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Second edition
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Soil quality — Characterization of contaminated soil related to groundwater protection

Qualité du sol — Caractérisation des sols pollués en relation avec la protection des eaux souterraines

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This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 7, *Impact assessment*.

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This second edition cancels and replaces the first edition (ISO 15175:2004), which has been technically revised.

The main change concerns the focus on contaminated land management. This second edition suggests a tiered approach from simple to complex assessment in order to evaluate the impact of soil contamination of groundwater.

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Soil quality — Characterization of contaminated soil related to groundwater protection

1 Scope

This document 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 retaining, releasing and transforming contaminants. It is focused on contaminated land management identifying and listing relevant monitoring strategies, methods for sampling, soil processes and analytical methods.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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3.1
aquifer
geological water-bearing formation (bed or stratum) of permeable rock, or unconsolidated material (e.g. sand and gravels) capable of yielding significant quantities of water

[SOURCE: ISO 5667-11:2009, 3.5]

3.2
contaminant
substance or agent present in the *soil* (3.10) as a result of human activity

Note 1 to entry: See *pollutant* (3.7).

Note 2 to entry: There is no assumption in this definition that harm results from the presence of the contaminant.

[SOURCE: ISO 11074:2015, 3.4.6, modified — a new Note 1 to entry has been added and the subsequent note has been renumbered.]

3.3
dissolved organic carbon
DOC
concentration of organic carbon remaining in solution after filtration and/or centrifugation under defined conditions

Note 1 to entry: Dissolved organic carbon is expressed in mg/l, g/m^3.

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3.4
groundwater
water in the saturated zone of an underground geological formation or artificial deposit such as made ground, e.g. fill material

[SOURCE: ISO 5667-11:2009, 3.9, modified — "and/or unsaturated zone" has been removed.]

3.5
water table
upper boundary surface of the *groundwater* (3.4)

[SOURCE: ISO 11074:2015, 3.2.4]

3.6
percolating water
infiltrating water that moves downward in the pore space due to gravity

[SOURCE: ISO 11074:2015, 3.2.5]

3.7
pollutant
substance or agent present in the *soil* (3.10) [or *groundwater* (3.4)] which, due to its properties, amount or concentration causes adverse impacts on *soil functions* (3.11) or soil use

[SOURCE: ISO 11074:2015, 3.4.18, modified — "or soil use" has been added.]

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3.8
pore water
water in the pores or cavities within a body of rock or *soil* (3.10)

[SOURCE: ISO 5667-11:2009, 3.18, modified — "water that fills the pores" has been replaced by "water in the pores".]

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3.9
risk assessment
process of risk analysis and evaluation of the damaging effects on humans and the environment, with respect to the nature, extent, and probability of occurrence of these effects

[SOURCE: ISO 11074:2015, 5.2.26, modified — "effects on man" has been replaced by "effects on humans".]

3.10
soil
upper layer of the Earth's crust composed of mineral particles, organic matter, water, air and organisms

Note 1 to entry: In a broader civil engineering sense, soil includes topsoil and sub-soil; deposits such as clays, silts, sands, gravels, cobbles, boulders, and organic matter and deposits such as peat, materials of human origin such as wastes, ground gas and moisture, and living organisms.

[SOURCE: ISO 11074:2015, 2.1.11, modified — "transformed by weathering and physical/chemical and biological processes" has been removed.]

3.11
soil function
description of the significance of *soils* (3.10) to man and the environment

EXAMPLE Control of substance and energy cycles as compartment of ecosystems, basis for the life of plants, animals, and man, basis for the stability of buildings and roads, basis for the yield of agriculture, horticulture, and forestry, carrier of genetic reservoir, document of natural history, archaeological and paleoecological document.

[SOURCE: ISO 11074:2015, 3.3.31]

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3.12
soil gas
gas and vapour in the pore spaces of *soils* (3.10)

[SOURCE: ISO 11074:2015, 2.1.13]

3.13
soil material
excavated soil, dredged materials and *soil* (3.10) treated to remove or destroy or reduce the environmental availability of *contaminants* (3.2)

[SOURCE: ISO 11074:2015, 7.4.16, modified — "materials composed of" removed.]

3.14
soil pores
part of the soil volume, between the solid particles of the *soil* (3.10)

[SOURCE: ISO 11074:2015, 2.1.14]

3.15
soil water
all water of the *unsaturated zone* (3.17)

[SOURCE: ISO 11074:2015, 3.2.7, modified — "and saturated" has been removed.]

3.16
total organic carbon
TOC
all carbon present in organic matter

[SOURCE: ISO 11074:2015, 2.1.22]

3.17
unsaturated zone
part of an *aquifer* (3.1) in which the pore spaces of the formation are not totally filled with water

[SOURCE: ISO 6107-2:2006, 150]

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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 contaminant particles);

— chemical filter functions (sorption and mobilization of substances);

— transformation functions (degradation or transformation of substances).

NOTE The liquid phase most commonly consists of solely of water but non-aqueous liquids can sometimes also be present as a separate phase.

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.

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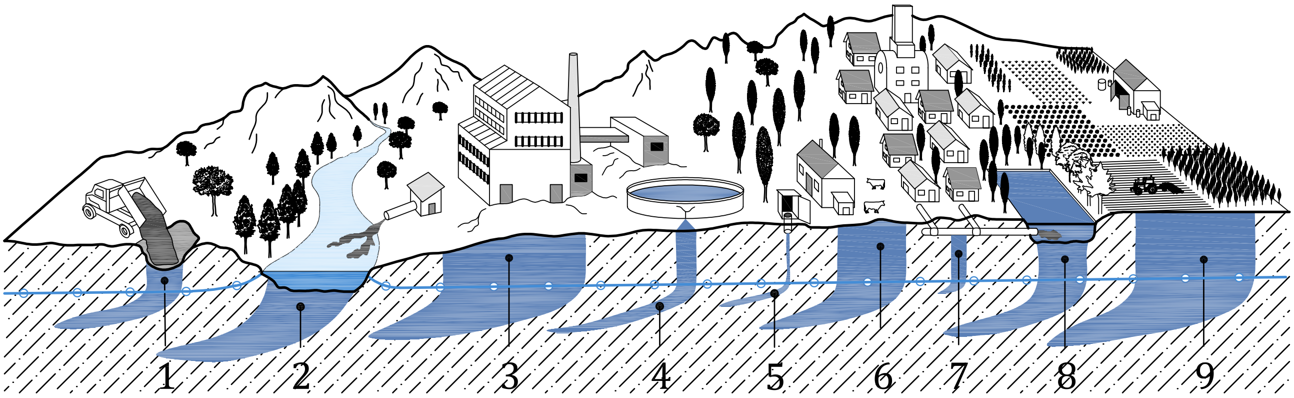
Vaporous contaminants, essentially volatile organic compounds (VOCs) are likely to migrate in the unsaturated zone in gaseous form. Knowledge of the soil gas quality in the unsaturated zone allows detection of contamination before it reaches the saturated zone as well as in the saturated zone.

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 should 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.



Key

1 solid waste tip of landfill
2 industrially-polluted “losing” river
3 industrial site drainage
4 leaking storage tanks
5 *in-situ* sanitation
6 farmyard drainage
7 leaking sewers
8 wastewater lagoons
9 agricultural intensification

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Figure 1 — Common sources of groundwater contamination (focus on contaminated land management)[1]

On regional and larger scales, soil contamination is caused, for example, by wet and dry atmospheric deposition. The contamination observed in these cases is generally diffuse and with fairly moderate levels of contamination. On a local scale, a variety of point sources can cause all kinds and magnitudes of soil and groundwater contamination. In the case of immiscible contaminants (for example hydrocarbons), most of the contamination forms a separate liquid phase from water. A fraction is soluble and capable of migrating to groundwater. In the unsaturated zone, another fraction could be in the vapour phase. Depending on the relative density in water, the behaviour of the contaminant is very different. Light non aqueous phase liquids (LNAPL) have a lower density and dense non aqueous phase liquids (DNAPL) have a higher density than that of water. Most point sources of contamination can 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. Furthermore, groundwater impact assessment depends on the aquifer system: unconfined or confined and the type of porosity: porous media, fractured media or karst environment. 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.

Investigation strategies may be simple to complex. Simple or qualitative approaches mostly refer to assessment of, for example, the potential leaching risk of chemicals through the soil towards groundwater. In contrast to complex or quantitative approaches, the level of actual soil contamination

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is not taken into account. Approaches of this type can also be used, for example, 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 used. Laboratory measurements can include physical, chemical and biological analysis, and leaching tests. Assessments of this kind should also 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 might not be measurable at the time of the investigation, but could happen sometime 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 is provided in the main part of this document (see Clause 5).

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 document.

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5 Assessment of direct and indirect inputs to groundwater

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 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).

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It is also necessary to describe the soil that is impacted by the contamination source, and the factors affecting the impact on the groundwater, e.g. the geometry, hydraulic conditions and natural chemical and biologic processes. Indeed, many processes occurring in the soil (physical, chemical and biological processes) may influence the groundwater impact.

The processes involved are illustrated schematically in Figure 2 and a description of the relevant parameters is given in Table 1.

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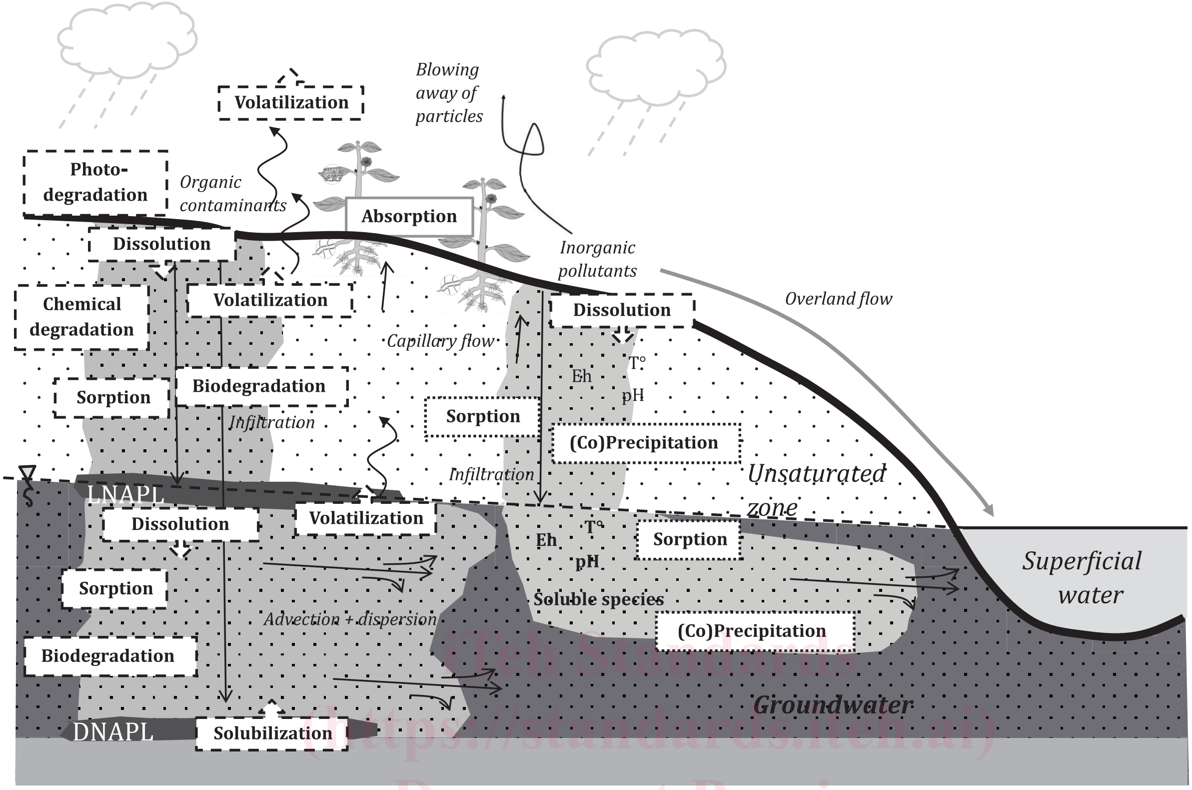

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Figure 2 — Schematic diagram illustrating the soil compartment covered by the assessment procedure and processes affecting the impact of contamination on groundwater[2]

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The types of information needed to describe the relevant soil compartment include pedology (e.g. soil unit), lithology of parent material, hydrogeology (e.g. permeability), physico-chemical conditions (e.g. pH) and biological conditions (e.g. substrate availability). The study area of the impact assessment depends on many factors, such as the following:

— the origin of the contamination: diffuse versus point source;

— the type and characteristics of contaminants (e.g. solubility, persistence);

— the type (e.g. consolidated, unconsolidated, sedimentary/metamorphic/igneous, fractured, karstic, dual porosity, etc.) and characteristics of the aquifer (e.g. homogeneous/heterogeneous, isotropic/anisotropic, bedding, jointing, confinement, dispersivity, velocity, etc.);

— the use of the aquifer (e.g. drinking water supply, industrial supply) and relations of the aquifer with superficial water (e.g. lakes, rivers, etc.).

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, physical and chemical processes. Which of these processes are to be considered important within a given context depends 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.

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Contamination ageing influences different processes in soil: decrease of degradation and mobility, increase of sorption and viscosity. This parameter should be taken into account for the impact assessment.

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

Process	Examples of soil parameters	Examples of contaminant parameters
Mass transport of contaminants	Hydraulic, conductivity, degree of saturation, porosity, pore size distribution, soil water-retention functions, relative permeability, residual saturation, wettability, surface tension, capillary pressure, tortuosity	Solubility, volatility, density, viscosity Adsorption/sorption
Contaminant transport in water:		
Advection	Pressure gradient, hydraulic conductivity, porosity	
Dispersion/diffusion	Dispersitivity, pore water velocity	Diffusion coefficient
Density transport	Pore water velocity, soil layering Viscosity Dispersion, change in density	Liquid density
Preferential flow	Pore size distribution, fissure size, macropore size, connectivity Dispersion, change in density	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 products
Precipitation	pH, redox, other components, water content	Solubility product, complexation constant
Complexation	pH, ligand concentration, dissolved organic compound DOC	Stability constant of complexes
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 coefficient
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 coefficient
Degradation		
Abiotic	Redox, pH, temperature	Presence of primary susbtrate, degradability, toxicity to microorganisms
Biotic	Microorganisms, redox, substrate, pH, temperature, water content	

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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;

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— analytical and testing strategies;

— for each site and/or media (soil, groundwater, soil gas) 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, the assessment should be carried out following a tiered approach (see Figure 3 which displays a generic approach which can be amended when necessary). The impact assessment is often an iterative procedure, each tier 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. (see Tier 2 on Figure 3).

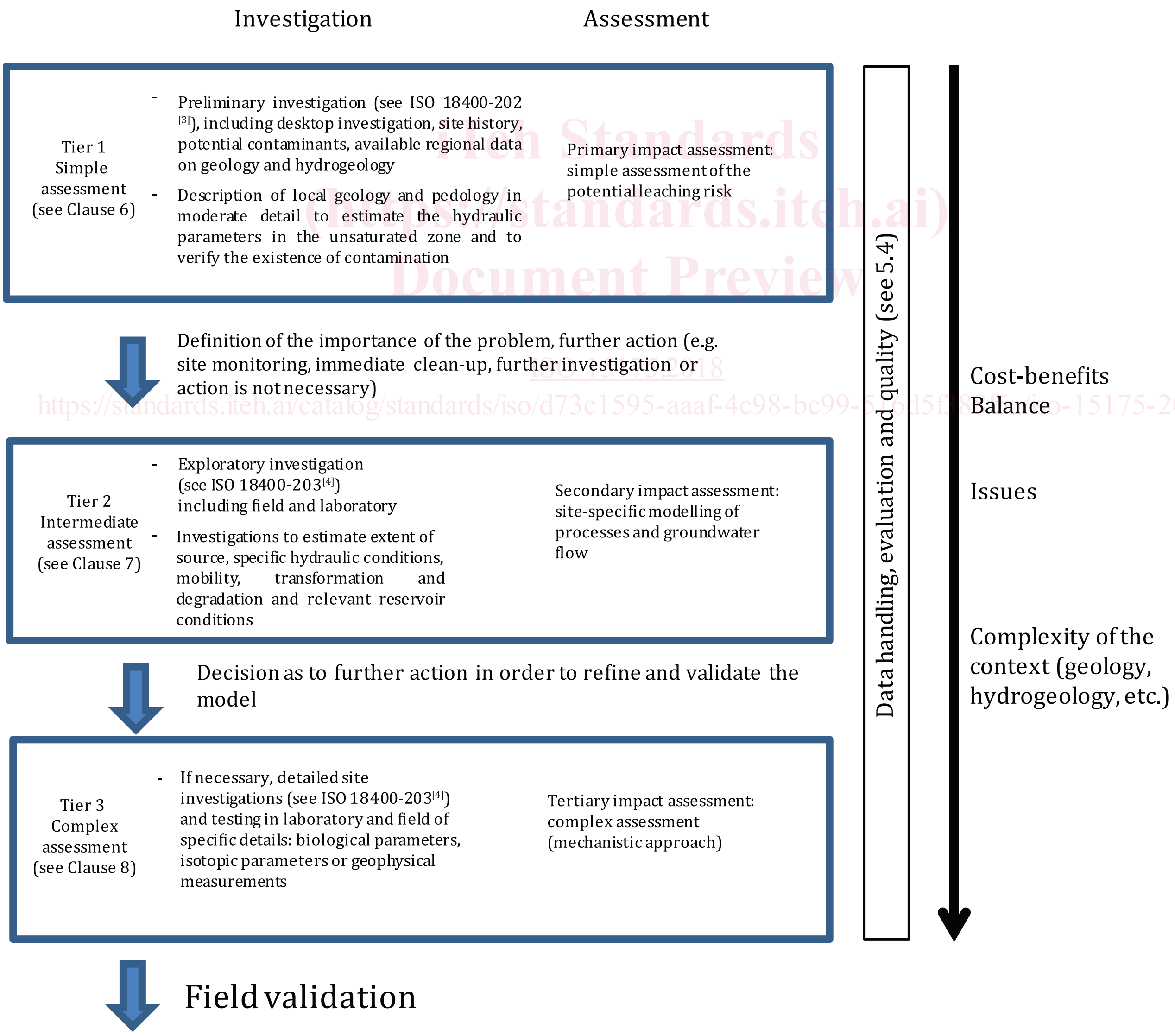

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Figure 3 — Graduated approach for impact assessment

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