Applicable International Standard[b]
Microbial activity	Mineralization of organic chemicals	X		ISO 14239 (s)
	Biodegradation under aerobic conditions	X		ISO 11266 (s)
	Biodegradation under anaerobic conditions	X		ISO 15473 (s)
	Nitrogen mineralization	X		ISO 14238 (s)
Ecotoxicity	Inhibition of luminescence		X	ISO 11348-1 (w)
			X	ISO 11348-2 (w)
			X	ISO 11348-3 (w)
	Inhibition of biomass (algae test)		X	ISO 15799 (w)
	Inhibition of plant growth (ecotoxical effect on early growth stage)		X	
	Acute immobilization (inhibition of mobility of Daphnia)		X	ISO 6341 (w) ISO 15799 (w)
Biological pathogens		X	X	

[a] "X" indicates that the information or characteristic may be relevant. However, decisions about relevance should always be made on a case-specific basis.

[b] If available, (s) standard method for soil, (w) standard method for water.

6 Data handling, evaluation and quality

The purpose of characterizing soil (or other media) as suggested in this International Standard is usually to enable site assessment with respect to impact on groundwater. This International Standard provides guidance on the types of data that might be required in an assessment, and indicates for which parameters or procedures there are International Standards available. The assessor shall choose those parameters that are appropriate to the task in hand.

Estimations of uncertainty are of crucial importance to risk assessments, as they provide a measure of confidence in the site investigation data and ultimately the final outcome of the risk assessment. Uncertainties typically concern

- the extent to which the contaminant data from single samples are spatially/vertically representative of the site conditions,
- the extent to which sampling techniques are adequate to ensure that a sample is representative of the site conditions at the point where it was taken,
- the extent to which analytical data reflects the actual characteristics (concentrations, form/state, mobility, etc.) of the contaminants present,
- the extent to which the pedological, geological, hydrogeological and geotechnical conditions at the site are understood,
- the ways in which the contaminants may behave in the environment setting of the site and surrounding areas (fate and transport issues),
- the extent to which behaviour of the receptors potentially at risk under the particular circumstances can affect the risk estimates,
- how the receptors can be affected by the contaminants, and what role the different receptor characteristics plays in this.

Before any judgement can be made about impact on groundwater, the sufficiency of data to be used shall be evaluated. The data shall be sufficient in terms of

- type,
- quantity, and
- analytical/testing quality.

In the context of data quality it is essential to

- define the objectives of the investigation,
- establish a sampling strategy in terms of types of samples to be obtained, sampling locations, and how samples are to be handled consistent with these objectives (more detailed guidance on stepwise sampling strategy is provided in 5.1),
- establish an analytical and testing strategy taking into account the guidance in this and other relevant International Standards,
- set data quality objectives consistent with the assessment procedure to be used.

It is essential to have sufficient data. The confidence that can be attached to any judgements made, for example through comparison with the requirements of a published standard (the requirements in such standards regarding sampling shall always be followed) or a site-specific risk assessment, is no greater than the confidence there is in the representativeness of the data.

The assessor will need to bear in mind the disproportionate costs and time delays that can result if it is necessary to carry out an additional sampling exercise if, for example, a particular parameter is not determined when the opportunity is available.

Care shall be taken in deciding what statistical expression(s) of the data is to be used in the assessment, as this may affect the choice of sampling procedures. For groundwater impact investigations, a statistic such as the “95% upper confidence level of the mean” or the “maximum observed value” is recommended.

The quality of the data to be used shall be assured by some or all of the following:

- setting formal data quality objectives (e.g. for accuracy, reproducibility, etc.);
- using standardized analytical and testing methods such as those listed in this International Standard or, where International Standard methods are not available, those published by national standardization or equivalent bodies;
- using laboratories accredited under ISO 9001:2000;
- using laboratories using methods accredited under regional schemes such as ISO/IEC 17025.

NOTE Often, the reports presenting the results of assessments will be scrutinized by regulators and other interested parties, including the general public. It is important, therefore, that such reports are of a high technical standard but also take account of the diverse and often non-technical readership. Use should therefore be made of tabular summaries, graphical and other means to present the data in ways that will make the data and conclusions as easy as is practicable to assimilate and assess.

Annex A
(informative)

Qualitative methods for assessing the potential leaching risk

A.1 General

The behaviour of inorganic or organic contaminants in soils with respect to the resulting leaching risk to groundwater can be assessed qualitatively or quantitatively. Qualitative methods only need a very limited number of easily available input data, but are consequently restricted in their assessment to qualitative (relative) evaluations. Mostly they are applied in order to classify the soil's inherent binding force and leaching risk, preferably on a regional or larger scale, when quantitative information about the actual soil contamination is lacking.

Qualitative assessment methods can be characterized as deterministic approaches with a modular structure. They are based on simple empirical relations using mathematically derived and formalized matrices, and thus they rigorously simplify the underlying physical and/or chemical processes. In contrast to quantitative assessment models (see Annex B), the relevant transport and transformation phenomena in soils are not described on a process-orientated basis. Qualitative assessment approaches are often categorized as “functional” or “non-mechanistic” models which consist of pedotransfer functions and rules (see [15]). With respect to water and solute fluxes, they refer at least to the principle of mass balance.

Functional forecasting models aim at qualitative (relative) evaluations, e.g. in terms of a low, medium or high leaching risk. The result of a qualitative risk assessment is expressed as a potential leaching risk because, in contrast to quantitative ”mechanistic” models (see Annex B), the actual soil contamination is not taken into account. The physical, chemical and biological properties (see Clause 5) of the soil and its contaminants are generally needed as input data. The information on soil properties is available from soil maps and digital soil-information systems, or can be derived from them by applying simple transfer rules and transfer functions (see [9]). Additionally, information on climate, hydrology and land use may be also provided in digital information systems or from paper maps.

The application of qualitative assessment models is restricted to moderately contaminated soils (databases typified by diffuse source input), whereas quantitative evaluations are carried out in case of strong suspicion of soil contamination predominantly on a local scale. With respect to the kind and limited number of input data and the level of risk evaluation, qualitative assessment models may not substitute for site-specific investigations (i.e. laboratory and/or field measurements in order to quantitatively evaluate an assumed or ascertained soil contamination) as suggested in Annex B. Qualitative assessment models should not be used for evaluation of accident situations or concentrated input from a point source. Nevertheless, a qualitative risk assessment may be a helpful introductory step in an assessment of an actual contaminated site.

The application of qualitative assessment models is recommended specifically for

- landscape management purposes (e.g. definition of drinking-water protection zones, environmental impact studies on regional and larger scales),
- evaluation of the potential and actual contamination of soil to the groundwater from inorganic and organic contaminants [e.g. fertilisers (nutrients like nitrogen), plant treatments (pesticides), treatments of sewage sludge, compost or other organic waste material (heavy metals, organic compounds)].

In A.2 to A.4, three examples of qualitative methods for the assessment of a potential leaching risk are given for

- inorganic non-reactive contaminants (see A.2),

- inorganic reactive contaminants (heavy metals) (see A.3), and
- organic contaminants (see A.4).

The examples have been selected from a set of comparable methods implemented in soil information systems of European soil survey institutes. The methods are developed and calibrated for northern and central European climatic and soil conditions (see [3]). The selected approaches should not be applied to different soils and climatic conditions (e.g. subtropical and tropical regions) before calibrating them under comparable boundary conditions. This is particularly important for reactive inorganic and organic contaminants (see [10]).

A.2 Qualitative methods for assessing the potential leaching risk — Non-reactive contaminants

A.2.1 Introduction

Non-reactive contaminants such as nitrate or chloride migrate through soil with little retardation compared to the speed of percolating water. Nitrate has a relatively high potential for groundwater contamination, especially in soils under arable land use. The following approach allows assessment of

- replacement rate of soil water at field capacity, and
- the speed of translocation and retention time of non-reactive contaminants at a qualitative level.

NOTE This assessment approach considers only vertical (upward and downward) movement of water and solutes.

The approach consists of the following three steps shown in Table A.1.

Table A.1 — Stepwise-approach scheme

Step	Specification	Input parameters	Sensitivity to the result
1	Replacement rate of water, n_s	percolating water rate, v_c	high
		actual rooting depth, d_r	medium
		field capacity in actual root layer, h_f	medium
2	Speed of translocation, v_u	percolating water rate, v_c	high
		volume fraction (expressed as column height) of water, h_u	medium
3	Retention time of the percolating water, t_u	speed of translocation, v_u	high
		thickness of the unsaturated zone, d_u	medium

A.2.2 Step 1: Assessment of the replacement rate of the soil water at field (retention) capacity

Through the replacement of the soil water, substances dissolved in the soil are washed out of the root layer and are no longer available for plants. A low replacement rate thus means a high retention capacity of dissolved substances in the actual root layer.

The replacement rate, n_s, expressed in reciprocal years (a^{-1}), is calculated according to the equation

$$n_s = \frac{v_c}{h_f} \qquad \text{(A.1)}$$

where

v_c is the percolating water rate, in millimetres per year;

h_f is the field capacity in actual root layer, expressed as height, in millimetres, of a column of water in the soil.

In order to take into account soil-water storage, the field capacity in the actual root layer is selected as the whole flow cross-section. It is determined in accordance with ISO 11274. For the assessment of the replacement rate of the soil water at field capacity, see Table A.2.

Table A.2 — Assessment of replacement rate

Replacement rate, n_s a^{-1}	$< 0{,}7$	0,7 to 1,0	$>$ 1,0 to 1,5	$>$ 1,5 to 2,5	$> 2{,}5$
Assessment	Very low	Low	Moderate	High	Very high

EXAMPLE Luvisol

Actual rooting depth, d_r = 1 100 mm

Field capacity in the actual root layer, h_f = 395 mm

Percolating water rate, v_c = 250 mm·a^{-1}

Replacement rate [according to Equation (A.1)]:

$$n_s = \frac{250}{395} = 0{,}63 \text{ a}^{-1}$$

Assessment: The replacement rate is very low.

A.2.3 Step 2: Assessment of the speed of translocation

The speed of translocation of the percolating water, v_u, expressed in millimetres per year, underneath the actual root layer is given by Equation (A.2).

$$v_u = \frac{v_c}{h_u} \qquad \text{(A.2)}$$

where

v_c is the percolating water rate, in millimetres per year;

h_u is the volume fraction of water in the soil, expressed as millimetres of water column per millimetre of soil column.

NOTE For the water content beneath the root layer soil zone, the field capacity is used as a “volume fraction” in the calculation.

The calculation of the mean volume fraction of water should be carried out for the whole percolated space, layer by layer.

A.2.4 Step 3: Assessment of the retention time

If the thickness of the percolated soil volume is known and the individual layers of the different soil types are taken into account, the retention time, t_u, in years, of the percolating water in the percolated soil volume can be estimated from the translocation speed according to Equation (A.3).

$$t_u = \frac{d_u}{v_u} \qquad \text{(A.3)}$$

where

d_u is the thickness of the unsaturated zone, in millimetres;

v_u is the translocation speed of the percolating water, in millimetres per year.

The assessment of the translocation speed of the soil water takes place in accordance with Table A.3.

Table A.3 — Assessment of the speed of translocation

Translocation speed, v_u mm/a	< 500	500 to 1 000	$>$ 1 000 to 1 500	$>$ 1 500 to 2 000	$>$ 2 000
Assessment	Very low	Low	Moderate	High	Very high

EXAMPLE Luvisol

Actual rooting depth: 1 100 mm

Field capacity in the actual root layer, h_f = 395 mm

Groundwater surface: 5 000 mm below land surface

Percolating water rate, v_c = 250 mm·a^{-1}

Mean volume fraction of water, h_u, beneath the actual root layer [volume fraction of water of all soil horizons (1 636 mm) minus the values for the root layer from the example in A.2.2]:

$$h_u = \frac{1\,636 - 395}{5\,000 - 1\,100} = \frac{1\,241}{3\,900} = 0{,}318 \text{ mm/mm}$$

Translocation speed, $v_u = \frac{250}{0{,}318} = 786 \text{ mm} \cdot \text{a}^{-1}$

Assessment: The speed of translocation is low.

Retention time, $t_u = \frac{3\,900}{786} = 4{,}9 \text{ a}$

NOTE 1 The quotient calculated according to Equations (A.2) and (A.3) describes only the mass focus of a translocation front. The flow of material moving in advance and following behind, caused by hydrodynamic dispersion, cannot be calculated with this estimation.

NOTE 2 Preferred flow paths (e.g. macropore flow) can influence the translocation speed, depending on the location of the substance in the soil. If the substance is lying directly on the surface (e.g. after fertilizer application), the process leads to an acceleration of deep translocation. If the substance is principally in the soil matrix, preferred flow paths lead to a reduction of deep translocation, because there is less water in total available for the matrix flow. The phenomenon of preferred flow paths applies primarily to clay soils, and thus plentifully layered soils. For the estimation of the replacement rate and the translocation speed of these soils, the mobile water content contributing to the transport can be used instead of the field capacity.

NOTE 3 At sites in hydraulic continuity with groundwater, capillary rise leads to a reduction in the net percolating water rate, as part of the winter percolation is transported into the root layer again in the summer season. How far this oscillating water movement leads to groundwater contamination through non-sorbable substances depends on whether the speed of translocation during the winter months is sufficient to force the substance front to the groundwater table. In these cases, the percolating water rate should be calculated separately for the hydrologic water season.

NOTE 4 Climatic site conditions (temperature) and degradation processes can influence the contaminant content in percolating water.

A.2.5 Database

The estimation of the percolating water rate can be undertaken with the aid of nomograms, simulation models and measuring methods (lysimeter).

The year (normal year, hydrologic year) should be taken into account as reference period, as percolating water can also be produced in the summer season (regions with heavy precipitation and/or light soils). At sites close to groundwater, the capillary rise from the groundwater should be also taken into account.

A.3 Qualitative methods for assessing the potential leaching risk — Inorganic contaminants (heavy metals)

A.3.1 Introduction

A simple qualitative approach for assessing the potential risk to groundwater brought about by the leaching heavy metals from soils in the unsaturated zone is described. The method makes use of information about soils and their characteristics, which govern their filter functions for selected inorganic compounds. This information is often available in soil maps or digital soil information systems.

The approach consists of the following three steps according to Table A.4.

Table A.4 — Stepwise assessment scheme

Step	Specification	Input parameters	Sensitivity to the result
1	Element-specific relative binding force, b_M, of the groundwater-free soil	pH value	high
		soil texture (topsoil and subsoil)	medium
		organic carbon content	medium
2	Annual climatic water balance, v_c	annual climatic water balance	medium
3	Distance to groundwater, d_u	mean groundwater table	very high

A.3.2 Step 1: Assessment of the relative binding force of the unsaturated soil

For assessing the relative binding force of soil materials in the unsaturated zone for heavy metals, all horizons should be taken into account down to the groundwater table (high).

The value of the metal-specific relative binding force of every horizon for a given pH can be deduced from Table A.5. It is defined for a weakly sorbing sandy soil with a clay content below 5 % and an organic carbon content below 1 %.

For setting the initial value of the assessment, select a minimum layer of 0,3 m thickness with the highest relative binding force, b_M. For thicknesses $< 0,3$ m, estimate the b_M from a 0,3 m layer surrounding this horizon.

The effect of higher organic carbon and clay contents shall be taken into account for topsoil and subsoil properties separately. Topsoil shall be understood as the upper 0,3 m of a soil profile (including humus cover of forest soils, see footnote in Table A.7).

For topsoil properties, the relative binding force for metal ions depending on soil components at a given pH as a threshold value can be taken from Table A.6. This value acts as an input parameter to Table A.7 (effect of organic carbon content), to Table A.8 (effect of clay content) and to Table A.9 (effect of oxides and hydrous oxides) for deducing values to be added to the initial value of the relative binding force, b_M, given in Table A.5.

The effect of average contents of oxides and hydrous oxides is already taken into account by the clay content, since the content of oxides and hydrous oxides normally correlates strongly with the clay content. High ferric oxide contents can be predicted from intense brown or red colouring. In this case, added values as defined in Table A.9 are obtained.

Added values with regard to subsoil properties can be taken directly from Table A.6 (minimum horizon thickness: 0,3 m).

In the case of highly swelling and shrinking soils (fissure width > 1 cm and at least in 0,5 m deep), the added value for high clay contents (> 45 % clay) according to Table A.8 shall be reduced by one stage with regard to the effect of rapid water infiltration into dry fissures. In the case of temporarily waterlogged soil conditions, a reduction of one stage (1,0) is recommended.

If the sum of the values defined in Tables A.5 to A.10 for the metal in question is above 5 ("very high"), the relative binding force to metal ions of the groundwater-free soil (b_M) shall be rounded to 5.

Table A.5 — Effect of soil acidity on the relative metal binding force (b_M) of sandy soils (< 5 % clay) with low organic carbon content (< 1 %)

Metal	Relative binding force b_M at pH ($CaCl_2$)-values of									
	2,5 to 2,7	> 2,7 to 3,2	> 3,2 to 3,7	> 3,7 to 4,2	> 4,2 to 4,7	> 4,7 to 5,2	> 5,2 to 5,7	> 5,7 to 6,2	> 6,2 to 6,7	> 6,7 to 8,0
Cd	0	0,5	1,0	1,5	2,0	2,5	3,5	4,0	4,5	5,0
Mn	0	1,0	1,5	2,0	2,5	3,0	4,0	4,5	5,0	5,0
Ni	0	1,0	1,5	2,0	2,5	3,0	4,0	4,5	5,0	5,0
Co	0	1,0	1,5	2,0	2,5	3,0	4,0	4,5	5,0	5,0
Zn	0	1,0	1,5	2,0	2,5	3,0	4,0	4,5	5,0	5,0
Al	1,0	1,5	2,0	3,0	3,5	4,5	5,0	5,0	5,0	5,0
Cu	1,0	1,5	2,0	3,0	3,5	4,5	5,0	5,0	5,0	5,0
Cr(III)	1,0	15	2,0	3,0	3,5	4,5	5,0	5,0	5,0	5,0
Pb	1,0	2,0	3,0	4,0	5,0	5,0	5,0	5,0	5,0	5,0
Hg	1,0	2,0	3,0	4,0	5,0	5,0	5,0	5,0	5,0	5,0
Fe(III)	1,5	2,5	3,5	5,0	5,0	5,0	5,0	5,0	5,0	5,0

NOTE Ranking ranges of metal binding force: 0 to < 0,5 = none, 0,5 to < 1,5 = very low, 1,5 to < 2,5 = low, 2,5 to < 3,5 = medium, 3,5 to < 4,5 = high, 4,5 to 5 = very high.

Table A.6 — Relative binding force (in terms of ranking ranges) of soils for metal ions independent of soil composition at a given threshold pH ($\mathrm{CaCl_2}$)

Metal	Threshold pH	Substrate-caused binding force[a] below threshold pH[b] by		
		organic carbon	clay	oxides and hydrous oxides[c]
Cd	6,0	4,0	2,0	3,0
Mn	5,5	2,0	3,0	3,0
Ni	5,5	3,5	2,0	3,0
Co	5,5	3,0	2,0	3,0
Zn	5,5	2,0	3,0	3,0
Al	5,0	5,0	4,0	4,0
Cu	4,5	5,0	3,0	4,0
Cr (III)	4,5	5,0	4,0	5,0
Pb	4,0	5,0	4,0	5,0
Hg	4,0	5,0	4,0	5,0
Fe (III)	3,5	5,0	5,0	

[a] Ranking ranges of metal binding force: < 0,5 = none, 0,5 to < 1,5 = very low, 1,5 to < 2,5 = low, 2,5 to < 3,5 = medium, 3,5 to < 4,5 = high, 4,5 to 5 = very high.

[b] Above given pH-threshold value, high accumulation by oxide formation (Al, Fe, Mn) and binding of hydroxy complexes (others).

[c] Oxides and hydrous oxides of Fe, Al, and M.

Table A.7 — Factors for estimating the effect of organic carbon content (of the upper 0,3 m) on the metal binding force based on the values defined according to Table A.6

Kind of organic matter[a]	Organic carbon content, % (mass fraction)	Binding force of organic carbon according to Table A.6			
		2,0	3,0	4,0	5,0
Sapric	⩽ 0,5	0	0	0	0
	> 0,5 to 1	0	0	0	0,5
	> 1 to 2	0	0	0,5	1,0
	> 2 to 4	0	0,5	0,5	1,0
	> 4 to 8	0,5	0,5	1,0	1,5
	> 8	0,5	1,0	1,5	2,0
Hemic		0,5	0,5	1,0	1,5
Fibric		0	0,5	0,5	1,0

[a] Intensity of humification: sapric: high, hemic: medium, fibric: low.

Table A.8 — Factors for calculating the effect of the clay content (mean of the upper 0,3 m soil) on the metal binding force based on the values defined according to Table A.6

Clay content[a] % (mass fraction)	**Metal binding force related to clay content according to Table A.6**[b]			
	2	**3**	**4**	**5**
< 5	0	0	0	0
5 to 12	0	0	0,5	0,5
> 12 to 25	0	0,5	0,5	1,0
> 25 to 45	0	0,5	1,0	1,5
> 45	0,5	1,0	1,5	2,0

[a] Limits of clay content have been derived from soil texture classes according to German soil classification system (see [2] in the Bibliography).

[b] For each 25 % (mass fraction) of gravel or sand, the added value shall be lowered by 0,5.

Table A.9 — Factors for estimating the effect of higher contents of ferric oxides in the upper 0,3 m on the metal binding force (b_M) based on the values defined according to Table A.6

Effect of oxides and hydrous oxides according to Table A.6	**Effect of higher ferric oxide contents on b_M at Hue $\leqslant$ 7,5 and Chroma/value ratio of**		
	up to 1	**1 to 1,5**	**> 1,5**
3	0	0,5	1
4	0	1,0	1,5
5	0	1,5	2,0

Table A.10 — Values to be added to take into account organic carbon content and substrate of subsoil or subground (minimum depth of 0,3 m) with regard to the metal binding force (b_M) based on values defined according to Table A.6

Subsoil properties (mass fraction)	**Value to be added**
> 1 % organic carbon	1,0
> 25 % clay	1,0

A.3.3 Step 2: Climatic water balance

The effect of the annual climatic water balance (v_c) on the hazard to groundwater at given ranges of the metal binding force (b_M), including all added values depending on the organic carbon and clay contents in groundwater-free soil, is shown in Table A.11.

Table A.11 — Effect of the climatic water balance (v_c) on the movement of heavy metal ions in the soil (in terms of ranking ranges) related to metal binding force

v_c[a] mm/a	Metal binding force b_M (according to Tables A.5 to A.10)[b]										
	5	**4,5**	**4,0**	**3,5**	**3,0**	**2,5**	**2,0**	**1,5**	**1,0**	**0,5**	**0**
− 100 to 0	0	0	0	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0
> 0 to 100	0	0	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5
> 100 to 200	0	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0
> 200 to 300	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,0
> 300 to 400	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,0	5,0
> 400 to 600	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,0	5,0	5,0
> 600	2,5	3,0	3,5	4,0	4,5	5,0	5,0	5,0	5,0	5,0	5,0

[a] vc is the infiltration, expressed as the difference between annual precipitation and evapotranspiration. For agricultural use, add 50 mm; for forestry use, reduce by 50 mm; for saturated hydraulic conductivity of 40 cm/d to 100 cm/d in the rooting zone, add 50 mm; for 100 cm/d to 300 cm/d in the rooting zone, add 100 mm; for > 300 cm/d or cracks in the rooting zone, add 150 mm.

[b] Ranking ranges of the movement: < 0,5 = none, 0,5 to < 1,5 = very low, 1,5 to < 2,5 = low, 2,5 to < 3,5 = medium, 3,5 to < 4,5 = high, 4,5 to 5 = very high.

A.3.4 Step 3: Groundwater table

Contamination of groundwater by heavy metals also depends on the length of the filter line above the groundwater level. Table A.12 shows the effect of the distance to the groundwater table and the movement ranking ranges on the groundwater hazard (in terms of ranking ranges).

Table A.12 — Potential groundwater contamination risk (hazard ranking ranges) of heavy metals in relation to groundwater level (low/high) and movement ranking ranges (according to Table A.11) in groundwater-free soil

Movement ranking range[a]	Groundwater table depth below surface m							
(according to Table A.11)	low high	< 0,4 < 0	0,4 to < 0,8 0 to < 0,2	0,8 to < 1,3 0,2 to < 0,4	1,3 to < 1,6 0,4 to < 0,8	1,6 to < 2,0 0,8 to < 1,6	2,0 to < 3,5 1,6 to < 2,0	⩾ 3,5 ⩾ 2,0
0 to < 0,5		5,0	4,5	3,5	2,0	1,5	1,0	0,5
0,5 to < 1,5		5,0	5,0	4,0	2,5	2,0	1,5	1,0
1,5 to < 2,5		5,0	5,0	4,5	3,0	2,5	2,0	1,5
2,5 to < 3,5		5,0	5,0	5,0	3,5	3,5	3,0	2,0
3,5 to < 4,5		5,0	5,0	5,0	4,5	4,5	4,0	3,0
4,5 to 5		5,0	5,0	5,0	5,0	5,0	4,5	4,5

[a] Hazard ranking ranges: < 0,5 = none, 0,5 to < 1,5 = very low, 1,5 to < 2,5 = low, 2,5 to < 3,5 = medium, 3,5 to < 4,5 = high, 4,5 to 5 = very high.

A.3.5 Examples of application

NOTE Symbols used in the following examples for soil designations are in accordance with the FAO system, where the upper case letter designates the soil horizon and the lower case letter designates a special feature of this horizon. This system is described in ISO 11259. Symbols used for soil colours are in accordance with the Munsell colour charts, also described in ISO 11259.

EXAMPLE 1 Soil unit: Arenosol from glacifluvial sand (arable soil) (Northern Germany); see Table A.13

— Annual climatic water balance: + 350 mm/a [200 mm/a plus 50 mm/a (arable soil) plus 100 mm/a (saturated hydraulic conductivity k_f = 200 cm/d)];

— Ap (0 m to 0,3 m): S (< 5 % clay), dark-grey brown (10 YR 3,5/2), low organic carbon content (< 1 %), pH 4,9;

— subsoil down to groundwater: S (< 2 % clay), brown (7,5 YR 5/3) — light grey (2,5 Y 7/2), low organic carbon content (< 1 %), pH 6,2, saturated hydraulic conductivity k_f = 200 cm/d;

— groundwater depth level (high) 2,5 m.

Table A.13 — Determination of potential groundwater contamination risk for Example 1 in A.3.5

Parameter	Cd	Zn	Cu
Effect of pH (Table A.5)	2,5	3,0	4,5
Effect of organic carbon[a] (Tables A.6 and A.7)	0	0	+ 0,5
Effect of soil texture (Tables A.6 and A.8)	0	0	0
Fe-oxide effect (Tables A.6 and A.9)	+ 1,0	+ 1,0	+ 1,5
Effect of subsoil (Table A.10)	0	0	0
Binding force in total soil, b_M	3,5	4,0	$\geqslant$ 5,0
Effect of climate (water balance): 350 mm (arable soil) Movement ranking range (Table A.11)	2,5	2,0	1,0
Potential groundwater contamination risk (hazard ranking range) according to Table A.12	3,0	2,0	1,5
Evaluation	**medium**	**low**	**low**

[a] Example: in Table A.6: relative binding force for Cd to organic carbon: 4; in Table A.7, for < 1 % organic carbon content (mass fraction), the relative binding force to organic carbon is 0.

EXAMPLE 2 Soil unit: mollic Gleysol from till (grassland) (Southern Germany); see Table A.14

— Annual climatic water balance: + 350 mm/a;

— Ah (0 m to 0,3 m); clayey loam (35 % clay), dark brown (7,5 YR 2,5/4), high organic carbon content (3 %), pH 5,1, saturated hydraulic conductivity k_f = 30 cm/d;

— Go (0,3 m to 0,5 m): sandy loam (20 % clay), red brown (5 YR 4/6), low organic carbon content (< 1 %), pH 5,1, saturated hydraulic conductivity k_f = 10 cm/d;

— Gr (> 0,5 m): sandy loam (20 % clay), green grey (5 BG 6/1);

— groundwater level (high): 0,42 m.

Table A.14 — Determination of potential groundwater contamination risk for Example 2 in A.3.5

Parameter	Cd	Zn	Cu
Effect of pH (Table A.5)	2,5	3,0	4,5
Effect of organic carbon (Tables A.6 and A.7)	+ 0,5	0	+ 1,0
Effect of soil texture (Tables A.6 and A.8)	0	+ 0,5	+ 0,5
Fe-oxide effect (Tables A.6 and A.9)	0	0	0
Reduction for temporary waterlogging	− 1,0	− 1,0	− 1,0
Effect on subsoil (Table A.10)	0	0	0
Binding force in total soil, b_M	2,0	2,5	5,0
Effect of climate (water balance): 350 mm (grassland) according to movement ranking range (Table A.11)	4,0	3,5	1,0
Potential groundwater contamination risk (hazard ranking range) according to Table A.12 (groundwater level at 4 dm to 8 dm below surface)	5,0	5,0	5,0
Evaluation	**very high**	**very high**	**very high**

A.4 Qualitative methods for assessing the potential leaching risk — Organic contaminants

A.4.1 Introduction

For assessing the potential leaching risk in soils moderately contaminated by organic compounds, a method is presented which considers and evaluates the essential processes which organic compounds undergo in the soil ecosystem. It should not be used in case of point-source contamination caused e.g. by accidents, landfills and deep hazardous abandoned sites. However, it may be used as a helpful means in the selection of sampling points for soil analyses in the case of large areas, in evaluation of soil clean-up activities and soil protection.

The basic processes which organic contaminants undergo in soil can be grouped into three steps:

a) **Binding step**

  1) to organic carbon, covered by the Freundlich K_{oC} value of a compound,

  2) to clay minerals and/or Fe/Mn oxides, covered by the Freundlich K_d value of a compound, related to the clay content and expressed as K_{clay},

  3) effect of pH on the binding constant.

b) **Elimination step**

  1) chemico-biological degradation, aerobic/anaerobic, covered by 90 % elimination,

  2) volatilization, determined for wet soils by the Henry constant or for dry soils by the vapour pressure.

c) **Water movement step**

  1) infiltration, dependent on the water balance of site,

  2) depth of groundwater.

These three process steps promote each other, but may have also an inhibitory effect. Strong binding, for example, generally inhibits degradation, infiltration and volatilization. However, highly bound compounds can also be mobilized by dissolved humic acids or solubilizers (e.g. tensides, solvents). It is clear that the properties of the element mainly determine binding, elimination and mobility in soil.

This assessment procedure should allow coverage of the site-specific characteristics, depending on pollutant properties, by following the steps given in Table A.15.

Table A.15 — Stepwise assessment scheme

Step	Specification	Input parameters	Sensitivity to the result
1	Binding stage (b_o) of the pollutants	adsorption constant K_{oC}/K_{clay}	high
		pH value	low
		soil texture (topsoil and subsoil)	medium
		organic carbon content	high
2	Elimination stage (e_o) of the pollutants	degradation	high
		temperature	medium
		volatilization	medium
3	Movement ranking range	annual climatic water balance	high
	Risk of groundwater contamination (hazard ranking range)	mean groundwater table	very high

A.4.2 Properties and behaviour of organic chemicals in soils

A.4.2.1 Binding ranking ranges

Binding ranking ranges are given as a function of sorption coefficient K_{oC} or K_{clay} (or K_d according to the Freundlich equation) of organic carbon or clay (liquid/solid ratio of 1 to 2 up to 1 to 5).

Binding ranking[a]	Sorption coefficient	
	K_{oC} l·kg^{-1}	K_{clay} l·kg^{-1}
0	$<$ 1	$<$ 0,5
1	1 to 100	0,5 to 50
2	100 to 300	50 to 150
3	300 to 1 000	150 to 500
4	1 000 to 10 000	500 to 5 000
5	$>$ 10 000	$>$ 5 000

NOTE pH effect + or –, binding increases with increasing or decreasing pH; pH value 0 = no effect on binding.

[a] 0 = practically none, 1 = very low, 2 = low, 3 = medium to high, 4 = high, 5 = very high.

A.4.2.2 Degradation ranking ranges

Degradation ranking[a]	Time for ~ 90 % degradation of parent compound
1	⩾ 3 years
2	1 year to < 3 ans
3	18 weeks to < 1 year
4	6 weeks to < 18 weeks
5	< 6 weeks
[a] 1 = very low, 2 = low, 3 = medium to high, 4 = high, 5 = very high.	

Data on degradation apply to reference arable land (wet, loamy topsoil with 1 % to 2 % organic carbon content, a pH of 5,5 to 6,5 and a mean air temperature of 11 °C to 16 °C). Note that some of the organic contaminants form toxic degradation products.

A.4.2.3 Volatilization ranking ranges

Volatilization ranking[a]	Wet soils (Henry's constant) (dimensionless)	Dry soils (vapour pressure) hPa
1	$< 4 \times 10^{-6}$	< 0,001
2	4×10^{-6} to 4×10^{-4}	0,001 to 100
3	4×10^{-4} to 0,04	100 to 500
4	> 0,04	> 500 (in this case the volatilization rank was put in brackets)
[a] 1 = very low, 2 = low, 3 = medium to high, 4 = high.		

When Henry's constant is not available, the vapour pressure of the pure substance, in hectopascals at 20 °C to 25 °C, may be used.

If properties of the compounds are classified between two rankings, the mean of both should be used (e.g. ranking 2 to 3 gives 2,5).

The behaviour of different chemicals in reference agricultural soils is shown in Table A.16. Modifications as a result of deviating site conditions should be predicted. The reliability of the statement in Table A.16 thus mainly depends on the state of knowledge about the behaviour of the different chemicals in reference (benchmark) soils. Predictions as to the binding and degradation in topsoil as well as to the volatilization from topsoil and contaminants mobility are essential with regard to the assessment of the potential groundwater pollution risk.

The classification of the organic substances to binding, volatilization and degradation ranking ranges is based on references [4], [8], [10], [11] and [12].

Table A.16 — Ranking ranges of key parameters determining the behaviour of organic chemicals in soils

Substance groups		Binding ranking		pH effect	Degradation ranking		Volatilization ranking[a]
		by organic carbon	by clay		aerobic	anaerobic	
Acyclic compounds (especially halogen derivatives)							
1	Dichloromethane (DCM)	1	1	0	3 to 4	2	4
2	Trichloromethane (chloroform)	1 to 2	2	0	2 to 3	1 to 2	4
3	Tetrachloromethane (Tetra)	1 to 2	2	0	1	3	4
4	1,2-Dichloroethane	1	2	0	3	2	3
5	Monochloroethene (vinyl chloride)	1	1	0	4	4	4
6	Trichloroethene (Tri)	2	1	0	3	2	4
7	Tetrachloroethene	1 to 2	1	0	3	2	4
Carbocyclic compounds (especially benzene derivatives)							
8	Benzene	1 to 2	1	0	3	2	4
9	1,2-Dichlorobenzene	3 to 4	2	0	2	2	4
10	1,2,4-Trichlorobenzene	3	1 to 2	0	2 to 3	1 to 2	4
11	Phenol	1 to 2	1 to 2	–	2	4	1 to 2
12	2,5-Dichlorophenol	2 to 3	2	–	3	4	2
13	2,4,5-Trichlorophenol	3	1 to 2	–	4	4	2
14	Pentachlorophenol (PCP)	3 to 4	2	–	3	2 to 3	1
15	Aniline	1 to 2	1	+	4 to 5	4	1
16	4-Chloroaniline	3	2 to 3	+	2	2	2
17	Toluene	1 to 2	1	0	4	2 to 3	4
18	Toluidine	2 to 3	1	+	2	1	1
19	Xylene	2 to 3	2	0	4	3	4
Polycarbocyclic compounds							
20	Naphthalene	4	2	0	3 to 4	1	3
21	Naphthylamine	4	3	+	2	1	
22	Anthracene	4 to 5	3	0	3	1	2
23	Phenanthrene	4 to 5	3	0	3	1	2
24	Pyrene	5	3	0	1 to 2	1	2 to 3
25	Benz[a]pyrene	5	3	0	2	1	2
26	Dibenz[a,h]anthracene	5	3	0	2	1	2
27	Fluoroanthene	5	2 to 3	0	1 to 2	2	1

Table A.16 (*continued*)

Substance groups		Binding ranking		pH effect	Degradation ranking		Volatilization ranking[a]
		by organic carbon	by clay		aerobic	anaerobic	
28	2,2´-Dichlorobiphenyl (DCB)	5	3	–	4	2	(2)
29	2,4,5-Trichlorobiphenyl (TCB)	5	3	–	2 to 3	2 to 3	2
30	2,2´4,5,5´-Pentachlorobiphenyl (PCB)	5	3	–	1	1	2
31	Hexabromobiphenyl	5	3 to 4	–	1	1	2
32	4,4´-Diaminobiphenyl (benzidine)	3	4	+	2	1	1
Heterocyclic compounds							
33	Pyridine	1	2	+	4 to 5	3	3
34	2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)	5	3	0	1	1	1 (2)
35	Octachlorodibenzo-*p*-dioxin (OCDD)	5	3	0	1	1	1 to 2
36	1,2,3,7,8-Pentachlorodibenzofuran (PCDF)	5	3	0	1	1	1 (2)
Oil refining products							
37	Petroleum	3 to 4	3	0	2	1	1
38	Kerosene	3 to 4	3	0	4	3	1
39	Diesel and light oil	3 to 4	3	0	4	3	2 to 3
40	Heating oil	3 to 4	3	0	4	3	2
Carbocyclic compounds (with aliphatic side chains)							
41	Benzene-*o*-dicarboxylic acid (phthalic acid)	1 to 2	1	–	4	4	4
42	Linear alkylbenzene sulfonate (LAS)	3 to 4	1	–	4	3	(1)
43	Nonylphenol	2 to 3	2	(–)	4	2 to 3	(3)
44	Diethylhexyl phthalate (DEHP)	4 to 5	3 to 4	0	3 to 4	2	1
45	Dibutyl phthalate (DBP)	3 to 4	2	0	4	3	2
Carbocyclic compounds (as carbon acids and derivatives)							
46	Acrylamide	1	1	(–)	4 to 5	4	(2)
47	Nitrilotriacetic acid (NTA)	2 to 3	1	–	4	3 to 4	

NOTE Alphabetical order of substance groups:

Acrylamide 46, Aniline 15, Anthracene 22, Benzidine 32, Benzene 8, Benzopyrene 25, Chloroaniline 16, Chloroform 2, DBP 45, DCB 28, DEHP 44, Dichlorobenzene 9, Dibenzopyrene 26, Dichlorophenol 12, Dichloroethane 4, Dichloromethane 1, Diethylhexyl phthalate 44, Fluoroanthene 27, Diesel 39, Hexabromobiphenyl 31, Kerosene 38, LAS 42, Naphthalene 20, Naphthylamine 21, Nitrilotriacetic acid 47, Nonylphenol 43, NTA 47, OCDD 35, Petroleum 37, Phenanthrene 23, Phthalic acid 41, Pentachlorophenol 14, PCB 30, PCDF 36, Phenol 11 Pyridine 33, Heating oil 40, Tetrachloroethene 7, Tetrachloromethane 3, Toluene 17, Toluidine 18, Trichlorobiphenyl 29, Trichlorobenzene 10, Trichloroethene 6, Vinyl chloride 5, Xylene 19.

[a] Ranking ranges: 0 = none, 1 = very low, 2 = low, 3 = medium to high, 4 = high, 5 = very high

A.4.3 Step 1: Prediction of binding

The binding force of organic substances related to the organic carbon content in the main rooting zone of a soil (upper 0,3 m) is classified according to Table A.17. The binding force related to clay content (Table A.18) can be derived on the basis of the average soil type. The effect of the degree of decomposition of peat or organic matter covers should be taken into account. Binding by ferric oxides can also be obtained from the soil type, as their content mostly correlates with clay content. It applies for clay minerals with a high illite content ($>$ 25 % of the clay content). In case of a higher bentonite content, an increase of 0,5 in ranking ranges is appropriate. Soils containing higher amounts of kaolinite shall have the range reduced by 0,5.

The binding ranking range for topsoils should be increased by 1,0 if subsoils exhibit horizons with a very strong, clay-independent ferric acid accumulation (e.g. Bs of Podzols, Gso of Gleysols). In case of reduced (or increased) binding due to a low (or high) pH value according to Table A.19, a reduction (or addition) according to Table A.19 shall be made for the binding force related to organic carbon and to clay.

The ranking range of total binding is then characterized by the sum of the binding rankings related to organic carbon and/or to clay. The values obtained should be between 0 and 5 (if values above 5 or below 0 are calculated, 5 or 0 shall be applicable): 0 is understood to mean “no binding to very low binding”, whereas 5 means “extremely strong binding” (see assessment Table A.19).

Table A.17 — Binding ranking range (b_o or stage of the K_{oC} value) of organic chemicals in soils related to the organic carbon content of mineral soils and to the decomposition degree of peats (mean value of the upper 0,3 m)

Organic carbon content[a] %	Binding ranking[b] related to organic carbon content according to Table A.16								
	1,0	1,5	2	2,5	3,0	3,5	4,0	4,5	5,0
$<$ 0,5	0	0	0	0,5	1,0	1,5	2,0	2,0	2,5
0,5 to 1	0	0	0,5	1,0	1,5	1,5	2,0	2,5	3,0
$>$ 1 to 2	0	0,5	1,0	1,0	2,0	2	2,5	3,0	3,5
$>$ 2 to 4	0	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0
$>$ 4 to 8	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5
$>$ 8	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0

[a] In case of low amaints decomposed organic matter (fibric), reduction of 1,0 for all binding ranking ranges; for medium amounts decomposed organic matter (mesic), reduction of 0,5 for all binding ranking ranges.

[b] Ranking ranges: $<$ 0,5 = none, 0,5 to $<$ 1,5 = very low, 1,5 to $<$ 2,5 = low, 2,5 to $<$ 3,5 = medium, 3,5 to $<$ 4,5 = high, 4,5 to 5 = very high.

Table A.18 — Binding ranking range (b_o or ranking range of the K_{clay}) of organic chemicals in soils related to the soil type (mean soil texture of the upper 0,3 m)

Soil texture (clay content) % (mass fraction)	Binding ranking[a] related to clay content according to Table A.16								
	1,0	1,5	2	2,5	3,0	3,5	4,0	4,5	5,0
$<$ 5	0	0	0	0,5	1,0	1,5	2,0	2,0	2,5
5 to 12	0	0	0,5	1,0	1,5	2	2,5	3,0	3,0
$>$ 12 to 25	0	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0
$>$ 25 to 45	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5
$>$ 45	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0

[a] Ranking: $<$ 0,5 = none, 0,5 to $<$ 1,5 = very low, 1,5 to $<$ 2,5 = low, 2,5 to $<$ 3,5 = medium, 3,5 to $<$ 4,5 = high, 4,5 to 5 = very high.

Table A.19 — Additions or reductions for consideration of the pH effect on the binding ranking range (b_o) of organic chemicals in soils

pH effect according to Table A.16	pH > 6,5	pH 6,5 to 5,5	pH 5,5 to 4,0	pH < 4,0
+	+ 0,5	0	− 0,5	− 1,0
−	− 0,5	0	+ 0,5	+ 1,0

A.4.4 Step 2: Prediction of degradation and volatilization

The intensity of degradation essentially depends on temperature. The degradation of the substances classified according to Table A.16 is derived, as defined in Table A.20, from the mean temperature of the year's summer period. In case of contamination outside the vegetation period, the annual mean temperature is used as the degradation usually extends up to the next summer. The highest achievable ranking range of the predicted elimination is 5.

Table A.20 — Elimination of organic chemicals in soils in terms of ranking ranges (e_O) related to the mean or annual air temperature (as a measure of soil heat)

Degradation ranking[a] (according to Table A.16)	Mean temperature of the vegetation period °C					Annual temperature °C					
	> 26[b]	21	16	6	0	> 16[b]	12	9	6	3	0
1,0	2,0	1,5	1,0	0,5	0	1,5	1,0	0,5	0	0	0
1,5	2,5	2,0	1,5	1,0	0,5	2,0	1,5	1,0	0,5	0	0
2,0	3,0	2,5	2,0	1,5	1,0	2,5	2,0	1,5	1,0	0,5	0
2,5	3,5	3,0	2,5	2,0	1,5	3,0	2,5	2,0	1,5	1,0	0,5
3,0	4,0	3,5	3,0	2,5	2,0	3,5	3,0	2,5	2,0	1,5	1,0
3,5	4,5	4,0	3,5	3,0	2,5	4,0	3,5	3,0	2,5	2,0	1,5
4,0	5,0	4,5	4,0	3,5	3,0	4,5	4,0	3,5	3,0	2,5	2,0
4,5	5,0	5,0	4,5	4,0	3,5	5,0	4,5	4,0	3,5	3,0	2,5
5,0	5,0	5,0	4,5	4,0	3,5	5,0	4,5	4,0	3,5	3,0	2,5

[a] Ranking ranges: < 0,5 = none, 0,5 to < 1,5 = very low, 1,5 to < 2,5 = low, 2,5 to < 3,5 = medium, 3,5 to < 4,5 = high, 4,5 to 5 = very high.

[b] In case of semi-arid and arid climatic conditions with water deficiency, reduction of 0,5 and 1,0 respectively.

The effect of volatilization according to Table A.16 on the total elimination is taken into account by a value added as defined in Table A.21.

Table A.21 — Values added to the elimination ranking range (e_o) for consideration of the effect of possible volatilization

With volatilization according to Table A.4.2	1	2	3	4
Monthly average temperature > 10 °C or long presence[a] in the upper soil layer	0	0,5	1	1,5
Monthly average temperature < 10 °C or short presence[a] in the upper soil layer	0	0	1	1,5

[a] Presence of compound in the soil (90 % degradation): long: > 1 year, short: < 1 year according to Table A.16.

A.4.5 Step 3: Prediction of leaching

After predicting the binding and elimination ranking range in the upper soil layer (the groundwater-free soil), an estimation of the relocation of the compound and the probability of a groundwater input in subsoil by infiltration using the climatic water balance (v_c) of the site and the groundwater level should be carried out.

In case of retardation by clay ($\geqslant$ 17 % clay) or organic matter layers ($\geqslant$ 2 % organic carbon) in the subsoil, movement rankings should additionally be decreased by 0,5 or 1,0 ranking respectively (minimum horizon width: 0,3 m). If relevant horizon widths are > 0,8 m, movement ranking shall be decreased by 1,5.

According to Table A.22, the probability of a groundwater input therefore results from the movement of chemical compounds as predicted according to Table A.23, and from the groundwater level: 1 indicates a very low probability, 5 a very high probability.

Table A.22 — Effect of climatic water balance (v_c) on the movement of organic substances (in terms of ranking ranges) related to the binding (b_o) and elimination (e_o) ranking ranges (according to Tables A.18 and A.20)

v_c[a] mm/year	**Ranking range for binding and elimination** [$(b_O + e_O)/2$] (available amount in the upper layer)					
	5 to 4,5	< 4,5 to 3,5	< 3,5 to 2,5	< 2,5 to 1,5	< 1,5 to 0,5	< 0,5 to 0
− 100 to 0	0	0	1,0	2,0	3,0	4,5
> 0 to 100	0	0,5	2,0	3,0	4,0	5,0
> 100 to 200	0	1,5	2,5	3,5	4,5	5,0
> 200 to 300	0,5	2,0	3	4,0	4,5	5,0
> 300 to 400	1	2,5	3,5	4,5	5,0	5,0
> 400 to 600	1,5	2,5	3,5	4,5	5,0	5,0
> 600	2,0	3,5	4,5	5,0	5,0	5,0

[a] v_c is the infiltration expressed as difference between annual precipitation and evaporation. For agricultural use add 50 mm/year to the range given, for forestry use subtract 50 mm, for saturated hydraulic conductivity of 40 cm/d to 100 cm/d in the rooting zone add 50 mm, for 100 cm/d to 300 cm/d in the rooting zone add 100 mm, for > 300 cm/d or cracks in the rooting zone add 150 mm.

Table A.23 — Potential groundwater contamination risk (hazard ranking) of organic chemicals in groundwater-free soil as a function of the groundwater level (high, low) and the movement ranking range (according to Table A.22)

Movement ranking range Groundwater table depth m below surface (according to Table A.22)	**Hazard ranking range**[a]							
	Groundwater level m below surface							
	low high	< 0,4 0	0,4 to < 0,8 0 to < 0,2	0,8 to < 1,3 0,2 to < 0,4	1,3 to < 1,6 0,4 to < 0,8	1,6 to < 2,0 0,8 to < 1,3	2,0 to < 3,5 1,3 to < 2,0	$\geqslant$ 3,5 $\geqslant$ 2,0
0 to < 0,5		5,0	4,5	3,5	2,0	1,5	1,0	0,5
0,5 to < 1,5		5,0	5,0	4,0	2,5	2,0	1,5	1,0
1,5 to < 2,5		5,0	5,0	4,5	3,0	2,5	2,0	1,5
2,5 to < 3,5		5,0	5,0	5,0	3,5	3,5	3,0	2,0
3,5 to < 4,5		5,0	5,0	5,0	4,5	4,5	4,0	3,0
4,5 to 5		5,0	5,0	5,0	5,0	5,0	4,5	4,5

[a] Ranking ranges: < 0,5 = none; 0,5 to < 1,5 = very low; 1,5 to < 2,5 = low; 2,5 to < 3,5 = medium; 3,5 to < 4,5 = high; 4,5 to 5 = very high.

A.4.6 Examples of application

Table A.24 gives an example, using tetrachloroethene as contaminant, to apply the evaluation scheme on a contaminated site, assuming a Luvisol (grassland) with 1,6 % organic carbon content and 9 % clay content in the upper layer and a pH of 8,2. In the deeper soil layer, a clay horizon of width 0,4 m with a clay content of 19 % is present (mean annual temperature: 8,2 °C, climatic water balance 250 mm, depth to the groundwater $>$ 10 m).

As a field investigation under these site and application conditions (application rate 750 mg tetrachloroethene/m^2) shows, traces of tetrachloroethene have reached soil depths of 70 cm within a few weeks. Because of the very deep groundwater table, negligible risk of ion contamination of groundwater could be identified at this site. If the groundwater table were 200 cm deep, contamination of groundwater would be possible. Several field tests with different soil types and organic compounds were carried out, and revealed good agreement with the predicted groundwater contamination risk.

Table A.24 — Scheme for evaluation using tetrachloroethene and Luvisol as an example

Estimation of binding (step 1)	
— on organic carbon (according to Table A.16: 1 to 2, 1,6 % organic carbon, according to Table A.17)	0,5
— on clay (according to Table A.16: 1,9 % clay content, according to Table A.18)	0,0
— pH influence according to Table A.16 (pH 8,2, according to Table A.19)	0
Binding ranking range (b_o)	0,5
Estimation of degradation (step 2)	
— aerobic (according to Table A.16: 3), influence of temperature (annual temperatures 8,2 °C) according to Table A.20	2,0
— influence of volatility according to Table A.16: 4 and Table A.21 (temperature $<$ 10 °C)	1,5
Elimination ranking range (e_o)	3,5
Prediction of leaching (step 3)	
— movement ranking ranges according to Table A.22 [v_c: 250 mm, $(b_o + e_o)/2$]	4,0
— reduction for retardation layer in the subsoil	− 0,5
Movement ranking range	3,5
Prediction of potential groundwater contamination	
— groundwater hazard ranking depending on groundwater level (according to Table A.23)	3,0
Evaluation of potential groundwater contamination risk (hazard ranking range)	**medium**

For interpretation of this example, no point-source contamination of the site (e.g. by accident or by direct and massive infiltration into the soil) is assumed. The evaluation is based on soil properties which can reduce the contaminant concentration during migration through the soil towards the groundwater. The evaluation concept is also applicable for pesticides.

Annex B
(informative)

Quantitative methods for assessing the actual leaching risk

B.1 Introduction

Investigations of contaminated sites are usually only carried out where contamination is expected. Thus, guidance given in ISO 10381-5 can be used. The area of interest (see Table 2) may provide elements forming a basis for decision-making and for determining if a site should be remediated.

In the second step, a desk-top investigation should be commenced (see 5.2), e.g. to collate information about contamination hot-spots and the range of expected contaminants. If this proves inconclusive, it may be necessary to determine contamination hot-spots during an orientated investigation. This includes the determination of total and pseudo-total concentrations of substances. The relevant methods of determination are given in Table 7 for inorganic contaminants/pollutants; for organic contaminants/pollutants, methods are given in Table 8.

If evidence of increased concentrations of contaminants can be deduced from the orientated investigations, then initial pathway-specific investigations are necessary (similar to preliminary evaluation of impact of groundwater). The risk of groundwater contamination in general can be derived from the concentration of substances in soil water. Soil water is considered to be percolation water, or groundwater directly in contact with contaminated soil (contact groundwater).

Evaluation of the exposure pathway of soil to groundwater within the framework of a first-stage risk assessment requires evaluation of the concentration of substances in the percolation water which will enter the groundwater and of the contact groundwater.

Within the framework of a detailed investigation, it may be necessary to consider in addition the volumes of transferable substance, potentially mobile fractions and other parameters.

B.2 Substance concentration in soil water

B.2.1 Introduction

For the estimation of concentrations of substances in percolation water, any of the following approaches can be used:

- direct investigation of soil water;
- estimation of concentrations in soil water based on soil investigations;
- estimation of concentrations in soil water based on groundwater investigations.

B.2.2 Direct investigation of soil water

The direct investigation of concentrations in percolation water requires sampling of soil percolation water by suitable means, e.g. suction devices to obtain soil water *in situ*. Application of this method can encounter the following problems:

- insufficient water to be sampled from the unsaturated zone;

- sorption effects, depending on the material of the device used;
- undefined spatial zone sampled by the method;
- high sampling frequency required to evaluate efforts to determine variability of the soil and concentrations of substances.

B.2.3 Estimation of concentrations in soil water based on soil investigations

To avoid problems caused in the direct investigation of concentrations of soil water as described above, investigation of the contaminated soil matrix can be undertaken. This requires methods which are as accurate as possible to confirm the natural soil solid/solution ratio. The soil saturation extract is considered to be useful since it has been validated for the determination of salt contents in soils.

The methods given in Table 7, which describe mobile/mobilizable contents of heavy metals and other trace elements (complexing/weak extractant/water soluble), have a greater solid/liquid ratio and/or as a result of higher ionic strengths, and in the presence of complexing agents an increased potential to release elements in traces. Therefore, concentrations determined on this basis tend to overestimate the real content of trace substances in soil percolation water.

In addition to the above-mentioned batch methods, the soil solution can also be obtained by using column tests (see Annex E). These methods are especially applicable for organic contaminants.

B.2.4 Estimation of the concentrations of substances in soil water based on groundwater investigations

Under constant conditions and known volumes of percolation water and groundwater flow, the concentrations in the soil water can be estimated from concentrations in the groundwater by following the hydraulic gradient downstream from the location of contamination.

The relevant data needed to draw a conclusion can only be obtained if the hydrogeological site conditions are not too complex. Moreover, this method is usually not sufficient to provide the local differentiation necessary for remediation measures.

B.3 Detailed investigation

If it is suspected from the preliminary investigation that contamination of the groundwater (see 5.2) cannot be excluded, supplemental sampling and testing shall be carried out in order to estimate mobility and degradation of contaminants. ISO 10381-5 should be consulted.

In addition, B.4 to B.7 should be considered.

B.4 Volume of transferable substances

To evaluate the risk of groundwater contamination, it may be necessary to determine substance volumes entering the groundwater. Therefore it is necessary to consider not only the concentration of substances, but also the volume of percolation water and the relevant soil area. In a first step, the net percolation rate, averaged over one year, can be determined as climatic water balance. The relevant site parameters are given in Table 3.

Depending on the specific site conditions and the substances under consideration, it may be necessary to determine the percolation rate and the corresponding substance concentrations at a higher resolution with respect to aspects of time and space.

B.5 Mobilizable contents

To estimate medium- and long-term inputs into the groundwater (beyond the temporary consideration of substance concentrations in the percolation water), the methods of varying extraction strength given in Tables 6 and 7 are suitable.

B.6 Degradation of organic contaminants

For organic contaminants, (bio-)degradation should be taken into account when extrapolating from a given substance concentration in the unsaturated zone to a substance concentration in the upper aquifer. If suitable data are not available, additional substance-specific degradation experiments may be necessary.

B.7 Model-based risk assessment of a groundwater pollution

B.7.1 General

The assessment of a groundwater pollution risk resulting from a given soil pollution can be performed at different levels of complexity. The more data available, the more processes can be taken into account in a risk assessment model. In the following example, a stepwise procedure is introduced to optimize the balance between the available data and the number of processes used in the model for the risk assessment.

The first two levels are simple conservative methods that can be used where only sparse data are available. Level 3 is less conservative and demands more data and calculations on a computer. Only level 3 includes sorption and decomposition.

The principles of the three levels are:

- **Level 1:** The concentrations of the contaminants are calculated only in the upper part of the groundwater under the contaminated site.
- **Level 2:** The concentrations of the contaminants are calculated as average concentrations in the groundwater under the contaminated site at a distance from the source equal to the distance of groundwater flow in e.g. 1 year.
- **Level 3:** The concentrations of the contaminants are calculated as average concentrations in the groundwater under the contaminated site at a distance from the source equal to the distance of groundwater flow in e.g. 1 year. Dispersion, sorption and decomposition are included.

B.7.2 Level 1

This level of calculation is based on the assumption that the mass concentration of contaminant in soil water in the unsaturated zone near to the source is equal to its concentration in soil water just above the groundwater. Hereafter the concentration is calculated for the upper 0,25 m of the groundwater reservoir. If appropriate, another mixing depth (d_m) can be used.

Dispersion, sorption and decomposition are not included, and it is assumed that the groundwater reservoir is homogeneous and isotropic.

The calculation of the mass concentration of contaminant in the groundwater is based on a mass balance for the upper part of the groundwater reservoir.

The mass concentration of contaminant (c_c) becomes:

$$c_\mathrm{c} = \frac{ANc_0 + Bd_\mathrm{m}k\nabla c_\mathrm{g}}{AN + Bd_\mathrm{m}k\nabla} \qquad \text{(B.1)}$$

where

c_c is the calculated mass concentration of contaminant in the groundwater, in micrograms per litre;

A is the area of the source of contaminant, in square metres;

N is the rate of rainwater infiltration, in millimetres per hour;

c_0 is the mass concentration near contaminant source, in micrograms per litre;

B is the length of the source perpendicular to the groundwater flow direction, in metres;

d_m is the depth of mixing in the groundwater reservoir (0,25 m at level 1), in metres;

k is the rate of groundwater conductivity in the reservoir, in millimetres per hour;

∇ is the hydraulic gradient;

c_g is the background (mass) concentration in groundwater, in micrograms per litre.

B.7.3 Level 2

This level of calculation is based on the assumption that the concentration in soil water in the unsaturated zone near to the source is equal to the concentration just above the groundwater. The contaminant is then mixed over the total thickness of the reservoir.

Based on these assumptions, the concentration is calculated as average concentration in the groundwater under the contaminated site at a distance from the source equal to the distance of groundwater flow in e.g. 1 year. In the saturated zone, the calculation is based on mixing in the reservoir to a depth of 1/40 of the distance from the source, however the mixing is assumed to take place in not less than the upper 0,25 m.

NOTE The dimensions given in time and space (mixing reservoir, distance from the source of contamination as a function of groundwater flow) may be useful for a first estimation. Nevertheless it is recommended that the assessor carefully consult the relevant literature and possibly carry out site-specific tests for estimating more accurately the mixing reservoir at the site under consideration. The heterogeneity of soils at the site under consideration can cause large deviations from averaged groundwater conductivity values, reducing the reliability of the estimate.

The calculation of the concentration of contaminant in the groundwater is based on a mass balance for the upper part of the groundwater reservoir similar to the principles in step 1, except for mixing in the groundwater reservoir. Hence d_m in Equation (B.1) is larger than 0,25 m.

B.7.4 Level 3

In this step, the calculations include additional processes like dispersion, sorption and decomposition and therefore this method demands more data. The concentration of the contaminant is calculated as average concentration in the groundwater under the contaminated site at a distance from the source equal to the distance groundwater flows in e.g. 1 year.

If there is no specific knowledge of soil transport characteristics, the unsaturated zone is again assumed to be homogeneous and isotropic, hence one-dimensional convective-dispersive transport models are applied. Otherwise, model approaches for transport in heterogeneous media could be applied.

In the saturated zone, the calculation is based on instantaneous mixing in the reservoir to a depth of 1/40 of the distance from the source, however the mixing is assumed to take place in no less than the upper 0,25 m of the groundwater reservoir. The groundwater reservoir is assumed to be homogeneous and isotropic. In the saturated zone decomposition, adsorption and dispersion are included in the model.

There are several model approaches available, taking the above-mentioned processes into account at different levels of complexity. The user has to carefully check and define the boundary conditions and application limits of alternative model approaches.

Annex C
(informative)

Types of contaminated site and associated contaminants

Type of industrial site	Typical contaminants
Petrol stations and other sites for storage, treatment and handling of oil and gas	Volatile aromatics: benzene, toluene, xylene and ethylbenzene, alkanes C_5 to C_{20}, methyl ethyl ketone, methyl t-butyl ether (MTBE), t-amyl methyl ether (TAME), lead
Manufacture of paint, lacquer and enamel	Solvents: petrol, turpentine, volatile aromatics, alcohols, ketones, esters, glycol ethers and esters, chlorinated hydrocarbons, acrylamides, As, Cr, Cu, Cd, Pb, Zn
Asphalt and tar production and products	Volatile aromatics: benzene, toluene, xylene, phenols, naphthalenes, polyaromatic hydrocarbons and other hydrocarbons
Gasworks	Phenols and alicylic phenols, polyaromatic hydrocarbons, volatile aromatics, cyanide, ammonia, sulfur compounds
Impregnation of wood	Phenols, Cr, Cu, As, F, Sn, Zn, polyaromatic hydrocarbons, creosote, chlorophenols, pesticides, dinitrophenol
Tanneries	Sulfides and sulfates, chlorophenols, cyanides, acids, Cr, Al, As, Pb, B, Co, Cd, alcohols, esters, ketones, xylenes
Plating industry	Solvents, Cr, Cu, Zn, Cd, Pb, As, Ag, Ni, cyanides, hydrocarbons
Auto repair	Aliphatic hydrocarbons, volatile aromatics, polyaromatic hydrocarbons, styrene, chlorinated hydrocarbons, other solvents, Pb, Cu, Al, amines, isocyanates, methyl t-butyl ether (MTBE), glycols, toluene diisocyanate (TDI)
Foundries, metalworks, etc.	Cd, Cu, Cr, Ni, Pb, Zn, Al, Mn, Fe, phenols, formaldehyde, acids, cyanates, carbamide, amines
Metal industry	Cd, Cu, Cr, Ni, Pb, Zn, Al, Mn, Fe, Sn, B, F, PCB, PCT, hydrocarbons, chlorinated hydrocarbons, solvents, glycols, turpentine, paraffins, cyanides, phosphorus, acids, ethers, silicates, polyaromatic hydrocarbons
Petroleum industries	Volatile aromatics: benzene, toluene, xylene; alkanes C_5 to C_{20}, gasoline, lubricants, polyaromatic hydrocarbones, lead
Rubber and synthetics industries	Volatile aromatics: benzene, toluene, xylene, ethylbenzene, chlorinated solvents, other solvents
Wood, wood fibre and laminate industries	Toluene, xylene, trichloroethene, methyl methacrylate, other solvents
Chemical laundries and dry cleaners	Trichloroethene, tetrachloroethene, (petroleum ether)
Printing industries	Chlorinated solvents, benzene, toluene, xylene, acetone, isopropanol, other solvents, Cr, Cu

Annex D
(informative)

List of priority pollutants with respect to groundwater pollution

Table D.1 — World Health Organization (WHO) list (Chemicals of health significance in drinking water)

A. Inorganic constituents

Antimony
Arsenic
Barium
Beryllium
Boron
Cadmium
Chromium
Copper
Cyanide
Fluoride
Lead
Manganese
Mercury
Molybdenum
Nickel
Nitrate (as NO_3^-)
Nitrite (as NO_2^-)
Selenium
Uranium

B. Organic constituents

a) Chlorinated alkanes

Carbon tetrachloride
Dichloromethane
1,1,1-Trichloromethane
Vinyl chloride
1,1-Dichloroethane
1,2-Dichloroethane
Trichloroethane
Tetrachloroethane

b) Aromatic hydrocabons

Benzene
Toluene
Xylenes
Ethylbenzene
Styrene
Benzo[a]pyrene

c) Chlorinated benzenes

Monochlorobenzene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Trichlorobenzenes

d) Miscellaneous

Di(2-ethylhexyl) adipate
Di(2-ethylhexyl) phthalate
Acrylamide
Epichlorohydrin
Hexachlorobutadiene
Edetic acid (EDTA)
Nitrilotriacetic acid
Dialkyl tins
Tributyl tin oxide

C. Pesticides

Alachlor
Aldicarb
Aldrin/Dieldrin
Atrazine
Bentazone
Carbofuran
Chlordane
Chlorotoluron
DDT
1,2-Dibromo-3-chloropropane
2,4-Dichloropropane
1,2- Dichloropropane
1,3- Dichloropropane
Ethylene dibromide
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Isoproturon
Lindane
MCPA
Methoxychlor
Metolachlor
Molinate
Pendimethalin
Pentachlorophenol
Permethrin
Propanil
Pyridate
Simazine
Trifluralin
Chlorophenoxy herbicides other than 2,4-D and MCPA
2,4-DB
Diochlorprop
Fenoprop
MCPB
MECOPROP
2,4,5-T

Table D.2 — Pollutants and pesticides [Environmental Protection Agency list (EPA, USA)]

Standard volatile priority pollutants	Standard pesticide priority pollutants
Acrolein	Aldrin
Acrylonitrile	Dieldrin
Benzene	Chlordane
Tetrachloromethane	4,4´-DDT
Chlorobenzene	4,4´-DDE
1,2-Dichloroethane	4,4´-DDD
1,1,1-Trichloroethane	Endosulfan I
1,1-Dichloroethane	Endosulfan II
1,1,2-Trichloroethane	Endosulfan sulfate
1,1,2,2,-Tetrachloroethane	Endrin
Chloroethane	Endrin aldehyde
2-Chloroethyl vinyl ether	Heptachlor
Trichloromethane	Heptachlor epoxide
1,1-Dichloroethene	α-BCH
1,2-*trans*-Dichloroethene	β-BCH
1,2-Dichloroethene	δ-BCH
1,3-*trans*-Dichloroethene	Lindane
Ethylbenzene	PCB-1242
Dichloromethane	PCB-1254
Bromomethane	PCB-1221
Tribromomethane	PCB-1232
Bromodichloromethane	PCB-1248
Fluorotrichloromethane	PCB-1260
Dichlorodifluoromethane	PCB-1016
Chlorodibromomethane	Toxaphene
Tetrachloroethene	2,3,7,8-p-Dioxin
Toluene	
Trichloroethane	
Vinyl chloride	
Nonstandard volatile priority pollutants	**RCA pesticides**
Acetone	Methoxychlor
2-Butanol	2,4-D
Carbon disulfide	Silvex
2-Hexanone	
4-Methyl-2-pentanone	

Table D.3 — Parameters concerning toxic substances (EC Drinking Water Standards)

Inorganic substances	Pesticides and related products
Arsenic	Insecticides
Beryllium	Persistent organochlorines
Cadmium	Organophosphorus compounds
Cyanides	Carbamates
Chromium	Herbicides
Mercury	Fungicides
Nickel	PCBs
Lead	PCTs
Antimony	Polycyclic aromatic hydrocarbons
Selenium	
Vanadium	

Table D.4 — Toxicity of substances according to European Communities (EC) Framework Directive 76/474/EEC

Substance	List I (Black list[a])	List II (Grey list [b])
1,2 Dichloroethane	X	
Aldrin, dieldrin, endrin and isodrin	X	
Arsenic		X
Atrazine and simazine		X
Azinphos-methyl		X
Boron		X
Cadmium	X	
Carbon tetrachloride	X	
Chloroform	X	
Chromium		X
Copper		X
Cyfluthrin		X
DDT (all isomers)	X	
Dichlorvos		X
Endosulphan		X
Fenitrothion		X
Flucofuron		X
Hexachlorocyclohexane	X	
Hexachlorobenzene	X	
Hexachlorobutadiene	X	
Iron		X

Table D.4 (*continued*)

Substance	**List I (Black list[a])**	**List II (Grey list [b])**
Lead		X
Malathion		X
Mercury	X	
Nickel		X
PCSDs		X
Pentachlorophenol	X	
Perchloroethylene	X	
Permethrin		X
PH		X
Polychlorinated biphenyls		X
Sulcofuron		X
Tributyl tin compounds		X
Trichlorobenzene	X	
Trichloroethylene	X	
Trifluralin		X
Triphenyl tin compounds		X
Vanadium		X

[a] Black list very harmful when discharged to water.

[b] Grey list less harmful when discharged to water.

Annex E
(informative)

Overview of soil leaching and extraction test

E.1 Introduction

Leaching/extraction tests are employed to characterize the soil, simulate field scenarios or to assess a specific potential risk such as the release of contaminants into groundwater. Many extraction tests are developed from soil science and geosciences to assess specific properties of the soil, such as the availability of nutrients and contaminants. This annex contains an overview of different types of leaching test and assumptions are given.

E.2 General assumptions for use of leaching test

It is often assumed in stationary leaching tests that equilibrium is reached. This assumption may sometimes be regarded as fulfilled even though the actual condition is only equilibrium-like. This may for instance apply to situations where the soil undergoes reactions which are very slow compared to the period of time for which the leaching properties are being evaluated. If the results are extrapolated beyond this time frame, such potential changes should be accounted for, e.g. by modelling.

In dynamic leaching tests, no equilibrium is reached. In fact, it is often attempted to maintain the leaching system at a condition as far from equilibrium as possible, in order to maximize the driving force for mass transfer from the solid phase to the liquid. The property measured in this case is the rate of release, often expressed in terms of a flux through a surface (e.g. milligrams per square metre per second).

The application of leaching tests, for which the interpretation of the results is based upon the assumption that equilibrium conditions are achieved, requires that thermodynamic equilibrium or a steady state condition between the solid and the liquid phases is attained within the liquid/solid contact time allocated for the test. The assumed equilibrium condition may in some cases correspond to a so-called local equilibrium assumption (LEA). This applies to the performance of column leaching tests on soil materials, provided the rate of percolation is sufficiently slow. Concentration gradients can exist along the length of the column but at any point within the column, equilibrium/steady state conditions must exist between the soil and the percolating liquid phase. Failure to fulfil the LEA results in poor reproducibility and results which depend strongly upon the rate of flow through the column. Such results cannot be subjected to a direct, liquid/solid (L/S) -based comparison with the results of batch leaching tests. For column leaching tests, a maximum flowrate therefore exists for any given material and any given constituent. This maximum flowrate should not be exceeded, in order not to invalidate the LEA.

E.3 Types of leaching test

E.3.1 Column leaching tests

In a column leaching test, the leachant is typically passed through a vertical column of the soil material in upflow or downflow collected in fractions and analysed. This simulates to a certain extent the leaching process occurring when rainwater infiltrates and percolates through the soil. The flowrate is often accelerated compared to natural conditions, but a rate of flow which fulfils the LEA must be used. The duration of column leaching tests is typically several weeks to several months, and if sufficiently large columns are used, fractions corresponding to liquid/solid ratios L/S = 0,0 l/kg to 0,1 l/kg or even lower may be collected. Column leaching tests are well suited to describe the progression of leaching in the range L/S = 0 l/kg to 2 l/kg, and are in some cases used up to L/S = 10 l/kg.

E.3.2 Lysimeter leaching tests

Lysimeter leaching tests are, in principle, large-scale column leaching tests. They are often performed outdoors under "natural" conditions and can be used to verify the results of laboratory leaching tests under field-resembling conditions. The duration of lysimeter leaching tests is typically one to several years. They can provide information on the composition of the initial leachate at very low L/S ratios. Lysimeter leaching tests are not discussed in further detail in this context.

E.4 Extraction or batch type tests

A number of different extraction or batch leaching procedures exist in which a certain amount of soil is brought into contact with a leachant in a closed or open vessel and agitated for a certain period of time (normally to attain equilibrium/steady state conditions). The liquid and solid phases are subsequently separated and the liquid is analysed for the parameters of interest. Contact times typically vary from a few hours to a few days, and are often adjusted to accommodate normal working hours. In a single-batch leaching test, this procedure is performed once at a specified L/S ratio. For most waste types, it is impractical to perform batch leaching tests at L/S ratios lower than approximately 2 l/kg. They may be performed at any L/S ratio above 2 l/kg, but at high L/S values analytical detection problems become an issue. Standardized batch leaching tests are often performed at L/S ratios between 2 l/kg and 20 l/kg. If aliquots of leachant are removed and analysed at different time intervals during the performance of a single-batch leaching test, the results can provide an indication of the contact time needed to attain equilibrium-like conditions. In a multiple-batch leaching test, the procedure described above is repeated a number of times, usually using fresh leachant each time (in a few variants the solid phase is renewed). Constant-pH leaching tests are single-batch leaching tests in which pH is maintained at a constant value through feed-back control and automated addition of acid or base. The results of such pH-static leaching tests are often used as input to hydrogeochemical models. Availability tests are single- or multiple-batch leaching tests carried out at high L/S ratios (typically 50 l/kg to 200 l/kg) on finely ground soil material (typical grain size < 100 µm to 200 µm) under pH-static conditions at one or two pH values favouring the solubility of the constituents in question or simulating specific conditions. The test conditions are usually designed to minimize physical and chemical resistance to leaching and to ensure availability control at the chosen pH value(s). In some regulatory tests, availability is sought merely through the application of aggressive leachants containing acids or complexing agents (e.g. carbonic acid/CO_2, acetic acid, ammonium acetate, EDTA, citric acid).

Special extractions and sequential extraction procedures (e.g. [13]) are sometimes used to investigate specific aspects of soil leaching, such as the association of leachable components with various mineral phases. It has been found useful to apply multivariate statistical techniques during interpretation of results from sequential leaching procedures (see [6]).

Insight into the leachibility of metals and organic compounds may be gained from mineralogical assessment of the soil, in addition to sequential leaching procedures. Such an assessment could include size fractionation of the sample followed by subsequent chemical analysis to determine the distribution of the pollutant among the separate size fractions, X-ray diffraction/thermogravimetric analysis to determine the mineralogical composition of fractions associated with the highest concentrations of pollutants, and electron microprobe techniques to determine the presence of pollutants and factors likely to control their mobility. The use of these techniques to establish the presence or absence of carbonate and/or iron oxide coatings has proved particularly useful if not essential in the interpretation of sequential leaching procedures (i.e. where reagents have associated pollutants with an iron hydroxide phase that was established not to be present in the analysed samples).

E.5 Tank leaching test for compacted granular materials

A test in which the diffusion-driven leaching from compacted soil and waste materials is investigated under non-equilibrium conditions is currently under consideration by the CEN/TC 292, *Characterization of waste*. The results are related to the exposed surface area of the compacted waste.

E.6 Test conditions

E.6.1 Pretreatment

Depending on the situation and the leaching test to be performed, it may be necessary to subject the soil to pre-treatment including liquid/solid separation, drying, subsampling, particle size reduction, compaction and/or conservation. It may be necessary to dry humid soil samples prior to particle size reduction. There will always be a risk of losing volatile components (e.g. mercury and various organics, as well as water of crystallization), and any drying operation should therefore be carried out as gently as possible at the lowest convenient temperature. The subsampling techniques used (coning and quartering or application of riffles or other dividing apparatus) should ensure that the subsamples obtained are truly representative of the bulk sample. Some contaminated soils, particularly when humid, may undergo ageing, carbonation and oxidation reactions with the atmosphere as well as microbial degradation reactions if stored prior to testing. If storage cannot be avoided, the waste should be placed in a dry state in airtight containers in a cool environment until testing can take place.

E.6.2 Composition of the leachant

In many leaching tests, non-aggressive leachants such as demineralized water or water initially adjusted to pH = 4 with HNO_3 are prescribed, often intending to simulate leaching with rainwater. At low and moderate L/S ratios, the pH and the composition of the eluate are often controlled by the solid phase and relatively independent of the composition of the leachant. At higher L/S values or if a more aggressive leachant is used, the pH and the leaching conditions may be influenced more extensively by the leachant. For tests simulating the leaching conditions of various scenarios such as disposal in a marine environment, disposal at a sanitary landfill, etc., other leachants such as seawater or artificial landfill leachate may be used.

E.6.3 Mode and method of soil/leachant contact

Since the objective of most leaching tests is to investigate the transfer of various components from a solid phase to a liquid phase, it is important to control conditions which may affect the transfer rate and to control the risk of transfer of matter between the leaching system and the surroundings, primarily the atmosphere. If the interpretation is based on the assumption that all of the waste present is in contact with the leachant, this must be ensured. For column leaching tests, good liquid/solid contact is often achieved by using upflow at a sufficiently slow flowrate. For batch leaching tests, good mixing can be achieved by rotating the leaching vessel end-over-end, by using special eccentric rotators or by stirring. The agitation should be sufficiently gentle to avoid extreme size reduction caused by abrasion. If the soil to be tested is thermodynamically unstable under ambient conditions or otherwise easily oxidized or carbonated, it may be necessary to prevent contact with the atmosphere. This can be achieved through the use of equipment made from diffusion-resistant materials or by performing the tests in a nitrogen atmosphere, e.g. in a glove box. Zero-headspace leaching equipment is sometimes used to prevent the escape of volatile components. In column leaching tests where fractions of eluate are collected over a period of time, it may be necessary to protect the eluate against O_2 (which oxidizes reducing components) or CO_2 (which lowers the pH of alkaline eluates and forms carbonates) by keeping it under a nitrogen atmosphere.

E.6.4 Liquid/solid ratio (L/S)

The L/S is defined as the ratio of the amount of leachant which at any given time is in soil contact to the amount of soil tested. L is generally expressed as a volume (e.g. litres) and S as the dry mass of the waste (e.g. in kilograms) prior to testing. The units of L/S are therefore usually l/kg. The choice of L/S ratio or range of L/S ratio for a leaching test depends in a given situation on the objectives and the type of test in question, the solubility of the components of interest and the analytical detection limits. Expressing the results of leaching tests on soils in terms of eluate composition or accumulated leached amounts of components as a function of L/S allows for the comparison of the results of different types of leaching test and, under certain circumstances, for the comparison of laboratory leaching test results with field observations. This means that with some (considerable) caution, laboratory leaching tests may in some cases be used for the prediction of various aspects of leaching under full-scale field conditions. Most laboratory leaching tests on soils performed under equilibrium-like conditions are accelerated in time compared to the actual duration of leaching under field conditions. Under certain conditions and when the physical design and the hydraulic situation is known, the L/S scale may be converted to a time scale for a specific scenario.

E.6.5 Contact time

The amount of time during which a liquid phase is in contact with a solid phase will influence the quantity of waste components leached, unless equilibrium-like conditions are achieved. In batch extraction tests the contact time equals the duration of the test, whereas the contact time in e.g. column leaching tests also is a function of the flowrate. In leaching tests based on thermodynamic equilibrium or local equilibrium, the attainment of this condition should be investigated. For test methods of short duration or methods for which small particle sizes are not prescribed or used, it may be difficult to attain equilibrium within the allocated contact time.

E.6.6 Temperature

Temperature affects the results of leaching tests. Both the van't Hoff relationship, which applies to thermodynamic equilibrium constants and solubility products, and the Arrhenius relationship, which applies to kinetic processes such as adsorption and diffusion, indicate that properties or mechanisms relevant to leaching vary exponentially with temperature. For convenience, most leaching tests are performed at room temperature. Higher temperatures may be used to accelerate the rate of leaching, although this may also change the properties of the soil. This practice is therefore not recommended.

E.6.7 Separation of eluate from the solid phase

Eluates are commonly separated from the soil phase by vacuum or pressure filtration using 0,45 µm membrane filter (a convention used to define soluble species). However, small colloid particles can pass through a 0,45 µm filter. A smaller pore size (e.g. 0,2 µm) should be used if these particles are to be removed. The use of the smaller filter size should be reported with the data. Glass fibre filters should be chosen when hydrophobic, low solubility organic molecules are expected in the eluate, since they may have a high affinity for membrane filters composed of an organic polymer such as cellulose acetate. In some cases, filtration may be preceded by centrifugation. For column leaching tests, the filter should be an integrated part of the eluate collection system which ensures that the eluate is not exposed to the atmosphere prior to filtration.

E.6.8 Chemical analysis and characterization of the eluate

The performance of leaching tests includes characterization of the eluate(s) produced. Most commonly, the characterization programme consists of chemical analyses of the components of interest. Any eluate produced should be analysed immediately for pH, conductivity and, if possible, redox potential. Eluates produced from leaching of soluble materials, particularly at low L/S ratios, are often complex, concentrated mixtures of numerous components (e.g. high salt contents), and chemical analysis can be difficult due to interferences (AAS, ICP-MS). Standard analytical methods used for drinking water and wastewater may not be applicable and special precautions may be necessary. It is therefore important to inform the analytical laboratory about the nature of the eluates prior to analysis. In addition to chemical characterization, eluates from leaching tests may be submitted to ecotoxicological testing.

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