LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg

Contaminated sites and groundwater contamination 42

Groundwater Investigation Strategy

Guide to investigating contaminated sites

Baden-Württemberg

LUBW Landesanstalt für Umwelt, Messungen und
Naturschutz Baden-Württemberg

Groundwater Investigation Strategy

Guide to investigating contaminated sites

PUBLISHED BY

LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg
(State Institute for Environment, Measurements and Nature Conservation Baden-Wuerttemberg)
76231 Karlsruhe, Postfach 10 01 63
www.lubw.baden-wuerttemberg.de

WRITTEN BY

Rainer Dinkel, Peter Rothschink
UW Umweltwirtschaft GmbH, 70499 Stuttgart

Thomas Osberghaus
Ingenieurgesellschaft Dr. Eisele mbH, 72108 Rottenburg

Stephan Denzel
dplan GmbH, 76199 Karlsruhe

Dr. Thomas Ertel
Sachverständigenbüro Dr. Ertel, 73734 Esslingen

EDITED BY

LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg
Department 44 – Contaminated Sites, Contamination

DESIGN/LAYOUT

Petra Dobusch
Zeichenbüro Dobusch, 74392 Freudental

AVAILABLE FROM

The brochure is available for xx euro from the distribution agent of LUBW's publishing department
JVA Mannheim – Druckerei
Herzogenriedstraße 111, 68169 Mannheim
Fax 0621/398-370
E-Mail bibliothek@lubw.bwl.de
and as a download from: www.lubw.baden-wuerttemberg.de

ISSN

1437-0158

DATE PUBLISHED

März 2009, 1st edition

Summary

The guide deals with the investigation of harmful soil changes (SBV) and contaminated sites as the basis for:

- the risk assessment according to the Federal Soil Protection Law (Bundes-Bodenschutzgesetz - BBodSchG) and Federal Soil Protection and Contaminated Site Ordinance (Bundes-Bodenschutz- und Altlastenverordnung - BBodSchV) within the scope of the preliminary investigation (Orientierende Untersuchung - OU) or detailed investigation (Detailuntersuchung - DU),
- the decision regarding the need for a remediation investigation (Sanierungsuntersuchung - SU),
- characterisation of the hydrogeological and hydrochemical conditions with respect to the selection and planning of remediation methods within the scope of the SU,
- the monitoring or review of the success of remediation measures or natural attenuation (NA).

Above all, it is aimed at experts, specialist consultants and functional authorities, as well as at property owners and bodies obligated to investigate, who develop, check or commission investigation strategies. It describes the procedure for developing investigation strategies to create the database for decisions according to contaminated site legislation concerning the sensitive receptor groundwater. The cost and time-saving potential of innovative investigation methods are also taken into account, such as integral pumping tests or fast methods of sample and measured value determination. Detailed explanations of individual methods is left to separate documents such as methods literature, status reports or special action aids and specialist literature.

The guide is divided into three sections:

- Chapter 1 explains the targets of the investigations as well as important soil protection and water legislation investigation and assessment principles.
- Chapter 2 explains the development of suitable investigation strategies as well as conceptual requirements for groundwater investigations. It explains both the legal issues and the technical investigation.
- Chapter 3 deals with the groundwater investigation methods. In particular, it encourages the use of innovative or newer investigation methods and equipment to save costs and time.

This guide contains the important decision-making criteria of the, now expired, joint administrative regulations of the Ministry of the Environment and Transport and the Ministry of Social Security Baden-Württemberg concerning indicative values for dealing with contaminated sites and contamination (VwV OW Verwaltungsvorschrift des Ministeriums für Umwelt und Verkehr und des Sozialministeriums Baden-Württemberg über Orientierungswerte für die Bearbeitung von Altlasten und Schadensfällen), so that future decisions of the administrative authorities can be based on these guidelines.

This guide also updates and replaces the "Leitfaden Erkundungsstrategie Grundwasser" [37] (Groundwater Investigation Strategy Guide) published in 1996 by the then LfU.

1 Basic Principles

Investigation of subsoil pollution, such as the contamination still frequently found today on many industrial and commercial sites as a consequence of careless handling of environmentally harmful substances in the past, is expensive and time-consuming. Because the investigation does not improve the hazardous situation, the aim is to keep the time and effort required for it as low as possible and to invest instead in the site remediation. On the other hand, reliable site investigations are a necessary precondition for proper professional site assessments and decisions regarding any action required as well as regarding well-directed and effective use of funds in the case of remediation measures. Excessive economising in the site investigation can, for example, lead to the failure to identify existing hazardous situations and as a consequence necessary defensive measures are omitted or remedial measures are ineffective.

If indications of site contamination or harmful soil changes exist, the suspected areas must be subjected to an initial preliminary investigation (OU) according to Art. 3 Para. 3 BBodSchV (Federal Soil Protection Ordinance). The results of the (OU) must be evaluated. If the suspect areas cause risks to the groundwater, a leachate forecast must be prepared within the scope of the detailed investigation (DU) for the assessment of the potential hazard in accordance with Art. 4 Para. 3 BBodSchV. To this end, the pollutant concentration must be determined or predicted in the place to which the assessment refers, i.e. the transition zone between the unsaturated soil zone and the groundwater.

The requirements for the remediation of bodies of water are defined by water legislation (Art. 4 Para. 4 Sentence 3 BBodSchG - Federal Soil Protection Law). In Baden-Württemberg, these are the Water Management Law (Wasserhaushaltsgesetz - WHG) and the Water Law for Baden-Württemberg (Wassergesetz - WG). The joint administration regulations on indicative values for dealing with contaminated sites and contamination (Gemeinsame Verwaltungsvorschrift des Ministeriums für Umwelt und Verkehr und des Sozialministeriums Baden-Württemberg über Orientierungswerte für die Bearbeitung von Altlasten und Schadensfällen - VwV OW) of Baden-Württemberg were issued on the basis of this. The regulations contain detailed provisions for the assessment of groundwater pollution and the decision regarding the necessary action. They have proven their worth in a large number of decisions in Baden-Württemberg; however, it has now expired. Nevertheless there are no objections to continued use of this procedure, provided this does not cause any breach of current laws or regulations. This guide summarises the important decision-making criteria from the regulations so that future decisions by the administrative authorities can be based on these guidelines and the VwV OW no longer have to be used.

In 1996, the then LfU published the groundwater investigation strategy guide ("Leitfaden Erkundungsstrategie Grundwasser") [37] to support enforcement of soil conservation and water legislation in groundwater investigation of suspected contaminated sites and contaminations. It described an approach to hydrogeological investigation of the subsoil as the basis of the risk assessment and decisions regarding further need for action. The strategy and implementation of this investigation were described with the help of central questions with methodical instructions for individual investigation stages and hydrogeological conditions and explained using case histories. The guide was widely used and accepted, however, many parts of it no longer corresponded to current laws and new technical options. The content of the old guide has been updated accordingly in this guide so that in future it will no longer have to be referred to.

The following explains which technical and legal issues have to be answered by groundwater investigations. To this end, Section 1.1 first explains models assumptions on pollutant propagation. Then, in Section 1.2, the soil protection and water legislation assessment principles and investigation objectives for the respective investigation stages are described.

1.1 POLLUTANT DISPERSION MODEL ASSUMPTIONS

Important questions in the assessment of the danger situation are:

- Is the pollution source located in the unsaturated zone or in the groundwater?
- Has groundwater contamination already occurred or will it be the case in the future? (This question only concerns pollution sources in the unsaturated zone).
- Has the pollution source been removed or can it not be found and is there nevertheless groundwater contamination?

Therefore, existing knowledge of the site and its surroundings as well as experience from comparable cases should be used to develop a **model assumption** of the presumed extents and behaviour of the contamination. In simplified terms, a differentiation can be made between the cases schematically described in Figure 1. The two cases II and IV are used in the following to explain important basic terms and concepts in the assessment of groundwater contamination.

Centre of pollution above the groundwater - This situation (Case II) is shown enlarged in Figure 2. The potential risk depends on the pollutant concentrations in the leachate of the centre of pollution c_{SH} and on the leachate flow rate. On the leachate's path from the pollution source to the groundwater, natural contaminant

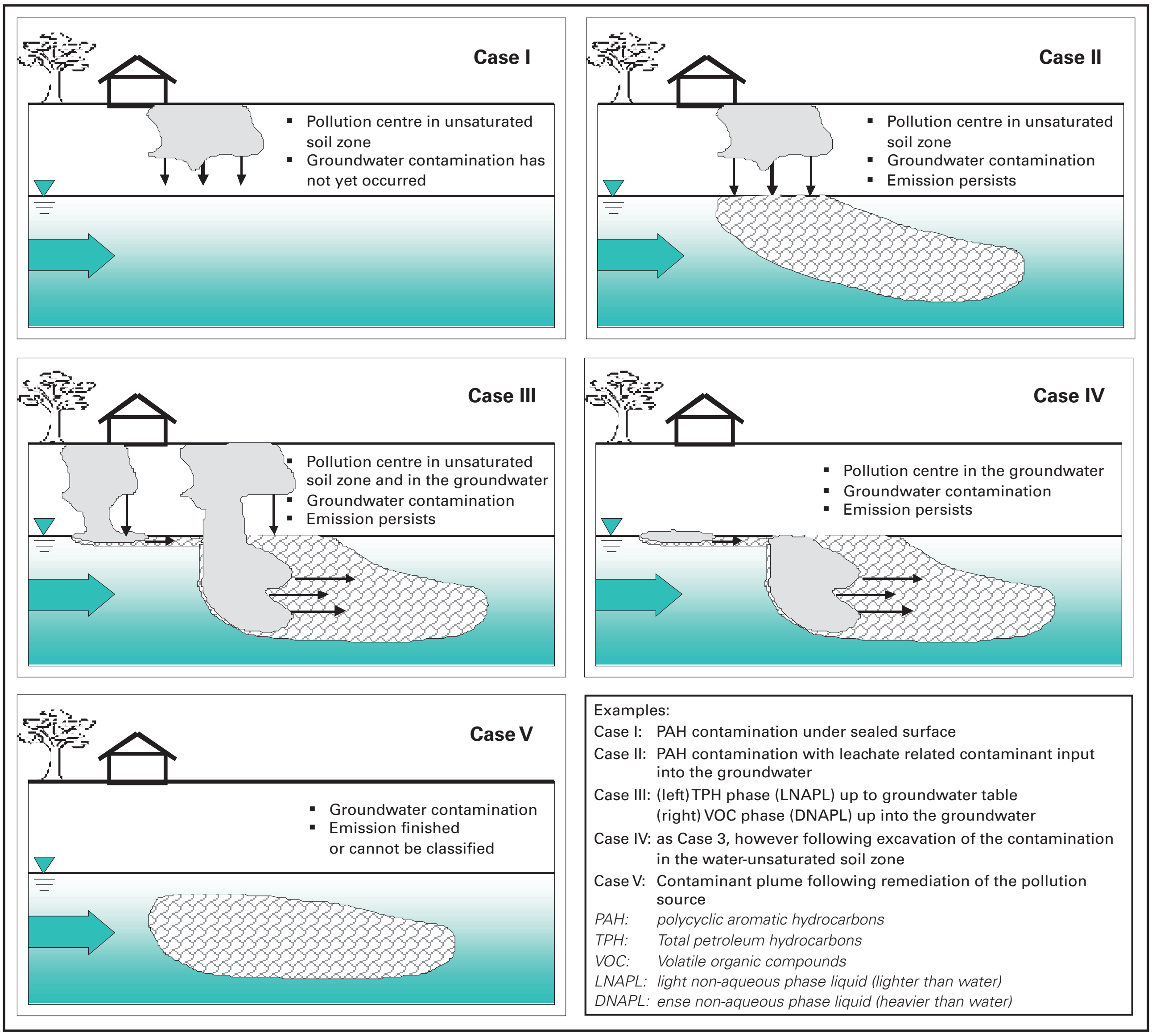


Figure 1: Cases of pollutant dispersion (based on [27])

reduction (attenuation) can occur so that the original pollutant concentrations and loads reduce. Only those pollutant concentrations c_{OdB} and loads E_{OdB} which reach the transition zone between the unsaturated and the water saturated soil zone or groundwater are relevant for the soil protection and water legislation risk assessment. The leachate forecast deals with this. The transition zone between the unsaturated and saturated soil zone is called the **site of assessment** in soil protection legislation terms (for further details, see Section 1.4.2). The current and future expected substance concentrations and loads at the site of assessment are determined or forecast in the leachate forecast. Annex 1 No. 3.3 of the BBodSchV names three leachate forecast options and admits that they provide approximate values only:

1. Conclusions or back-calculations from investigations in the groundwater outflow, taking into account the substance concentration in the groundwater inflow, the dilution, the pollutant behaviour in the unsaturated and saturated soil zone as well as the contaminant inventory in the soil,
2. on the basis of in-situ investigations,
3. on the basis of material investigations in the laboratory (elution, extraction).

Within the groundwater the contaminants are diluted by diffusion and convection. Therefore, the pollutant concentrations c_A in the groundwater and at the surface of the groundwater c_{OdB} differ. In the direct groundwater outflow – view from above this area is the boundary of the centre of pollution and by definition is not yet significantly affected by natural contaminant reducing (attenuation) processes (cf. Section 2.3.2.1) – the outflowing pollutant loads E_A are, however, still approximately the same as input into the groundwater. It is not until further downstream that retardation and natural attenuation processes (NA) result in significant reductions in both the concentrations and the pollutant loads with respect to space and time.

The **contaminant plume** is defined as the area with concentrations of dissolved contaminants above the insignificance thresholds (GFS) or screening levels.

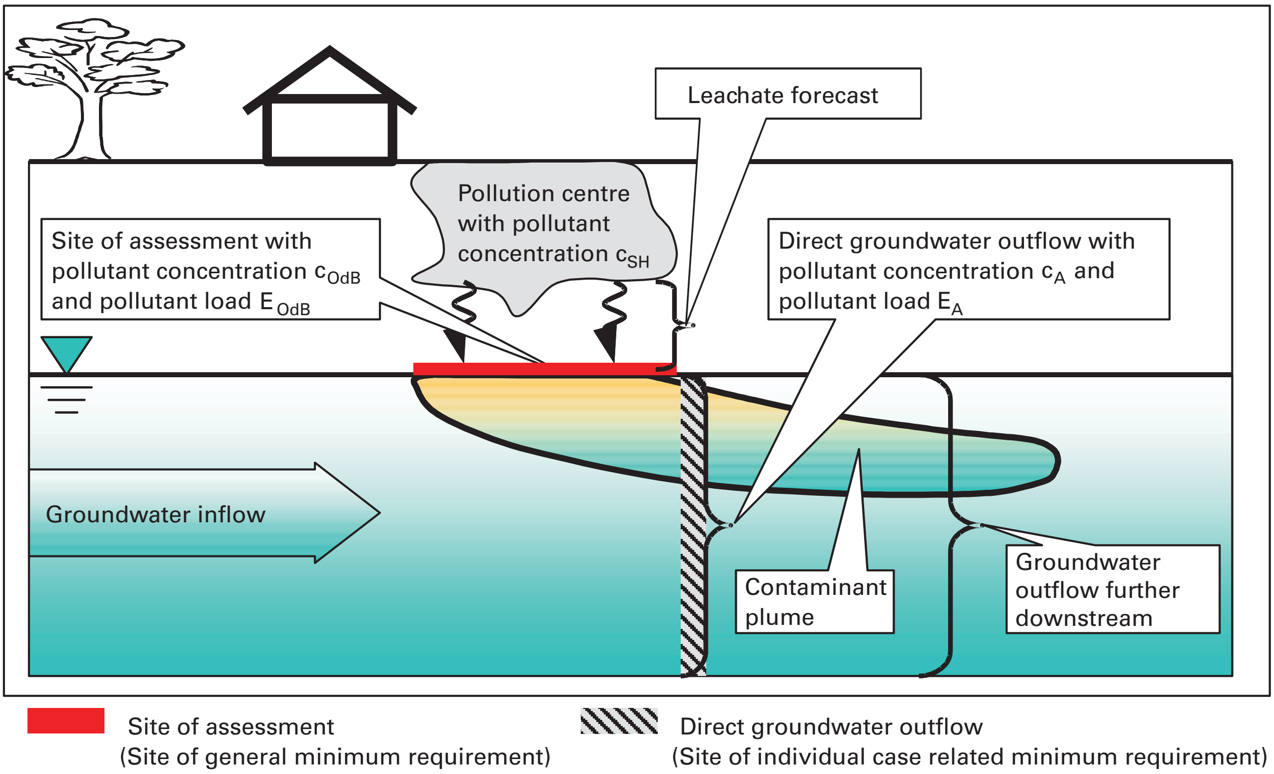


Figure 2: Basic terms for centre of pollution above the groundwater

If both loads from the centre of pollution E_{OdB} and from the groundwater outflow E_A exist, this is used for the plausibility check. If the groundwater is examined directly at the downstream boundary of the centre of pollution (cf. Section 2.3.2.1), both variables should be more or less the same. If E_A is less than E_{OdB}, this could be due to retardation and natural attenuation processes along the route from the contaminant input and the downstream boundary of the contaminant input.

Centre of pollution centre in the groundwater - This situation (Case V) is shown enlarged in Figure 3. The terms and explanations used correspond to those of Figure 2.

In the case of centres of pollution in the groundwater, unlike centres of pollution **above** the groundwater, there is no difference between the source strength c_{SH} and the pollutant concentration at the site of assessment c_{OdB}. In this case the site of assessment is the so-called contact groundwater, i.e. the transition zone between the centre of pollution and the groundwater flowing past.

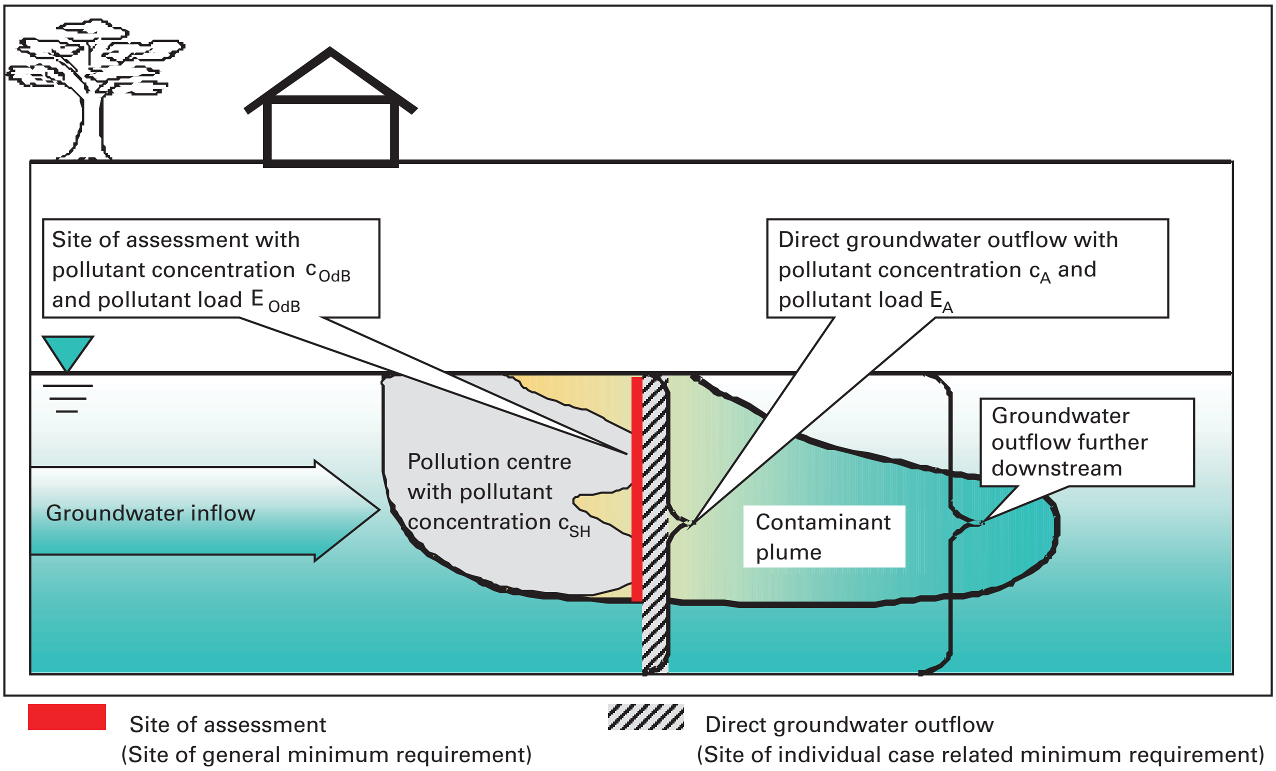


Figure 3: Basic terms for centre of pollution in the groundwater

1.2 ASSESSMENT PRINCIPLES AND PHASED PROGRAMME

Assessment of the hazardous situation for centres of pollution in the unsaturated soil zone is based on the BBodSchG and BBodSchV with the screening levels contained in them. If centres of pollution in the water saturated soil zone and in the groundwater the basis of assessment is - as mentioned - the WG as well as the VwV OW.

The need for action under soil protection and water legislation is advisably examined and assessed in several steps. This ensures that the investigations are limited to the necessary extents and that it is possible to flexibly respond to the respective knowledge available. If necessary, a preliminary investigation (OU) is followed by a detailed investigation (DU), which if necessary is followed by a remediation investigation (SU), which forms the basis for the remediation decision. The phased procedure is shown in Figure 4 and explained in Table 1. Deviations from this procedure are possible, for example if their is a risk in delay or if hazards can be averted or removed by simple means (Art. 3 Para. 5 Sentence 2 BBodSchV).

Notes on the individual investigation steps are given in the following sections. These are based on soil protection and water legislation provisions as well as technical explanations such as the LUBW explanations on the VwV OW named in the following:

- Explanation No. 1 Core points
- Explanation No. 2 Background to the groundwater protection provisions
- Explanation No. 3 Need for remediation and remediation target for the protection of groundwater
- Explanation No. 5 Worthwhile use of a groundwater source
- Explanation No. 6 Depth-averaging over the directly affected aquifer
- Explanation No. 7 Effects of the VwV on the assessment at level of confidence 3
- Explanation No. 9 Assessment of soil vapour values (sensitive receptor groundwater)
- Explanation No. 10 On the need for remediation in case of ammonium emissions

These explanations are contained in updated form in the contaminated site information system AlfaWeb [28] of the LUBW as an annex to the VwV OW.

1.3 PRELIMINARY INVESTIGATION

With the results of the preliminary investigation (OU) it must be possible to decide whether specific grounds exist to justify sufficient suspicion of a contaminated site.

The OU is the task of the responsible authorities (Art. 9 Para. 1 BBodSchG). An OU is not necessary if the survey or other sources already indicates sufficient suspicion of a risk or an urgent need for action and therefore immediate risk prevention measures can be initiated [25]. Notes for implementation of the administrative tasks for the OU and case studies are given in the LUBW guide on official investigations into suspected contaminated sites ("Die Amtsermittlung bei altlastverdächtigen Flächen nach § 9 Abs. 1 BBodSchG") [30].

In-situ investigations or material investigations in the laboratory are often performed as part of the OU. A leachate forecast based on back-calculations from the groundwater outflow is only made at this stage of the investigations if it appears suitable and proportionate in view of the site situation and the hydrogeological conditions. For example, this can be the case if the actual suspected area is not directly accessible, particular heterogeneities are to be expected or if several suspected areas are to be integrally recorded by means of outflow measurements.

1.4 DETAILED INVESTIGATION

1.4.1 GENERAL INFORMATION, FACTUAL ELEMENTS

The results of the detailed investigation (DU) must enable the following decisions to be made:

- Do hazards result from spatially limited accumulations of contaminants within a harmful soil change or a contaminated site and is containment and demarcation from uncontaminated areas advisable (Art. 3 Para. 5 BBodSchV)?
- To what extent are the screening levels exceeded at the **site of assessment** or will they be exceeded in the future?
- To what extent are screening levels exceeded **in the** groundwater or does a substantial pollutant load exist (exceeding of the E_{max} value) or is this to be expected in the future in accordance with a leachate forecast?
- Do risk prevention measures have to be checked (SU according to Section 1.5)

Please refer to Section 1.6 regarding the consideration of NA processes in the detailed investigation.

The DU is not necessary if the risks, substantial disadvantages or substantial nuisances due to harmful soil changes or contaminated sites can be averted by simple means (Art 3 Para. 5 Sentence 2 BBodSchV). The simple means can include, for example, excavating soil contaminations in the dome shaft area of underground tanks.

1.4.2 IMMISSIONS/EMISSIONS CONSIDERATION

Criteria for the assessment of the extent of hazards or contaminations and for deciding whether there is a need for remediation are described in the following.

If "locally limited increased pollutant concentrations" only and "low pollutant loads" only permanently exist in the groundwater, according to Art. 4 Para. 7 BBodSchV this must be taken into account in the proportionality check of investigation and remediation measures. Hazards or contaminations with respect to groundwater can therefore be tolerated to a certain extent, if the weighing up of the circumstances shows that complete risk prevention or contamination removal would be disproportionate for economic, technical or legal reasons.

When deciding whether there is a need for action for used or worthy of use groundwater sources a differentiation is made between the **general** and the **individual case related** minimum requirement (VwV OW).

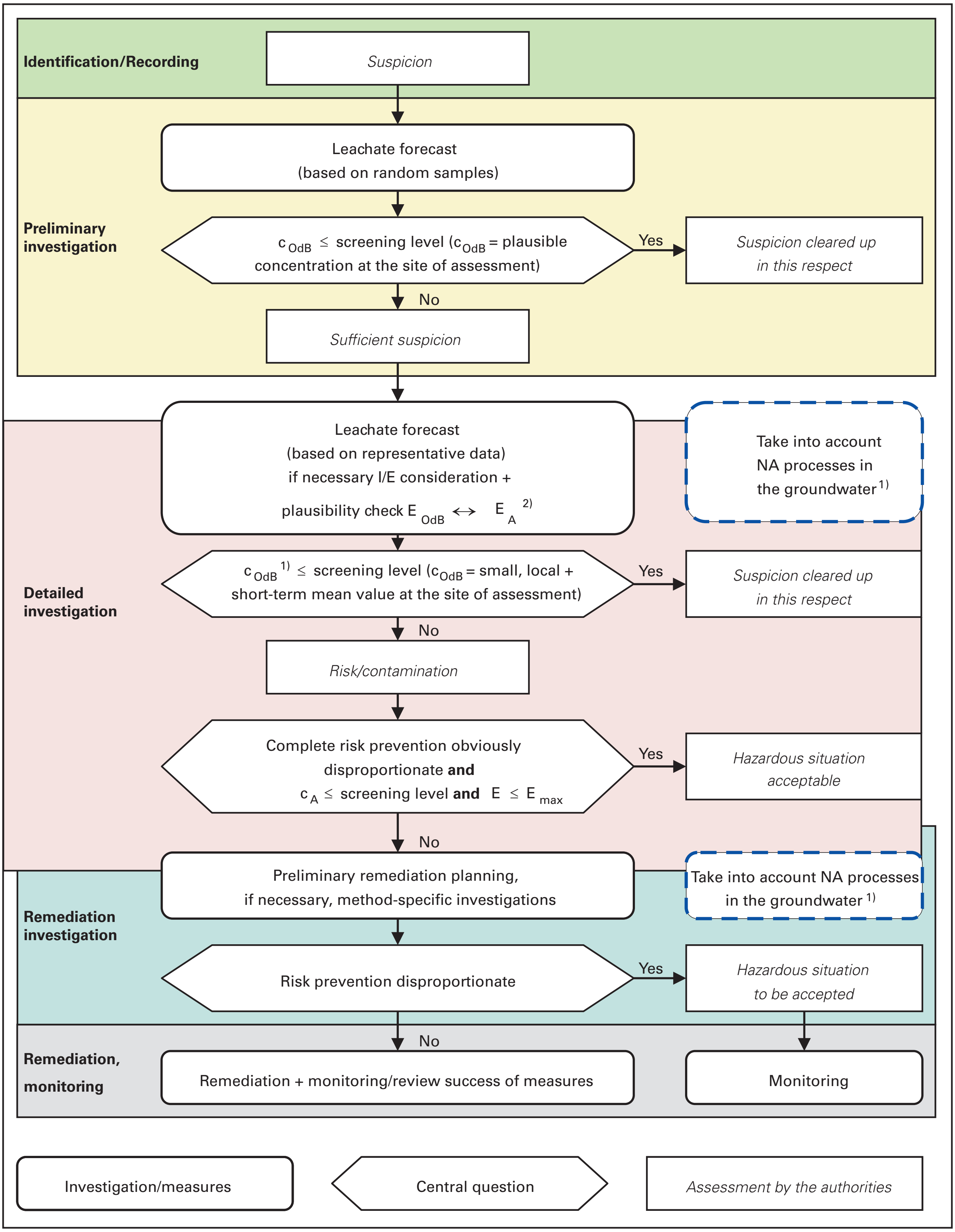
The **general** minimum requirement is:
There is no need for remediation if

- the values at the site of assessment are less than the screening levels (cf. Appendix II).

The **individual case related** minimum requirement is:
There is no need for remediation if the two following conditions are fulfilled:

- The pollutant concentration c_A averaged over depth, i.e. vertically diluted located directly at the outflow boundary of the centre of pollution is below the water legislation insignificance threshold or the screening level (cf. Appendix II). This is what is meant by the term **"Immission control"**.
  In simplified terms the insignificance threshold is shifted from the site of assessment according to BBodSchV into the direct groundwater outflow.
- The daily pollutant load E is below the E_{max} value (cf. Appendix II). This is what is meant by the term **"Emission control"**.
  Without this limitation or control, excessive pollutant emissions could occur in high-yield aquifers with high dilution capacity.
  Note: Whether the emission control is checked on the basis of the load E_{OdB} or E_A is a question of the investigation or data situation and the site conditions. Therefore, a differentiation between E_{OdB} and E_A is no longer made here.

The check of the two conditions is also called the **immissions/emissions consideration (in short: I/E consideration)**. Figure 5 illustrates the site of assessment and the test criteria for the individual case related minimum requirement.



[1] if necessary identify and quantify

[2] if both E_{OdB} and E_A are known

Figure 4: Phased programme for dealing with contaminated sites (standard)

Table 1: Basis of decisions following defined investigation stages

<table>
<tr><th>Phase</th><th>Location</th><th colspan="3">Decision</th></tr>
<tr><td>Identification</td><td>Pollution centre</td><td colspan="3">Suspicion (grounds?)</td></tr>
<tr><td rowspan="3">Preliminary investigation OU
(The data situation is selective/ localised, i.e. the centre of pollution is spatial extents not yet determined)</td><td rowspan="2">Site of assessment</td><td rowspan="2">Compliance with screening level, current and future?</td><td>Yes</td><td>Suspicion cleared up in this respect</td></tr>
<tr><td>No</td><td>Sufficient suspicion
(specific grounds)</td></tr>
<tr><td colspan="4">Explanations:
If there were no indications of exceeding of the screening levels in the OU[1] at the site of assessment the suspected hazard is cleared up in this respect. There is no need for any further action.
If a screening level is exceeded at the site of assessment or it is expected to be exceeded there is sufficient suspicion of an SBV/site contamination. However, after the OU it must not yet necessarily be known how large the area with forecasted exceeding of screening levels is and whether the exceeding of the screening levels is subject to seasonal fluctuations. This is the subject of the DU.</td></tr>
<tr><td rowspan="4">Detailed investigation DU
(The data is localised and averaged over the short-term, the spatial extents of the centre of pollution are determined)</td><td rowspan="3">Site of assessment</td><td rowspan="3">Compliance with screening level, current and future?</td><td>Yes</td><td>Suspicion cleared up in this respect</td></tr>
<tr><td>No (future)</td><td>Risk → SBV/site contamination</td></tr>
<tr><td>No (current)</td><td>Risk + contamination → SBV/site contamination</td></tr>
<tr><td colspan="4">Explanations:
The pollutant concentrations which result from small and short-term averaging are to be estimated for the site of assessment [25]. Averaging is small / localised if it extends over a maximum 100 m^2 leachate forming ground surface. The time averaging can relate to approximately one year[21][2]. (Factual elements)
If it can be assumed that the screening level at the site of assessment will not be exceeded, either now or in the future, the suspected hazard <u>is cleared up</u> in this respect.
If exceeding of the screening level at the site of assessment not only occur localised in small areas and if this is all the case for the annual average, this is deemed to be verification of a hazardous situation and contamination. If the exceeding of the screening level at the site of assessment is not to be expected until a later date, until then there is only a risk[3]. In both cases (risk or contamination) an SBV/site contamination circumstance is involved (Art. 2 Para. 3 and 5 BBodSchG), which in general requires an SU.</td></tr>
<tr><td></td><td>Site of assessment and outflow</td><td colspan="3">Hazardous situation "acceptable"? (complete risk prevention is obviously disproportionate and in the long term locally limited increased contaminant concentrations only exist (screening level/GFS depth-averaged complied with) <u>and</u> low pollutant loads only ($E < E_{max}$)). This is the "individual case related minimum requirement" (cf. Section 1.4.2). (Legal consequences side)</td></tr>
<tr><td>Remediation investigation SU</td><td>Site of assessment and direct outflow</td><td colspan="3">Hazardous situation to be accepted or need for remediation? (Check suitability and appropriateness of remediation measures taking into account the individual case related minimum requirement). If the individual case related minimum requirement can also not be achieved due to lack of proportionality, the hazardous situation is "to be accepted".</td></tr>
<tr><td>Remediation, monitoring</td><td>Site of assessment and direct outflow</td><td colspan="3">Achievement of the remediation target and compliance with the control objectives.</td></tr>
</table>

[1] The geogenic background situation must be taken into account on applying the screening levels (Annex 2 BBodSchV).

[2] Irrespective of these guideline variables the averaging must be specified for specific individual cases. For example, in the event of small but large contaminations in the area of underground tanks it can appropriate and proportionate to relate the averaging to less than 100 m^2 area.

[3] If groundwater investigations from the outflow only are available without data from the centre of contamination it is not possible to evaluate whether a risk exists or not (Case I in Figure 1), only whether contamination has already occurred or not.

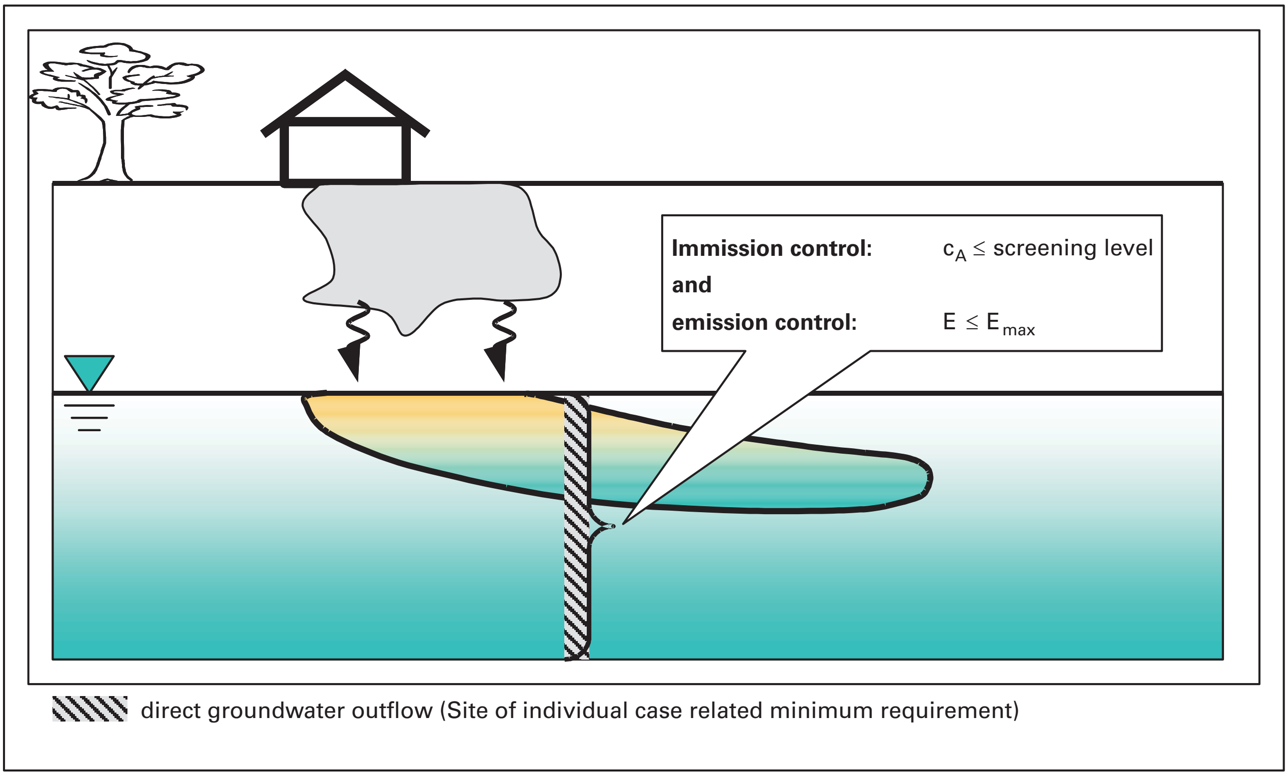


Figure 5: Site of assessment and test criteria for the individual case specific minimum requirement according to VwV OW (the same applies accordingly for centres of pollution in the groundwater (Figure 3))

The screening levels are shown in Appendix II and - where known - are compared to the background values or insignificance thresholds (GFS).

The pollutant levels c_A in the direct groundwater outflow of a pollution source (immission) are defined as average concentrations over the thickness (depth) of the groundwater. If the thicknesses are large a depth of maximum 30 m only should be used for the averaging. Important requirements for the depth averaging are, according to Explanation No. 6 to the VwV OW "Depth averaging over the directly affected aquifer" [28]:

1. The depth averaging extends over the depth up to the aquifer base or up to the next intermediate horizon.
2. Only the depth which ensures protection of the groundwater capture should be used for the depth averaging.
3. If aquifer sections alone are not worth using, however together they are worth using, they are to be grouped together to form a (worth using) aquifer.
4. The depth averaging takes place there where the contaminants of the contaminated site enter an aquifer (if necessary made up of several aquifer sections), which is worth using and therefore is included in the worth using groundwater source.

The way in which the depth is averaged (for example, on the basis of inflow weighted pumping samples from suitable monitoring wells or mathematically on the basis of levelled measurement data) is to be defined in the investigation concept (cf. Chapter 3).

The depth averaging relates to the contaminants dissolved in the groundwater. Phase bodies of organic contaminants are not affected by this and have to be subjected to a separate assessment.

Larger contaminated areas must be divided into several, roughly equally contaminated **sub-streams** (stream tubes) for the I/E consideration (Explanation No. 3 to the VwV OW).

The responsible water authority makes decisions regarding lower requirements for the protection of groundwater sources not worth using.

Compliance with the individual case related minimum requirement can be dispensed with in special cases, for example, in case of:

1. extremely low yield (unusable) aquifers,
2. very narrow bank strips between the centre of pollution and outfall or
3. particularly small emissions of less than 1 % of the E_{max} value.

For groundwater sources not worth using it is sufficient to comply with emission control (Explanation No. 5 to VwV OW) [28].

Reference is made to the "principles of after care groundwater protection in case of small localised (point) pollution sources" of the LABO LAWA [27], which also define Art. 4 Para. 7 BBodSchV in more specific terms. The approach of discretionary provisions introduced in Baden-Württemberg as an immissions/emissions consideration in 1993 is therefore picked up at federal government/Länder level for the first time. In addition, it also introduces a supplementary criterion for contaminations with **completed** substance input from the **unsaturated** zone (case groups IV and V in Figure 1), namely the variable of groundwater contamination or the contaminant quantity. According to this, contamination of the groundwater (i.e. the pollution source within the groundwater including plume) can be deemed to be **"small"** if the maximum pollutant levels in 10,000 m^3 water and rock volume is 100 times the insignificance threshold or at the insignificance threshold as a maximum value in 1,000,000 m^3 water and rock volume. Intermediate variables are to be interpolated. This criterion can also be used for technical individual case consideration of the need for further measures.

Finally, it should be noted that harmful soil changes or contaminated sites occurring after 01.03.1999 **must be removed**, provided this is proportionate with respect to the soil's previous contamination (Art. 4 Para. 5 Sentence BBodSchG).

1.5 REMEDIATION INVESTIGATION AND REMEDIATION

The remediation investigation (SU) has the following objectives:

- Determine in which way and with which cost &/or effort the screening levels can be complied with at the transition zone between the unsaturated and saturated soil zone. (**General** minimum requirement according to Section 1.4.2).
- Determine in which way and with which cost and/or effort the screening levels and E_{max} values in the groundwater outflow can be complied with. (**Individual case related** "minimum requirement" according to Section 1.4.2).

Both investigation objectives are illustrated in Figure 6.

Depending on the circumstances of the individual case, it may be necessary to forecast future development of the contaminant plume in the groundwater outflow in order to make decisions concerning the need for remediation and its target.

The remediation investigation requirements are listed in Annex 3 of BBodSchV

1.6 CONSIDERATION OF NATURAL ATTENUATION

TERMS AND DEMARCATION

The term natural attenuation (NA - natural contaminant reduction) describes the sum of all physical, chemical and biological processes which – without human involvement and under load reduction – reduce contaminants in the soil and groundwater. Load-reducing processes are usually microbiological in nature; abiotic processes are secondary. Sorption and precipitation reactions are other important load reduction processes within the contaminant plume. They are reversible and do not result in degradation of the contaminants, only in their transfer out of the groundwater and into the soil. Dilution or volatilization effects are not considered to be NA processes. In this case the contaminated

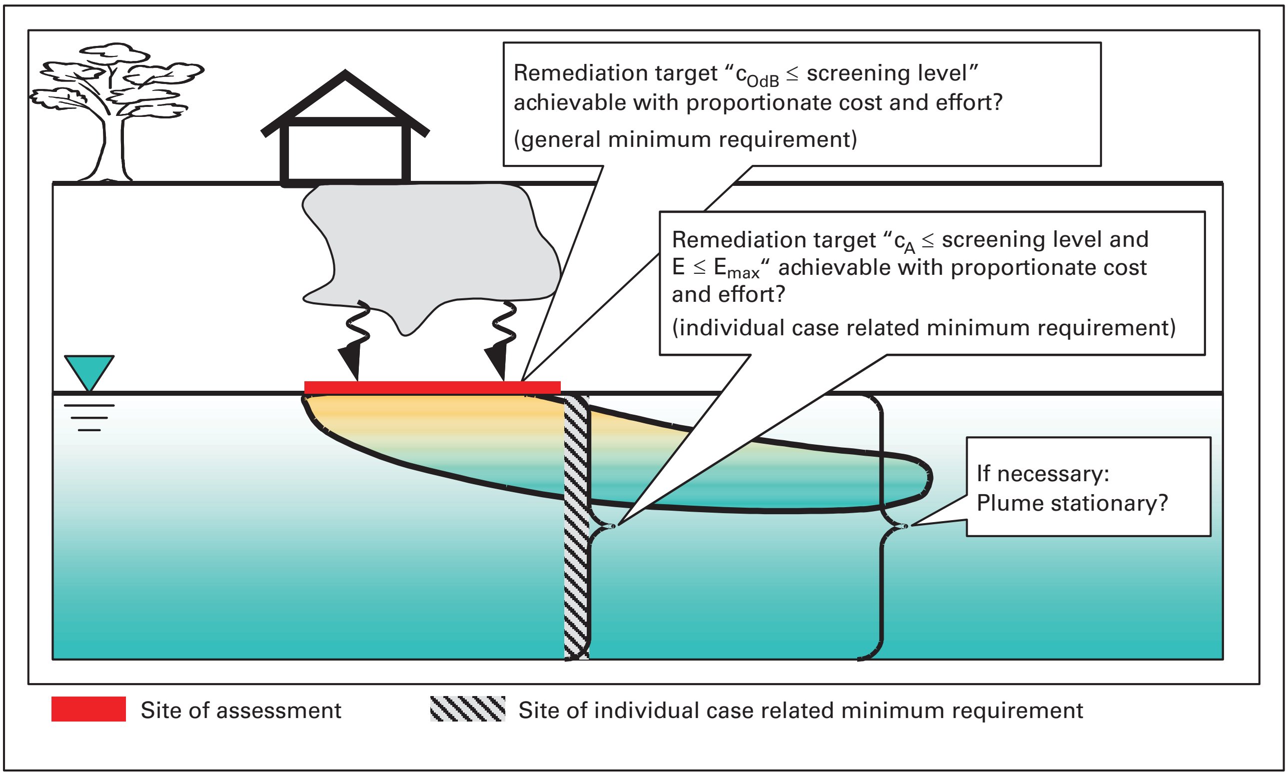


Figure 6: Weighing up remediation targets within the scope of the remediation investigation (the same applies accordingly for centres of contamination in the groundwater (Figure 3))

area of the aquifer acts as a reaction space in which the degradation reactions take place. Contaminant reducing (attenuation) processes are also possible in the unsaturated zone. These are the subject of the leachate forecast in the unsaturated zone (cf. Section 1.2) and are not considered any further here.

The term monitored natural attenuation (MNA) is used to describe the monitoring measures of of a controlled NA process. The official decision is based on an MNA concept. The document verifies comprehensive understanding and the successful progress of contaminant reducing processes and contains the requirements for monitoring all NA processes.

Enhanced natural attenuation (ENA) is a special form of the in-situ remediation measures. The NA processes are initiated, stimulated or supported by introducing substances into the reaction spaces of contaminant plumes.

BASIC PRINCIPLES FOR THE CONSIDERATION OF NA PROCESSES

1. NA processes which are to be tolerated as an option for risk reduction/risk prevention on a site are to be identified and monitored (MNA).
2. MNA is not an active remediation measure according to BBodSchG. The remediation investigation and the NA investigations included in it are subjected to a technical check by the responsible authorities or the assessment committee. If a need for remediation exists it recommends a remediation option. NA processes are therefore only tolerated as an alternative or supplement to active remediation.
3. Apart from the technical requirements, a condition for acceptance of an MNA concept is the disproportionateness of a conventional remediation measure.
4. The basic need for remediation is not questioned by the acceptance of an MNA concept.
5. The following proofs are necessary for an individual case related MNA concept:
   a. The contaminant plume behaves quasi stationary (steady state).
   b. The forecasted NA process sequences are stable and on-reversible in the long-term.
   c. A hazardous situation does not yet exist for impaired groundwater and other sensitive receptors.

d. An alternative action option (usually remediation measure) is available if the NA processes can no longer be observed to the required extent on the site.
6. There is not entitlement to acceptance of an MNA concept as an alternative to a remediation measure. It is always an official decision made on a case by case basis.

MNA CONCEPT STRUCTURE AND SYSTEM

The investigation of the NA processes has a phased structure and is additionally intensified within the scope of the systematic handling of contaminated sites. The depth of investigation depends on the respective knowledge available. In the systematic handling of contaminated sites in Baden-Württemberg, NA processes are usually taken into account as follows:

IDENTIFICATION/RECORDING:

Contaminant-reducing processes in the subsoil and groundwater are not considered in the identification and recording of suspected contaminated areas.

PRELIMINARY INVESTIGATION (OU):

The determination of contaminant-reducing processes is not the subject of the OU. Even if the OU includes a groundwater investigation, the problem is limited to determination of sufficient suspicion or clearing up the suspicion of an SBV or site contamination. Therefore, further results indicating an NA process do not usually exist.

DETAILED INVESTIGATION (DU):

Plume investigations are carried out within the scope of the DU in individual cases only. On the other hand, groundwater investigations in the centre of pollution or in the direct outflow (cf. Section 2.3) regularly take place. However, general indications of possible NA processes can already result from these. For example, degradation products and a reduction in nitrate in the aquifer indicate microbiological degradation reactions, as do certain redox potentials which are relatively easy to measure. If, in a specific case, a need for remediation becomes apparent at an early stage in the procedure it can be advantageous to use the DU groundwater samples to determine additional measuring parameters which care useful for an initial estimation of the applicability of NA and the development of follow-up investigation programmes.

REMEDIATION INVESTIGATION (SU):

Specific, special NA investigations are not carried out within the scope of the SU until MNA materialises as a possible alternative to active remediation measures (decision-making processes). The relatively time-consuming and expensive special investigations into NA processes often take place in a supplementary phase of the SU.

1.7 Official monitoring and self-checking

The **official monitoring** within the scope of the groundwater investigation relates, in particular, to the

- monitoring accompanying the measures during the investigation and remediation, including long-term monitoring of containment measures, e.g. building the monitoring wells and groundwater monitoring,
- check the effectiveness and sustainability of measures (review of success).

According to Art. 15 Para. 1 BBodSchG, contaminated sites and suspected contaminated areas, where necessary, are subject to monitoring by the responsible authorities. Art. 15 Para. 2 BBodSchG authorises the responsible authorities to impose self-checking measures on the parties responsible for the investigations. The requirements of Art. 15 BBodSchG are transferred to harmful soil changes (SBV) with Art. 4 LBodSchAG. Self-checking measures are possible, for example, in the following cases:

- Checking immission and emission control in the groundwater, especially if contamination is accepted due to proportionality consideration,
- Checking the success of the remediation and after care after carrying out decontamination and containment measures.

The guide “Technical control of suspected contaminated areas, contaminated sites and contamination” [36] provides further technical information on monitoring the groundwater quality, for example on the selection or positioning of groundwater monitoring wells, on the determination of a physical-chemical control programme or for the determination of measurement intervals and sampling requirements.

2 Concept

2.1 GENERAL INFORMATION

The investigation strategy describes the basic procedure for achieving an investigation objective. The aim is to obtain the necessary data as the basis for legal and technical decisions. In Chapter 1, central questions and test criteria for frequent problems have been derived from BBodSchV and VwV OW. Most of the central questions and criteria can be worded as Yes/No decisions. The primary aim of the investigations is therefore not to obtain the best possible description of the situation on site but instead to acquire suitable data for making decisions regarding specific issues. This can cause a reduction in investigation costs.

The conceptual site model is a first step at the start of the considerations for an investigation strategy. It describes the hydrogeological situation and the presumed transfer of contaminants from the centre of pollution to the groundwater and threatened uses. It is refined, disproved or confirmed at a later date with site investigations so that conclusions can be drawn from it for the following stage in the procedure. The conceptual site model is discussed in more detail in Chap. 2.2.

Various investigation strategies using all kinds of different investigation methods can be suitable for achieving the investigation objective. For example, it is necessary to clarify for the specific issue, whether depth-averaged, inflow-weighted or depth-oriented determination of pollutant concentrations in the groundwater is necessary in order to solve the problem. The type and construction of groundwater monitoring wells and the type and frequency of sampling are based on this.

There are frequently several alternatives for acquiring certain information or making a decision regarding a specific issue. Examples are:

- The pollutant concentration at the site of assessment (c_{OdB}) can be estimated using concentrations from the centre of pollution (leachate forecast, which is not the subject of the guide) or recalculated from the groundwater outflow using measured concentrations. If, following careful checking of the circumstances, it can be assumed that the contaminant input into the groundwater has already taken place, groundwater investigations for indirect determination using back-calculations often provide more useful and reliable results than direct determination of emissions from the centre of pollution. Among other things, this is due to small, localised heterogeneities of the contaminant distribution and subsoil quality, which are frequently more marked in the centre of pollution than in pore aquifers and can make it difficult to determine representative data.
- Material samples and subsoil data can either be acquired using permanent, large calibre monitoring wells or using small calibre direct push methods.
- The flow-producing porosity can either be measured using tracer tests, estimated from material characteristics or taken from comparable situations.
- A specific capture width in a groundwater outflow can either be realised using a few (large calibre) monitoring wells and a high pumping rate or with a large number of (small calibre) monitoring wells with a lower pumping rate.

The different methods for determining the same measured variables usually have substantial differences in time required, accuracy, reliability and costs, which must be taken into account in the further considerations on the investigation strategy.

The main relationships between the problem, concept and method as the basis of an investigation strategy are shown in Table 2.

The choice of a suitable investigation strategy is advisably made by comparing alternative investigation strategies, taking into account aspects such as:

- Achievability of the investigation objective,
- Required data quality and quantity,
- Contamination and subsoil situation,
- Contamination experience in similar cases,
- Time required and time specifications,
- Practicability, local accessibility,
- Ability to use monitoring wells in subsequent stages,
- Occupational health and safety and
- Costs required.

If it is foreseeable that further investigation stages will have to be carried out on the site, it can be useful to take this into consideration when developing an investigation concept and, for example, to take samples as reserve samples for possibly required measurements or to determine the required measured data in advance to save time or multiple starting up of sampling equipment and multiple visits to the site by the sampling team.

Taking into account quality assurance requirements, the conceptual and methodical considerations of the investigation strategy lead into the investigation plan. The investigation plan contains all the necessary descriptions and work instructions for building the monitoring wells, taking and handling the samples, work scheduling, occupational safety as well as quality assurance. The actual investigation is carried out on the basis of the investigation plan. Deviations may be unavoidable in the actual implementation of the investigation plan. If so they must always be documented and justified.

The planning and implementing of the investigation strategy and plan can be carried out in the following phases:

Phase 1: Identification of the question(s) to be clarified
Phase 2: Development of the conceptual site model
Phase 3: Development of an investigation concept,
Phase 4: Development of the investigation plan and quality assurance plan
Phase 5: Investigation preparation and implementation
Phase 6: Evaluation, assessment and documentation

Examples of the individual work steps in these phases are summarised in Appendix V.

PROPORTIONALITY

Investigations and remediations must be proportionate. Therefore, the investigation cost and effort should be weighed up against the increase in knowledge acquired. If high investigation costs and effort result in only a small increase in decision-making security, it may be necessary to make decisions on the basis of unfavourable assumptions.

Table 2: Connections between question/problem, concept and method as basis of an investigation strategy

Phase	Question (Chapter 2) Legal issue (following completion of the investigation)	Basis of technical decision-making	Concept (Chapter 3) Investigation concept (options depending on conceptual site model)	Method and quality assurance (Chapter 4) Determination of hydrogeological and hydro-chemical parameters (examples)
OU	Suspicion cleared up in this respect or sufficient suspicion?	Pollutant concentration at the OdB (transition zone between unsaturated and saturated zone or contact groundwater) (The data is selective/localised, the extents of the centre of pollution are not determined)	Investigation at the OdB (measurement of c_{OdB})	Desk study/evaluate files (hydrogeological mapping, regional experience, etc.) Examination of samples taken from GWM with small filter section or from other types of exploration points
			Investigation in direct groundwater outflow with leachate forecast (back-calculation to c_{OdB} using c_A, Q_A, Q_{SH}, Q_Z, c_Z)	Information sources: as above (planning phase). Examination of samples taken from partly or fully filtered GWM Determination of hydraulic parameters
DU	Suspicion cleared up in this respect or SBV/site contamination (sufficient suspicion confirmed)?	Pollutant concentration at the OdB (The data is localised in small areas and averaged over short periods, the extents of the centre of pollution have been determined)	as OU	as OU
	In case of SBV/site contamination: Hazardous situation acceptable or need for further action?	Pollutant concentration and pollutant load in the direct groundwater outflow, depth-averaged	Investigation at the OdB (measurement of c_{OdB}) with subsequent calculation of c_A and E_A using Q_A, Q_{SH}, Q_Z, c_Z (= direct determination of emission)	Desk study/evaluate files (hydrogeological mapping, regional experience, etc.) Examination of samples taken from GWM with small filter section or from other types of exploration points
			Investigation in direct groundwater outflow to determine c_A and E_A taking into account Q_A, Q_{SH}, Q_Z, c_Z (= indirect determination of emission)	Examination of samples taken from partly or fully filtered GWM, preferably by means of immission pumping tests Determination of hydraulic parameters
		Location, pollutant concentration and spatial extents of the centre of pollution (source term)	Investigation in the centre of pollution (alternating area and saturated zone) (measurement of c_{SH})	Examination of samples taken from GWM with small filter section or from other types of exploration points
			Forecast based on empirical values (estimation of c_{SH})	Consideration of the material properties and pollutant concentrations at the OdB
		Contaminant plume (length, extents and development) and affected usages	Investigation in groundwater outflow further downstream to determine c_{plume} and E_{plume}	Examination of samples taken from partially or fully filtered GWM or from other types of exploration points Determination of hydraulic parameters
			Forecast based on empirical values (estimation of c_{plume} and E_{plume})	Consideration of the chemical-physical material properties, the source term and the pollutant concentrations at the OdB Determination of hydraulic parameters
	Disturber identification	Location of the centre of pollution	see above (source term)	see above (source term)
SU	Hazardous situation to be accepted or need for remediation?	Suitability and appropriateness of remediation measures (complete or limited risk prevention)	Preliminary remediation planning (investigation of cost effectiveness)	not applicable
		Contaminant plume (length, extents and development)	as DU, however, related to NA	Investigation and database as DU, however, related to NA
Con-trol	as DU	as DU	as DU (at the OdB, in direct or further downstream of groundwater outflow)	Investigation and database as DU
	Hazard removed?	as DU (taking into account the remediation method)	as DU (taking into account the remediation method)	

2.2 CONCEPTUAL SITE MODEL

A basic model understanding of the centre of pollution and the propagation paths of the contaminants through to possibly affected sensitive receptors (conceptual site model) is prerequisite for the planning, implementation and evaluation of the groundwater investigation. This requires basic knowledge of the hydrogeology, site history, possible cause of contamination and transport processes, which can frequently be deduced from maps, literature, previous investigations or similar cases. The conceptual site model consists of the following parts:

- Hypothetical hydrogeological model (Section 2.2.1) and
- Pollutant dispersion (Section 2.2.2).

2.2.1 HYPOTHETICAL HYDROGEOLOGICAL MODEL

Knowledge or assumptions on the following aspects are incorporated in the hypothetical model:

- Geometry and location of the pollution source
- hydrogeological circumstances within the investigation area such as:
  - Strata build-up and bedding
  - Aquifer type, aquifer geometry
  - Groundwater recharging
  - Direction of groundwater flow
  - Hydraulic characteristics and flow rates
  - Geogenic groundwater quality
  - Structure of the unsaturated zone.

Please refer to the “Hydrogeological Models” guide [20].

The considerations and assumptions concerning the hydrogeological model as well as all the assured basic information including their sources must be documented. Please refer to the checklist on documentation of the hypothetical hydrogeological model in Appendix IV.

2.2.2 POLLUTANT DISPERSION

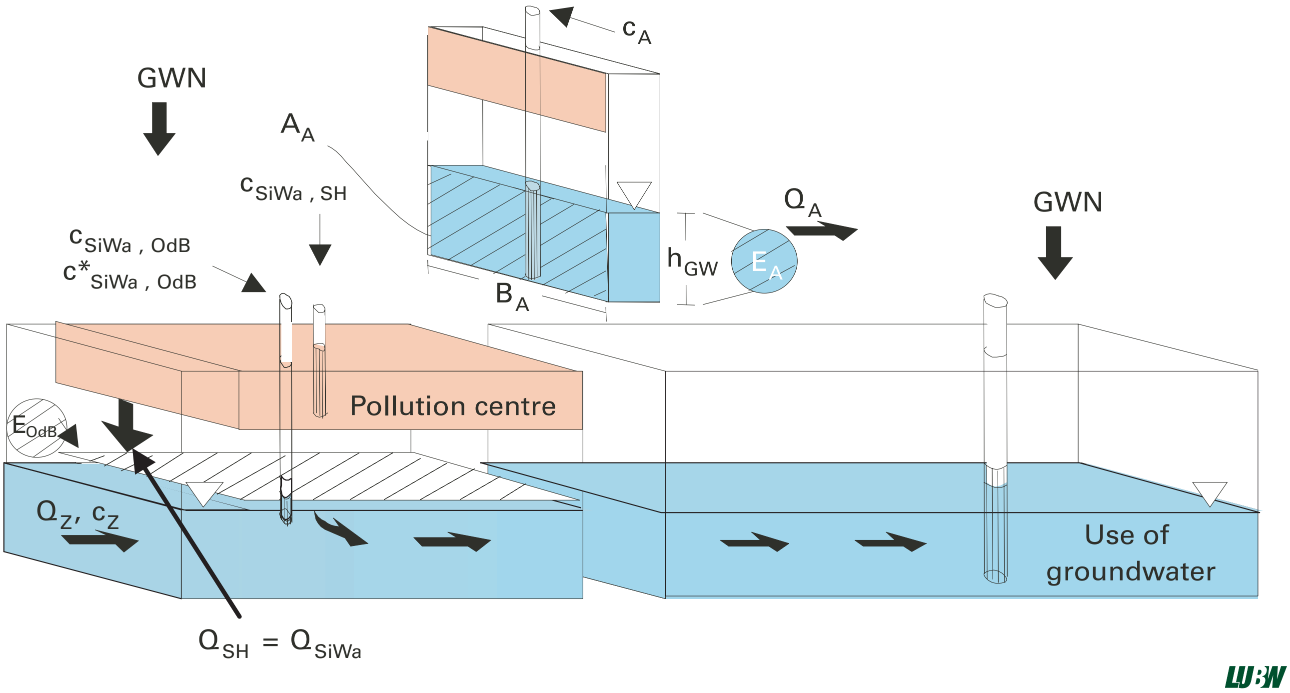
Possibilities for pollutant dispersion to possibly affected sensitive receptors must be deduced from the results of documentation, investigations and findings on site as well as its surroundings and experience from similar cases. Aspects such as the leachate forecast, pollutant concentrations in the groundwater (immissions) and the emissions in the groundwater must be checked for the contaminants relevant for the assessment.

As a result of this consideration, the decisive measured and calculated variables for any action to be taken must be named. Their spatial location in a schematised site are graphically illustrated in Figure 7 (centre of pollution in the unsaturated zone) and Figure 8 (centre of pollution in the groundwater).

In practice, combinations of both cases frequently occur if the centre of pollution is located only partly above the groundwater. Both approaches for determining the emission E_{OdB} are then required. Without localising the centre of pollution, i.e. exclusively with back-calculations from the groundwater outflow, it is not however possible to separate the load fractions from the unsaturated and saturated zone from each other in mathematical terms.

The measured and calculated variables determined are documented in a tabular summary together with the characteristic values of the hypothetical hydrogeological model in accordance with Table 3. This data sheet is available for downloading from the contaminated site technical information system “Altlasten-Fachinformationssystem” AlfaWeb [28]. It summarises all input parameters (estimated values as well as measured geometric, hydraulic or hydrogeolocial parameters and all pollutant concentrations). Provision is made for giving details of value intervals for the input parameters (“min.” and “max.” column). The interval limits can be evaluated using the "plausible" column. Mathematical cell links result in the function of a simple analytical model. The model can be subjected to sensitivity analysis by varying the input parameters and simultaneously viewing the fluctuation range of the parameters ultimately relevant for the assessment (c_{OdB}, c_A und E).

Four typical cases are illustrated at the end of Table 3. This shows which parameters in the bottom part of the "pollutant dispersion" data sheet, depending on the investigation concept, can be determined by measurement or subsequent calculation. For the purposes of simplification, the flow rates and inflow concentrations are not shown.



The **concentration** of the leachate at the site of assessment

results from back-calculation:	$c^*_{SiWa, OdB} = E_A / Q_{SiWa}$		
Emission calculation:	$E_{OdB} = Q_{SiWa} \cdot c_{SiWa, OdB}$	(direct determination of emissions)
	$E_A = Q_A \cdot c_A - Q_Z \cdot c_Z$	(indirect determination of emissions)

For all other calculations and formulae, see Table 3 "hydrology and pollutant dispersion model data"

Figure 7: *Important calculated variables for centres of pollution above the groundwater*

Table 3: Hydrogeology and pollutant dispersion model data

	Parameters		Formula, comment		min.	plausible	max.
Hypothetical hydrogeological model	Geometry						
	A_{SiWa}	[m²]					
	B_A	[m]					
	h_{GW}	[m]	(under certain circumstances relevant h_{GW})				
	A_A	[m²]	$B_A \cdot h_{GW}$				
	h_{KGW}	[m]					
	A_{KGW}	[m²]	$B_A \cdot h_{KGW}$				
	Hydraulic						
	Flow	[°]					
	T	[m²/s]					
	k_f	[m/s]					
	I	[-]					
	n_f	[-]					
	a	[m]	Cylinder formula				
	a	[m]	Bear & Jacobs				
	Q_{PV}	[m³/s]					
	t_{PV}	[h]					
	Flow rates						
	Q_A	[m³/d]	$k_f \cdot A_A \cdot I \cdot 86\,400$				
	Q_{SiWa}	[m³/d]	$(A_{SiWa} \cdot GWN) / 365\,000$				
	Q_{KGW}	[m³/d]	$k_f \cdot A_{KGW} \cdot I \cdot 86\,400$				
	Q_{SH}	[m³/d]	$Q_{SiWa} + Q_{KGW}$				
	Q_{ZT}	[m³/d]	$Q_A - Q_{SH}$				
	GWN	[mm/a]					
Pollutant dispersion	Concentrations and loads for: ...		E_{max} value: ... [g/d]	Screening level: ... [µg/l]			
	c_Z	[µg/l]					
	c_{SH}	[µg/l]	$c_{SiWa,\,SH}$ or $c_{KGW,\,SH}$				
	AF	[-]	c_{SH} / c_{OdB}	(reduction)			
	c_{OdB}	[µg/l]	$c_{SiWa,\,OdB}$ or $c_{KGW,\,OdB}$				
	c^*_{OdB}	[µg/l]	$E_A / (Q_{SH} \cdot 10^{-3})$				
	c_A	[µg/l]		(direct immission)			
	c^*_A	[µg/l]	$(Q_{SH} \cdot c_{OdB} + Q_{ZT} \cdot c_Z) / Q_A$	(indir. immission)			
	E_{OdB}	[g/d]	$Q_{SH} \cdot c_{OdB} \cdot 10^{-3}$	(direct emission)			
	E_A	[g/d]	$(Q_A \cdot c_A - Q_{ZT} \cdot c_Z) \cdot 10^{-3}$	(indir. emission)			
	$E_{plausible}$	[g/d]			X		X

(yellow) Measurement of concentrations in the centre of pollution or at the OdB

(cyan) Measurement of concentrations in direct groundwater outflow

c* are pollutant concentrations which are not measured but were calculated taking into account dilution in the groundwater.

Explanations to Table 3

Case 1: Measurement at the OdB and groundwater investigation in the direct outflow

Parameters		Formula, comment
c_{OdB}	[µg/l]	**Measured value**
c^*_{OdB}	[µg/l]	$E_A / (Q_{SH} \cdot 10^{-3})$
c_A	[µg/l]	**Measured value**
c^*_A	[µg/l]	$(Q_{SH} \cdot c_{OdB} + Q_{ZT} \cdot c_Z) / Q_A$
E_{OdB}	[g/d]	$Q_{SH} \cdot c_{OdB} \cdot 10^{-3}$
E_A	[g/d]	$(Q_A \cdot c_A - Q_{ZT} \cdot c_Z) \cdot 10^{-3}$
Measurement of concentrations in the centre of pollution or at the OdB		
Measurement of concentrations in direct groundwater outflow		

Measured values are available for c_{OdB} and c_A. Therefore, c^*_{OdB}, c^*_A, E_{OdB} and E_A are calculated and subjected to a plausibility check (comparison between direct and indirect determination of emissions).

Case 2: Measurement in the centre of pollution and groundwater investigation in the outflow

Parameters		Formula, comment
c_{SH}	[µg/l]	**Measured value**
c_{OdB}	[µg/l]	Forecast value
c^*_{OdB}	[µg/l]	$E_A / (Q_{SH} \cdot 10^{-3})$
c_A	[µg/l]	**Measured value**
c^*_A	[µg/l]	$(Q_{SH} \cdot c_{OdB} + Q_{ZT} \cdot c_Z) / Q_A$
E_{OdB}	[g/d]	$Q_{SH} \cdot c_{OdB} \cdot 10^{-3}$
E_A	[g/d]	$(Q_A \cdot c_A - Q_{ZT} \cdot c_Z) \cdot 10^{-3}$
Measurement of concentrations in the centre of pollution or at the OdB		
Measurement of concentrations in direct groundwater outflow		

Measured values are available for c_{SH} and c_A. Unlike case 1, c_{OdB} is not available as a measured value but instead is estimated on the basis of c_{SH} (leachate forecast). Otherwise there are no differences between case 3 and case 1.

Case 3: Measurement in the centre of pollution

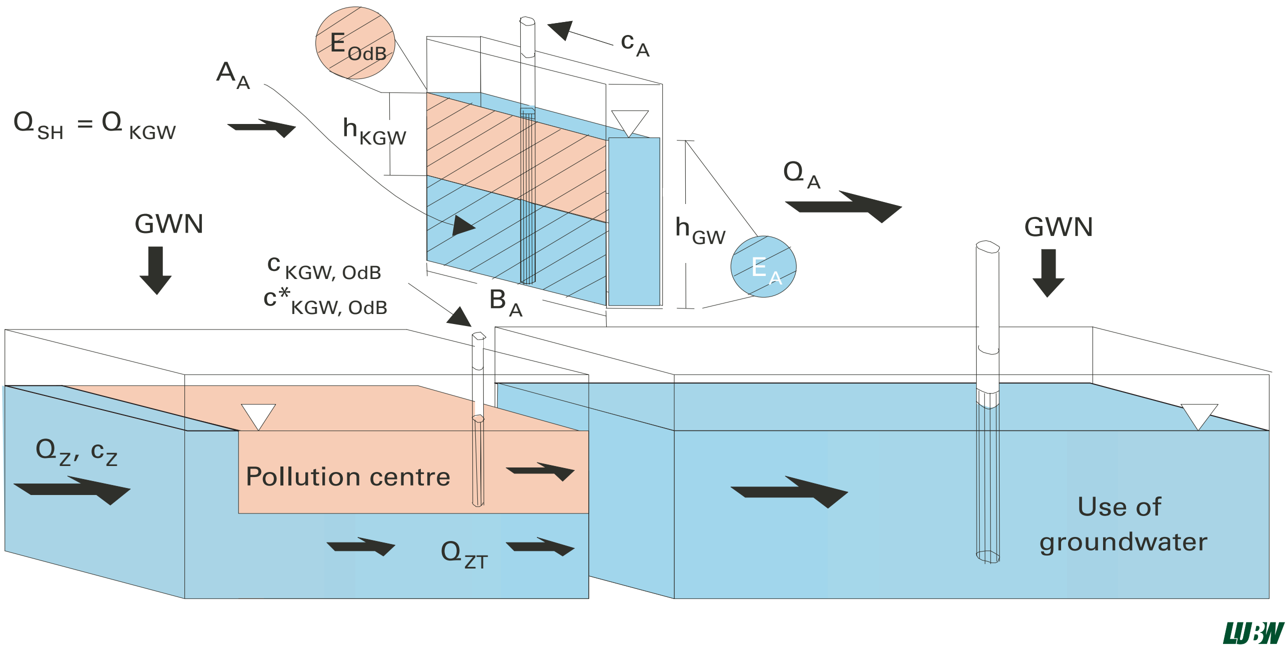
Parameters		Formula, comment
c_{SH}	[µg/l]	**Measured value**
c_{OdB}	[µg/l]	Forecast value
c^*_A	[µg/l]	$(Q_{SH} \cdot c_{OdB} + Q_{ZT} \cdot c_Z) / Q_A$
E_{OdB}	[g/d]	$Q_{SH} \cdot c_{OdB} \cdot 10^{-3}$
Measurement of concentrations in the centre of pollution or at the OdB		

Measured values exist for c_{SH}, c_{OdB} is estimated (leachate forecast). Then, E_{OdB} and c^*_A are calculated. It is not possible to perform a plausibility check between the direct and indirect determination of emissions.

Case 4: Measurement in the direct outflow

Parameters		Formula, comment
c^*_{OdB}	[µg/l]	$E_A / (Q_{SH} \cdot 10^{-3})$
c_A	[µg/l]	**Measured value**
E_A	[g/d]	$(Q_A \cdot c_A - Q_{ZT} \cdot c_Z) \cdot 10^{-3}$
Measurement of concentrations in direct groundwater outflow		

Measured values for c_A are available. E_A and c^*_{OdB} (leachate forecast) are calculated.



The **concentration** of the contact groundwater at the site of assessment results from back-calculation: $c^*_{KGW,\,OdB} = E_A / Q_{KGW}$

Emission calculation: $E_{OdB} = Q_{KGW} \cdot c_{KGW,\,OdB}$ (direct determination of emissions)

$E_A = Q_A \cdot c_A - Q_{ZT} \cdot c_{ZT}$ (indirect determination of emissions)

with $Q_{ZT} = Q_A - Q_{KGW}$

For all other calculations and formulae, see Table 3 "hydrology and pollutant dispersion model data"

Figure 8: Important calculated variables for centres of pollution in the groundwater

2.3 QUALITY REQUIREMENTS FOR SPATIAL IDENTIFICATION & RECORDING OF A POLLUTANT INPUT

Adequately secured, reliable data is required to answer the legal and technical questions explained in Sections 2.1 and 2.2. An important criterion is the representativeness of the measured values which, in particular, also includes the spatial layout of the groundwater investigation points. Corresponding requirements are dealt with in this section. Techniques and methods for fulfilling these requirements are the subject of Chapter 3 (investigation method).

2.3.1 INVESTIGATIONS AT THE SITE OF ASSESSMENT

If the concept is aimed at direct investigation at the site of assessment the location of the exploration points results from the location of the assumed or verified centre of pollution.

2.3.2 INVESTIGATIONS IN THE DIRECT GROUNDWATER OUTFLOW

2.3.2.1 DISTANCE FROM THE CENTRE OF POLLUTION

Investigations into the direct groundwater outflow are either aimed at recalculating outflow concentrations to the site of assessment or checking immission/emission control at the site of the individual case related minimum requirement. Therefore the groundwater must be taken as close as possible to the centre of pollution. However, due to a lack of accessibility, it may be necessary to move monitoring wells further downstream. This can result in failure to detect the actual immission and emission of contaminants as a result of natural attenuation or dilution. For this reason, the **direct groundwater outflow** is defined as the downstream boundary of the centre of pollution (viewed from above), at which there are not yet any significant effect of NA processes in the aquifer on the pollutant concentrations in the groundwater. For reasons of data quality and practicability it is necessary to define a maximum distance between the groundwater exploration points and the pollution source. The following is recommended as a convention: The distance between the groundwater monitoring wells and downstream boundary of the centre of pollution should lie within the range of the single depth to water table, however should not exceed 30 to 50 m.

The following factors point in favour of outflow sampling located as close as possible to the centre of pollution [14]:

- large groundwater flow rate
- high permeability of the aquifer
- highly absorbable substances or subsoil with sorption capacity
- small width of pollution source at right angles to the groundwater direction of flow, small length of pollution source along the flow direction and small groundwater depth to water table.

2.3.2.2 DEFINING THE OUTFLOW WIDTH

The spatial location of the monitoring wells must be appropriately defined to ensure that the origin of a contaminant plume is identified with adequate reliability. The probability of a "plume hit" is all the more higher in groundwater exploration points,

- the better the location of the centre of pollution and the direction of flow are known,
- the wider the contaminant outflow is at right angles to the direction of flow and
- the more homogenous the contaminant outflow with respect to hydraulic and hydrochemical aspects.

The width of the outflow depends, in particular, on the following factors:

- Shape and extents of the pollution source
- Homogeneity or heterogeneity of the aquifer
- Direction of groundwater flow and its fluctuation during the year
- Permeability of the aquifer
- Groundwater gradient
- Type of contaminants.

Numerous investigations verify that contaminant plumes in the groundwater can be very narrow, even if they have shallow hydraulic gradients. Further, marked heterogeneities must be expected, which is shown in Figure 9.

When planning the investigations, justified assumptions are necessary with respect to the width and depth of the contaminant outflow. The assumed outflow width B_A is defined on the basis of the groundwater direction of flow and the geometry of the centre of pollution (cf. Figure 10).

If the groundwater direction of flow is known and constant, B_A at right angles to the direction of flow is in the direct outflow of the centre of pollution. B_A is limited by the envelope of the centre of pollution in the direction of flow. If a dominant direction can be determined where the groundwater direction of flow is changeable, the

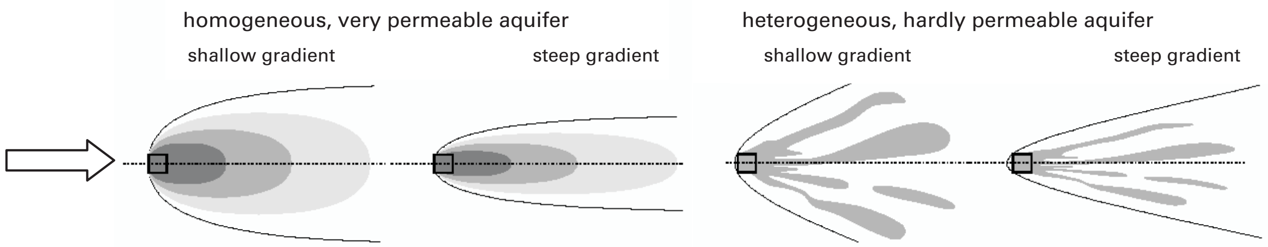


Figure 9: Plume types in the groundwater outflow (schematic, according to [14])

same method as described above can be used. However, if the fluctuation range of the direction of flow has to be taken into account, the tangents in the direction of the two extreme flow directions are placed at the centre of pollution first and B_A is determined via the perpendiculars to the angle bisectors.

Figure 10 merely takes into account geometric factors. An additional criterion is the assumed homogeneity or heterogeneity of the outflow. The greater the uncertainty regarding the location of the contaminant outflow the larger the initially assumed width to be recorded (captured) should be. Further options for determining the groundwater direction of flow such as photo lineations, geomorphological phenomena or the results of tracer tests are explained in the methods literature [34].

Registering the complete geometric width of the outflow often involves disproportionate effort and costs. Therefore, part of the whole outflow width is often considered only. In the case of leachate forecasts based on back-calculations from the groundwater outflow and in I/E considerations, experience to date the following minimum B_A fraction has proven its worth according to the investigation stage, whereby known or assumed contaminant input points must always be included:

- **Preliminary investigation:**
  Capturing **around 20** % of the outflow width (B_A)
  This criterion can be dispensed with if exceeding of the screening level is detected at the site of assessment, for example by selective/localised measurements.
- **Detailed investigation:**
  Capturing **at least 50** % of the outflow width (B_A)

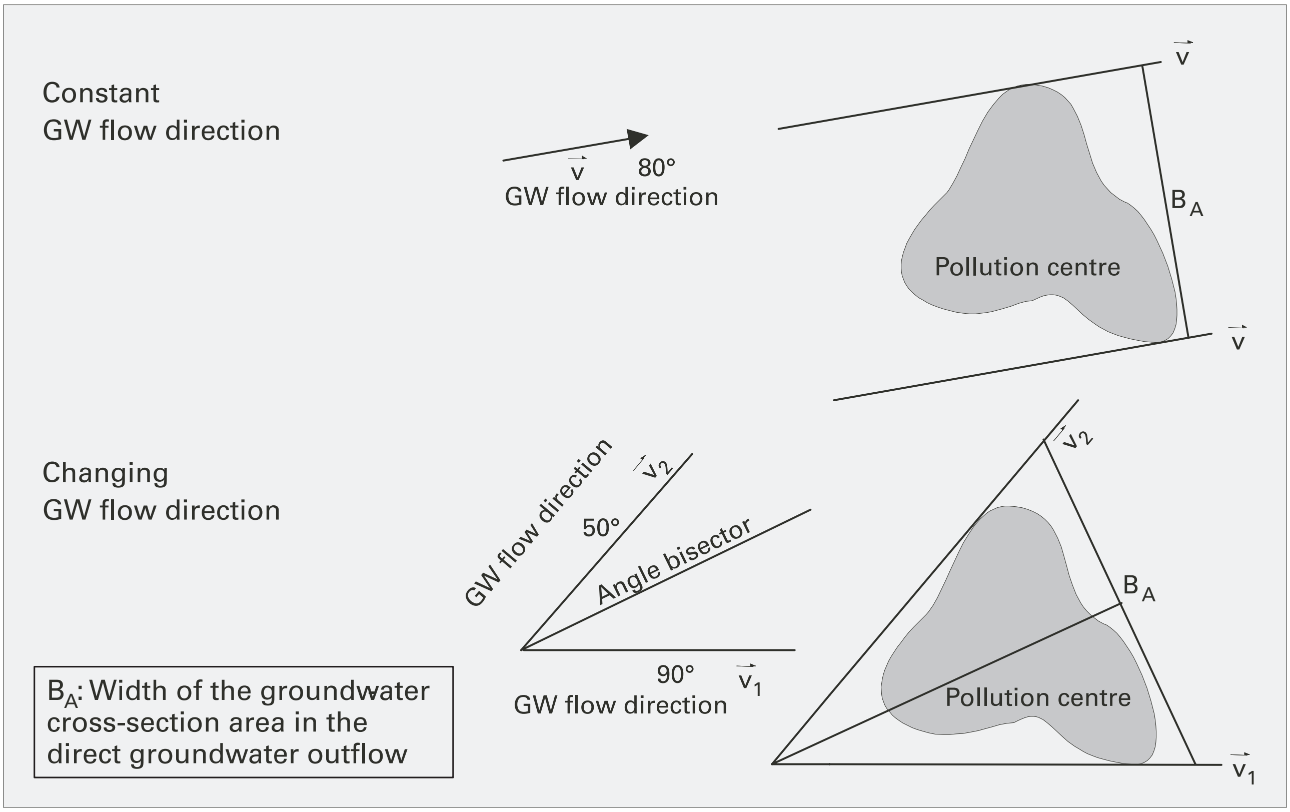


Figure 10: Defining the width of the direct groundwater outflow

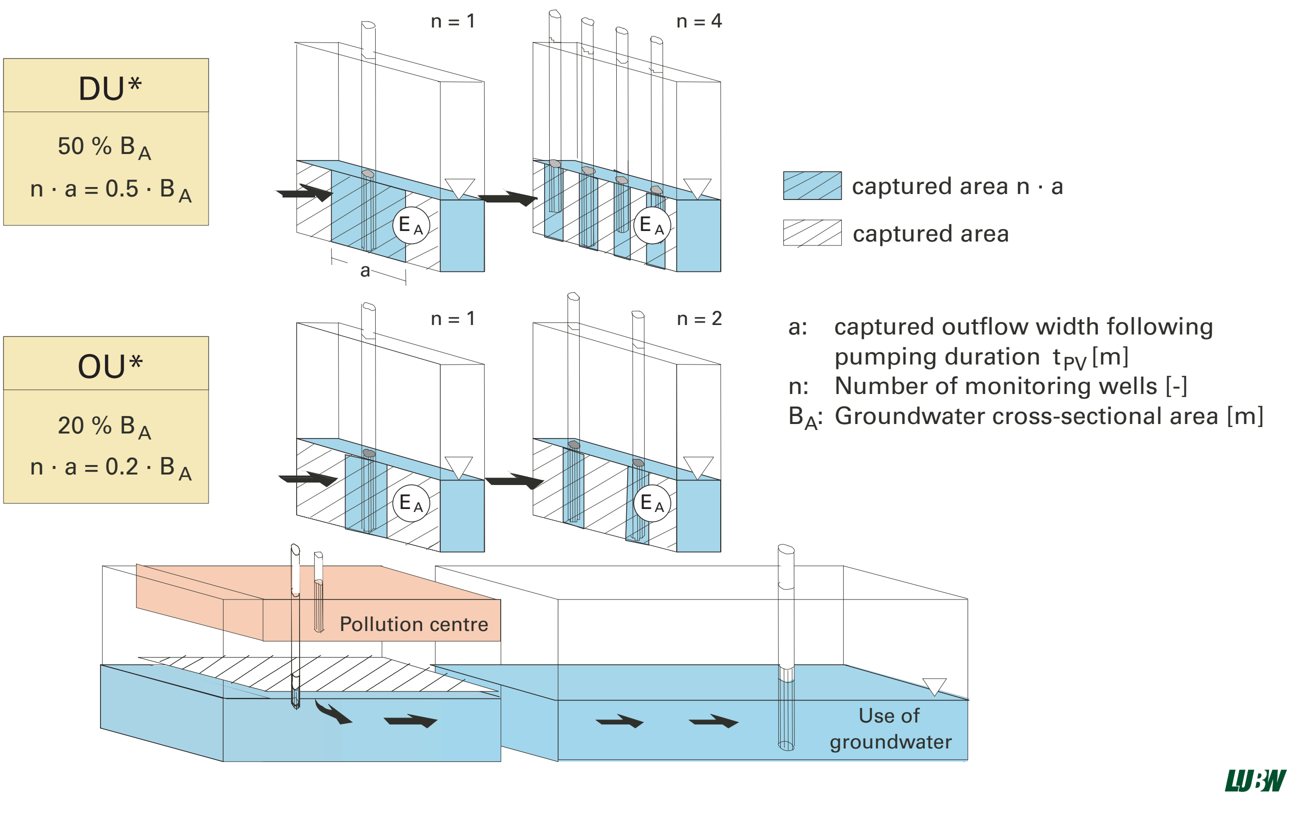
The term "20/50 % criterion" has established itself for the different capture widths for the OU and DU.

Figure 11 graphically illustrates the basic principles of the emission forecast. The outflow width (around 20 % in the OU or 50 % in the DU) can be achieved by a suitable combination of the number of monitoring wells and an appropriate choice of pumping test duration and rate. A larger number of monitoring wells would tend to be used for small groundwater depths to water table and small aquifer thickness while for cost reasons the number of monitoring wells is minimised as far as possible for large depths to water table and aquifer thicknesses. It is the task of the planning expert to find the optimum. When drawing up the investigation concept, justified deviations from the aforementioned standards are possible. Notes on individual case specific definition are given in Table 4.

To ensure excessive dilution is not caused the captured outflow width at each monitoring well should however not be more than 20 m. Exceptions to this are immissions pumping tests (cf. Section 3.3.3) with relevant calculated evaluation.

2.3.3 INVESTIGATIONS OF THE GROUNDWATER OUTFLOW FURTHER DOWNSTREAM

To investigation contaminant plumes and for NA concepts, if necessary also if the direct outflow is inaccessible, it can be useful to position groundwater exploration points in the outflow further downstream. Their position must be defined for each specific individual case and justified.



* for leachate forecasts based on back-calculations from the groundwater outflow and for I/E considerations

Figure 11: Minimum fraction of B_A to be captured in the OU and DU (20 %/50 % criterion)

Table 4: Individual case criteria for defining the outflow to be captured

Individual case specific special feature	Possible deviations or alternatives to standard recommendation
GW - depth to water table > 30 m	Reduction in outflow width to be captured
Particularly low flow rate of the direct outflow (< 0.25 l/s)	
Very heterogeneous conditions: e.g. marked karstification and high GW depth to water table	Definition according to karst-hydrological aspects Investigation of existing representative and informative GW exploration points (e.g. springs, if there is no need to worry about contaminant volatilisation effects) instead of the direct outflow Limit to one centre of pollution investigation
Several groundwater storeys affected	Investigation of the deeper storeys
Thickness of the unsaturated zone > 15 m and coefficient of permeability $< 1 \cdot 10^{-7}$ m/s	Limit to one centre of pollution investigation
Particularly high extraction rates (> 5 – 10 l/s)	Reduction in outflow width to be captured

3 Investigation Method

The investigations are carried out on the basis of the investigation plan (cf. Section 2.1). The investigation plan describes in detail the practical procedure for selecting and building the monitoring wells as well as sampling and handling samples. Important aspects in the planning and carrying out of the groundwater investigations are described in the following. A comprehensive summary of groundwater investigation methods is given in the methods literature of the LUBW [34].

3.1 SELECTION AND BUILDING GROUNDWATER EXPLORATION POINTS

The requirements for the technical construction of groundwater exploration points depend on the investigation stage and the investigation concept selected for the technical decision. When selecting monitoring wells, already existing and suitable openings (e.g. springs and wells) are to be taken into account. From experience, in the majority of cases it is necessary to establish additional exploration points within the scope of the investigation program and, depending on the problem concerned, to build them as temporary or permanent monitoring wells. An important advantage of permanent groundwater monitoring wells is the repeatability of sampling over longer periods. In the case of permanent monitoring wells a construction diameter of over 125 mm has proven its worth in many cases.

Important information on the petrographic structure and geometry of the aquifer can be read from drill logs. Properly built groundwater monitoring wells provide important information on the groundwater hydraulics and substance concentrations in the groundwater.

Drillholes for the construction of groundwater monitoring wells should wherever possible be sunk as dry core boreholes. This makes it possible to detect groundwater inrushes during the drilling work. If drilling fluids are unavoidable, drinking quality water only should be used without flushing additives.

The construction of groundwater monitoring wells must be matched to the water level, the water inrushes, the rock structure, the expected yield of the monitoring well and the investigation objective. When building a borehole, if the areas to be filtered cannot be reliably determined from examination of the geological core and from the hydrogeological interpretation of water inrushes or water levels, borehole geophysical measurements such as flowmeter, salinometer, temperature, electric and gamma logs can provide useful information.

Separate groundwater storeys must be tapped and investigated with separate monitoring wells. For basic water management considerations, groundwater monitoring wells must not establish any hydraulic connections between separate aquifers. The measured values at such monitoring points are also almost impossible to interpret.

Apart from the simple and completely filtered groundwater monitoring well which taps a mainly homogeneous aquifer over its whole thickness, multi-filtered groundwater monitoring wells can be built in the event of strata-bound contaminant or groundwater inflows. Where there are several partially or completely separated groundwater storeys it is absolutely necessary to build storey specific monitoring wells (monitoring well groups). Special monitoring wells are characterised by the fact that filter sections with stationary sampling systems, which can be operated hydraulically separate from each other, are installed at various depths.

The various types of monitoring wells are shown in Figure 14. Please refer to the special literature for details of the advantages and disadvantages of the individual types (for example [51]).

Where pollution sources are above the groundwater, preference is to be given to small monitoring points rather than groundwater monitoring wells to determine c_{OdB}, as they supply representative samples of small localised areas. Small monitoring points are usually less expensive to build.

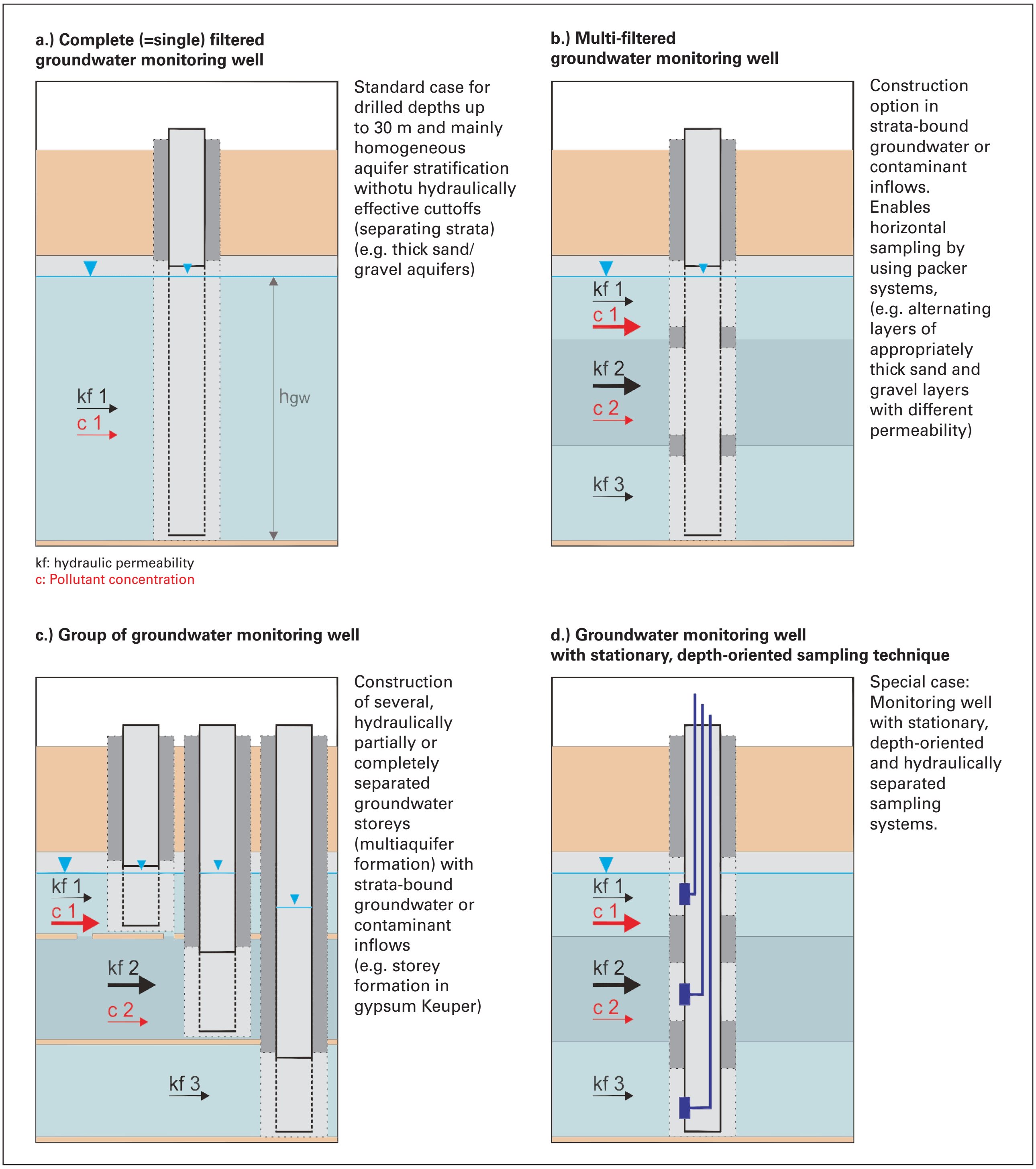


Figure 12: Types of monitoring wells [47]

The embedment depth of groundwater monitoring wells and the depth of the filter section are to be matched to the aquifer thickness and the expected contaminants. Table 5 describes several selected cases.

Table 5: Embedment depth and depth of the filter section of groundwater monitoring wells

Case	**Embedment depth/filter section**
Standard case	Embedment depth at least 0.7 h_{GW} (from this depth correction can be dispensed with in the hydraulic evaluation [45])
Sampling at the OdB	Embedment depth < 1 m (for centres of pollution above the GW)
Contaminants in phase LNAPL (e.g. mineral oil)	Embedment depth 0.5 h_{GW} and filter section above the groundwater table for capturing floating phase
Contaminants in phase DNAPL (e.g. VOC)	Embedment depth h_{GW} (possible investigation of deeper groundwater storeys)
Sensitive receptor GW usage (e.g. vertical wells)	Adjustment to depth of the GW usage
Location at the outfall with rising GW stream	Embedment depth < 0.7 h_{GW}
Confined groundwater conditions	Limit filter section to the area of the aquifer
Large aquifer thickness without DNAPL	Embedment depth max 30 m
Floating groundwater body and strata-bound groundwater inflows	Deviations from the standard are possible, small localised existing separating layers can be drilled through as long as precautions are taken and provided there is no contaminant phase. Nevertheless, the filter section may not connect independent water bearing strata

LUBW

Apart from outflow investigation of a site, newer investigation techniques such as direct push technologies, i.e. sampling equipment or sensors which are sunk in the subsoil through small calibre hollow strings by means of drilling, pressing or vibration and transport material samples or generate readings, are especially aimed at investigation of centres of pollution. Compared to conventional investigation techniques in which soil and groundwater can be removed, direct push enables in particular in-situ measurement of physical and chemical parameters as well of both the soil and the groundwater. The advantages of these investigation techniques are depth-oriented measurements and high investigation density for comparatively small amount of time; however, sometimes with restricted sensitivity and precision. Direct comparison of direct push method measured results and those of conventional investigation methods is frequently not possible because the measuring location and sampling conditions are not identical. A comprehensive description of these techniques and their possible uses is summarised in [4]. The possible uses of direct push methods and sensors in contaminated site investigations summarised in Table 6 was derived from this.

Table 6: Possible uses of direct push methods and sensors

(The figures in square brackets refer to the number of the method sheet in "Innovative measuring and monitoring methods (groundwater monitoring)", a series of texts published by the altlastenforum Volume 11 [4])

	Task, problem or question	Exploration or access method	Sampling method	Parameter determination method
Investigation of the hydrogeology				
1	Subsoil structure, stratification	Fugro [1]	CMT [4]	
2	Groundwater level	Geoprobe [2]		
3	Hydrogeological parameters	Sonic drilling [3]		
Investigation of the pollution source or the centre of pollution				
4	Spatial extents (direct)	Fugro [1] Geoprobe [2] Sonic drilling [3]	CMT [4] Multi-level lost pumping system [9] MP system - depth-oriented sampling system [10] Multi-level inflatable hose packer system [11] Profiler [13] Screen point sampler [14] Waterloo system - depth-oriented sampling system [15]	MIP technique [8] EFA® sensor [16] Fluorometer fibre optic system [17] Kontavisor fibre optic system [18] NAPL probe, fibre optic system [19]
5	Spatial extents (indirect)			Radon measurement
6	Contaminant inventory	Fugro [1] Geoprobe [2] Sonic drilling [3]	VOC sampler [7] Multi-level lost pumping system [9] MP system - depth-oriented sampling system [10] Multi-level inflatable hose packer system [11] Profiler [13] Screen point sampler [14] Waterloo system - depth-oriented sampling system [15]	MIP technique [8] EFA® sensor [16] Fluorometer fibre optic system [17] Kontavisor fibre optic system [18] NAPL probe, fibre optic system [19]
Investigation of the contaminant plume				
7	Spatial extents (direct)	Fugro [1] Geoprobe [2] Sonic drilling [3]	VOC sampler [7] Multi-level lost pumping system [9] MP system - depth-oriented sampling system [10] Multi-level inflatable hose packer system [11] CMT [4] Gore™ surveys - passive collector [5] PDB collector [12] Profiler [13] Screen point sampler [14] Waterloo system - depth-oriented sampling system [15]	MIP technique [8] EFA® sensor [16] Fluorometer fibre optic system [17] Kontavisor fibre optic system [18] NAPL probe, fibre optic system [19]

Continuation of Table 6

	Task, problem or question	Exploration or access method	Sampling method	Parameter determination method
8	Spatial extents (indirect)	Small monitoring point	Gore^{TM} surveys - passive collector [5]	In-situ measurement
			Soil vapour investigation	Laboratory investigation
9	Pollutant load	Fugro [1] Geoprobe [2] Sonic drilling [3] Small monitoring point	Ceramic dosimeter and toximeter [5] in addition the method named in row 7 in conjunction with hydraulic characteristics	Laboratory investigation
10	Monitoring, accompanying of the remediation, system control	Fugro [1]	see row 7 or 9	MIP technique [8]
		Geoprobe [2]		EFA® sensor [16]
		Sonic drilling [3]		Fluorometer fibre optic system [17]
		Small monitoring point		Kontavisor fibre optic system [18]
				NAPL probe, fibre optic system [19]
				Preussag CHC indicator [20]

Abbreviations:

CMT	Continuous Multi-channel Tubing	NAPL	Non-aqueous phase liquid
CPT	Cone Penetration Test	PDB	Polyethylene diffusion bag collector (passive collector)
EFA	Evanescent Field Absorbance Sensor	ROST	Rapid Optical Screening Tool
MIP	Membrane Interphase Probe		

3.2 SAMPLING GROUNDWATER EXPLORATION POINTS

The aim of sampling groundwater exploration points is to determine the concentrations c_A or c_{OdB}. The sampling procedure must differentiate between the following types of groundwater exploration points:

- Groundwater monitoring wells (≥ DN 125)
- Small boreholes (< DN 125) built as monitoring point
- Small calibre boreholes with possibility of direct sampling, for example the direct push method.

Underwater motor pumps can be installed in groundwater monitoring wells with diameters ≥ DN 125 without limitation. The sampling specifications, such as extracting the standing water volume [51] or achieving a specified extraction width can - provided an appropriate yield is available - be complied with from a technical point of view. Pumping tests can be carried out for sampling, provided the pumping rate is at least in the order of size of 0.1 l/s. Pumped samples from groundwater monitoring wells are particularly suitable for determining c_A, as depth averaging over the groundwater body takes place via the filter section.

Sampling at small monitoring points takes place, for example, with the help of submersible pumps, foot valve pumps, low-flow miniature pumps or peristaltic pumps. In particular, pumping tests are not necessary for sampling to record c_{OdB}.

Alternatively to pumped samples, if suitable conditions exist, samples can also be acquired with the help of passive collectors. In passive collectors the physical properties of suitable sorbents (solid or liquid phase) are utilised to bound the contaminants to be examined. The following requirements must be fulfilled for the use of passive collectors:

- The substances to be examined must be adequately sorbable and be able to diffuse through the membrane required to protect the sorbent. Concentration of the substances to be examined in the membrane must be prevented. The suitability of the sampling system must be verified.
- The precise characteristic hydrogeological values of the aquifer must be known for quantitative statements.
- The monitoring point must be suitable. For example, disruptive vertical currents must be prevented.

In suitable subsoil conditions the direct push method can be used to determine c_{OdB} and c_A. In the ideal case the site of assessment can be directly sampled. It is theoretically possible to separately sample any profile section. The method fails in solid rock. It only allows very small sample volumes to be taken. Repeat sampling requires substantial effort. Large extraction widths cannot be achieved.

Various factors must be taken into account to define the number of sampling sessions required:

- changing flow conditions,
- fluctuating groundwater levels,
- pollutant discharge and contaminant transport, non-uniform in time and location,
- degradation and retention of contaminants.

Pumped samples are advisable for groundwater extraction rates of less than 0.1 l/s, whereby the pumping duration must be adjusted to the respective circumstances before taking the samples. In extreme cases (deep monitoring well, deep water level) scooped (bailing) samples can also be taken.

When sampling groundwater exploration points a differentiation must always be made between depth-averaged samples (possibly additionally inflow weighted) and depth-oriented samples. The **depth-averaged** sample is e.g. achieved by the pumping test for sampling (cf. also Section 3.3). All stimulated inflows contribute to the pumping rate. The depth-averaged sample supplies the assessment-relevant value c_A. **Depth-oriented** samples can be taken from appropriately built monitoring wells (see Figure 12 in Section 3.1), e.g. using pneumatic double-valve pumps or mini-pumps. Depth-oriented samples are necessary if c_{OdB} is to be determined directly by means of measurement. If particular conditions exist in the groundwater outflow, e.g. horizontal usage of the groundwater by means of shallow garden wells, depth-oriented samples are indispensable for determining c_A.

The quality assurance requirements for sampling must be noted and observed [23]. A summary description and assessment of various sampling systems and techniques is given in [51]. As the quality of the sampling is decisive for the results and therefore for the assessment, samples must be taken competently and by trained personnel. Appropriate qualifications can be acquired, for example, by successfully attending the annually held sampling courses given within the scope of analytical quality assurance (AQS) in Baden-Württemberg.

The planning and implementation of the investigation require a great deal of care and reliability and should be monitored by the client.

Instructions for the deployment on site are to be summarised in an **investigation plan** (cf. Stage 4 in Section 2.1). The investigation plan contains all information and data required for faultless building of the monitoring wells and carrying out of the sampling.

The sampling, preliminary sample treatment and sample analysis in the chemical laboratory must be coordinated with each other.

Table 7 shows the coordination of the sampling to the case and investigation objective.

Table 7: Special problems in taking groundwater samples

Case	Note on sampling
High discharge/disposal costs to be expected for the pumped groundwater on performing the pumping test Location at outfall, pumping test can cause influent conditions (surface water influence)	Dispense with pumping test, instead 2 to 5 fold exchange of the water column in the monitoring well
Suspected NAPL phases	Perform depth-oriented sampling (for details of monitoring well construction, cf. Table 5)

3.3 PUMPING TESTS AND OTHER HYDRAULIC TEST METHODS

Pumping tests are used within the scope of the OU, DU or SU to determine hydraulic characteristic values of the aquifer, of pollutant concentrations (immission) and pollutant loads (emission).

3.3.1 PLANNING PUMPING TESTS

In order to capture the required fraction of the outflow width B_A (cf. section 2.3.2), an optimum must be found by varying the number of monitoring wells and pumping duration or extraction width and a concept drawn up specifically for an individual case. In the case of aquifers with low groundwater flow, good yield and small to medium thickness (e.g. valley lowland), adequately large extraction widths can generally be achieved. In these cases the outflow monitoring wells can be spaced further apart. On the other hand, in aquifers with large hydraulic gradients and low yield, small extraction widths only are achieved which necessitates a larger number of monitoring wells along the outflow width.

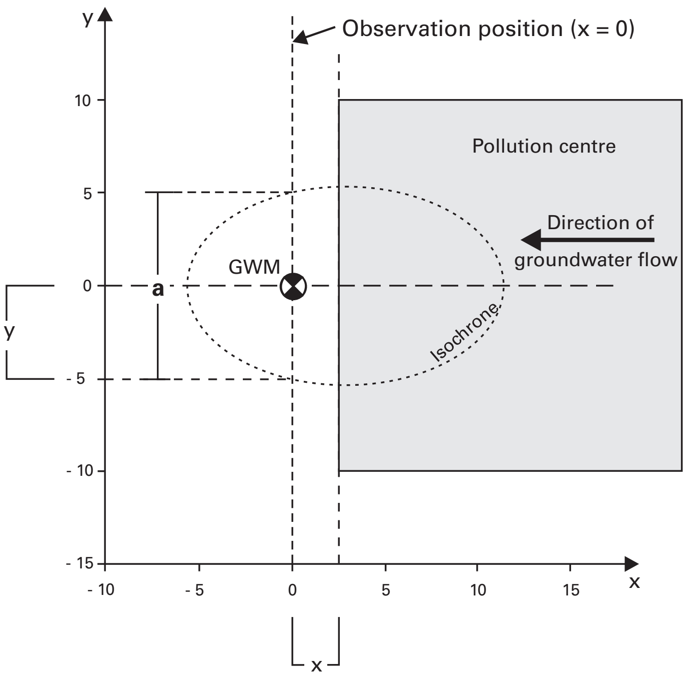
The achievable or achieved extraction width of a pumping test can be determined using so-called flow equations (e.g. Bear & Jacobs equation, as shown in Figure 13). In many cases the extraction width increases by small amounts only after a few days of pumping. The duration of the pumping test should also be checked with respect to economic aspects, especially for lengthy pumping periods of several days.

$$t_{PV} = \Big(\frac{n_f \cdot Q_{PV} \cdot 86{,}400}{2\pi \cdot v_f^{\,2} \cdot h_{GW}} \cdot \Big[\, x \cdot \frac{2\pi \cdot h_{GW} \cdot v_f}{Q_{PV} \cdot 86{,}400} - \ln\Big(x \cdot \sin\Big[\, y \cdot \frac{2\pi \cdot h_{GW} \cdot v_f}{Q_{PV} \cdot 86{,}400}\Big] / y + \cos\Big[\, y \cdot \frac{2\pi \cdot h_{GW} \cdot v_f}{Q_{PV} \cdot 86{,}400}\Big]\Big)\Big]\Big) \cdot 24$$

Lines of equal flow time (isochrones) for stationary (steady state), parallel groundwater flow.

t_{PV} = Pumping test duration [h]
n_f = Flow-producing porosity [-]
Q_{PV} = Extraction rate [m^3/s]
V_f = Filtration velocity $v_f = k_f \cdot I \cdot 86{,}400$ [m/d]
h_{GW} = Groundwater thickness [m]
x, y = Location coordinates [m]

Arguments for sin and cos in the circular measure



a = captured outflow width for x = 0 m [m]

Figure 13: Bear & Jacobs flow equation

The cylinder formula can also be used for a rough estimate of the pumping time and extraction width where the hydraulic gradient is shallow or during the early phase of a pumping test; this formula ignores any existing groundwater flow:

$$a = 2 \cdot \sqrt{\frac{t_{PV} \cdot Q_{PV} \cdot 3.600}{\pi \cdot h_{GW} \cdot n_f}} \quad \Rightarrow \quad t_{PV} = \frac{a^2 \cdot \pi \cdot h_{GW} \cdot n_f}{Q_{PV} \cdot 14.400}$$

with:

a = captured outflow width of the monitoring well at time t_{PV} [m]

t_{PV} = pumping test duration [h]

n_f = flow-producing porosity [-]

Q_{PV} = extraction rate [m^3/s]

h_{GW} = groundwater thickness [m]

Especially where higher permeabilities (k_f larger than $1 \cdot 10^{-3}$ m/s), large groundwater gradient (I greater than 1 %) and lengthy pumping times (over 48 hours) exist, a calculation method taking into account the groundwater flow should be used to avoid substantial misinterpretations of the test's measurement results.

3.3.2 DETERMINATION OF AQUIFER CHARACTERISTIC VALUES

The hydraulic characteristics of the respective aquifer concerned must be determined as reliably as possible to estimate the emission E_A from concentration measurements. The hydraulic aquifer properties (transmissivity, kf value, storage coefficient) are usually determined by means of pumping tests where monitoring well yields are over 0.1 l/s. If pumping tests are combined with tracer tests the important flow-producing porosity parameter can also be determined.

If the yields are lower, other test methods (e.g. slug test) should be used as an alternative to pumping tests. However, experience shows that if k_f values are less than 10^{-7} m/s, even if the pollutant concentrations are high, hardly any relevant pollutant loads are moved in the aquifer. The suitability of borehole tests for various permeability ranges is shown in Figure 14.

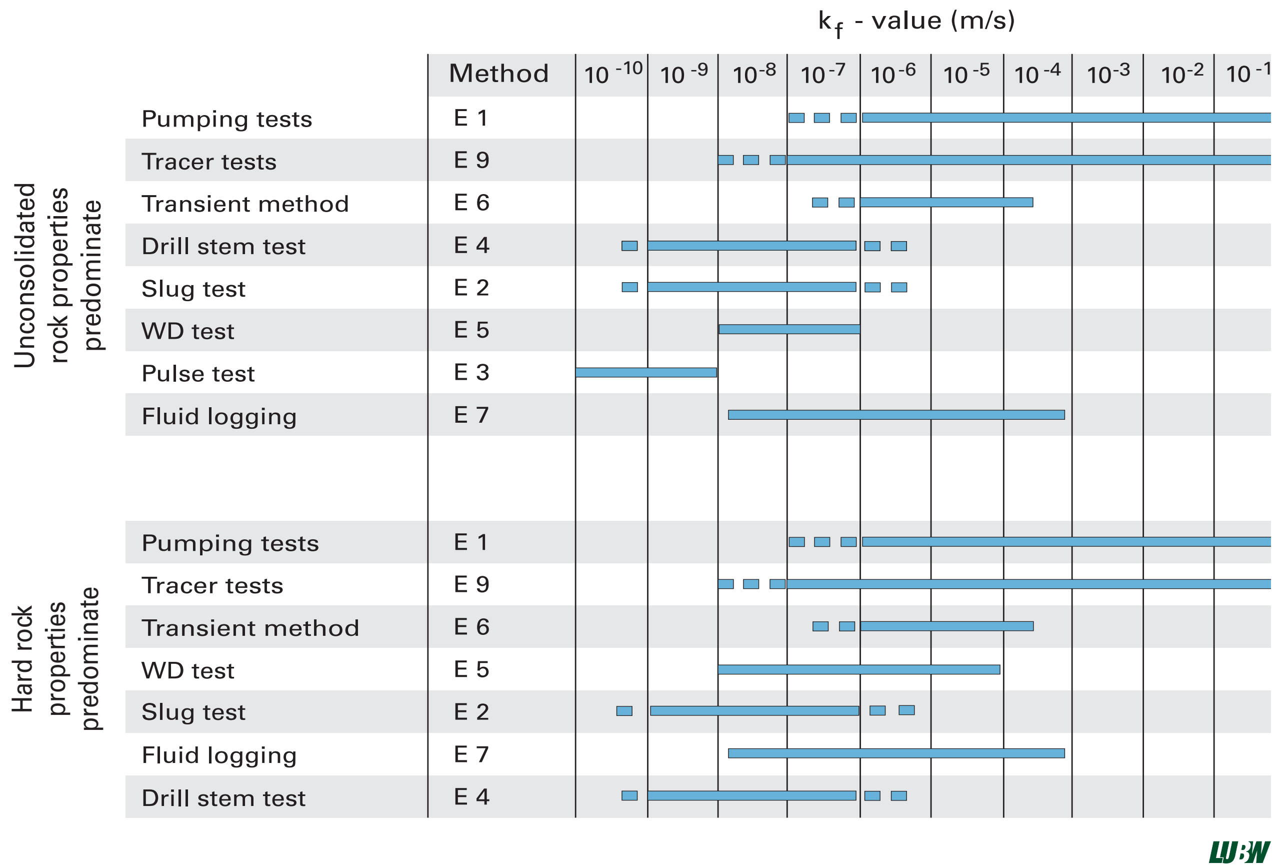


Figure 14: Suitability of borehole tests (changed according to [38])

3.3.3 IMMISSION PUMPING TESTS

In immission pumping tests, subject to certain requirements and assumptions, the determined concentrations in water samples in conjunction with the extraction time can be used to deduce the averaged pollutant concentration over the extraction width of the contaminant plume as well as the spatial distance of the pollution concentration location from the extraction well. The shorted the periods between the individual sampling and the more samples examined the more precise the results. Approximately 5 to 10 water samples are usually taken for each pumping test. The times for taking the samples are sensibly chosen so that the increase in extraction width between the individual sampling is as constant as possible. The size of the increase in extraction width from sample to sample determines the spatial resolution with which the statements on the location of a contaminant plume can be made. The results of the immission pumping test in simple hydrogeological conditions are evaluated using analytical methods, e.g. using the IPV tool [28], or in special cases with marked heterogeneities and complex subsoil conditions, numerical flow and transport models are used.

Groundwater samples which are taken during a pumping test are made up of combined water from the respective whole isochrone area. If this is not taken into account when determining concentrations and freights, substantial misinterpretations of the measured values can occur. Calculated evaluation of the change in concentration during the pumping test can be used to deduce the concentration in a contaminant plume and therefore the pollutant load. Analytical evaluation methods are mostly based on homogeneous, isotropic model assumptions.

Figure 15 exemplarily explains the relationship between the pollutant concentrations measured in the laboratory and the concentrations which actually occur in the groundwater for the assumed case of a contaminant plume laterally flowing past the monitoring well with homogeneous contamination with c = 100 µg/l. Simple model assumptions are made for improved understanding of the main relationships, such as homogeneous and isotropic aquifer, no transition zone between uncontaminated and contaminated groundwater and no concentration gradient in the groundwater flow direction. Furthermore, calculated variables are rounded off if applicable. This contaminant plume is recorded and consulted during the course of the pumping test. The isochrones of samples 1, 2 and 3 at the start of the pumping test do not yet record the contaminant plume. The contaminant levels in these samples are zero or smaller than the limit of quantification. Sample 4 registers the contaminant plume. According to the site plan, three quarters of its isochrone is made up of uncontaminated groundwater (c = 0 µg/l) and one quarter contaminated groundwater (c = 100 µg/l). As a result it has a mixed concentration of 25 µg/l. This (analysis) value must not be confused with the mean over the extraction width, which is frequently used as the basis of assessments. This is made up – as clearly shown in the site plan - of seven eighths of uncontaminated groundwater (c = 0 µg/l) and only one eighth contaminated groundwater (c = 100 µg/l) and is 12.5 µg/l here.

Vice versa, the curve of the measured values of samples 1 to 4 can be used to deduce the level of pollutant concentration in the plume (100 µg/l). In the example:

- the concentration of the plume (100 µg/l) should be used to check the immission condition and
- the mean pollutant concentration along the extraction width (12.5 µg/l) should be used to calculated the load to check the emission condition.

Expertise and experience are required to plan immission pumping tests because important characteristic data which essentially determine the accuracy and reliability of the test results, such as pumping rates, test duration, number of samples and sampling interval, have to be determined in advance and only afterwards can a check be made to see whether they were correctly selected.

The greatest costs in groundwater investigations are incurred for construction of the monitoring wells and for operating the pumping tests. Viewed from this aspect, with relatively low additional costs, substantially improved conclusions can be drawn regarding the contamination on the site from immission pumping tests compared to once-off sampling.

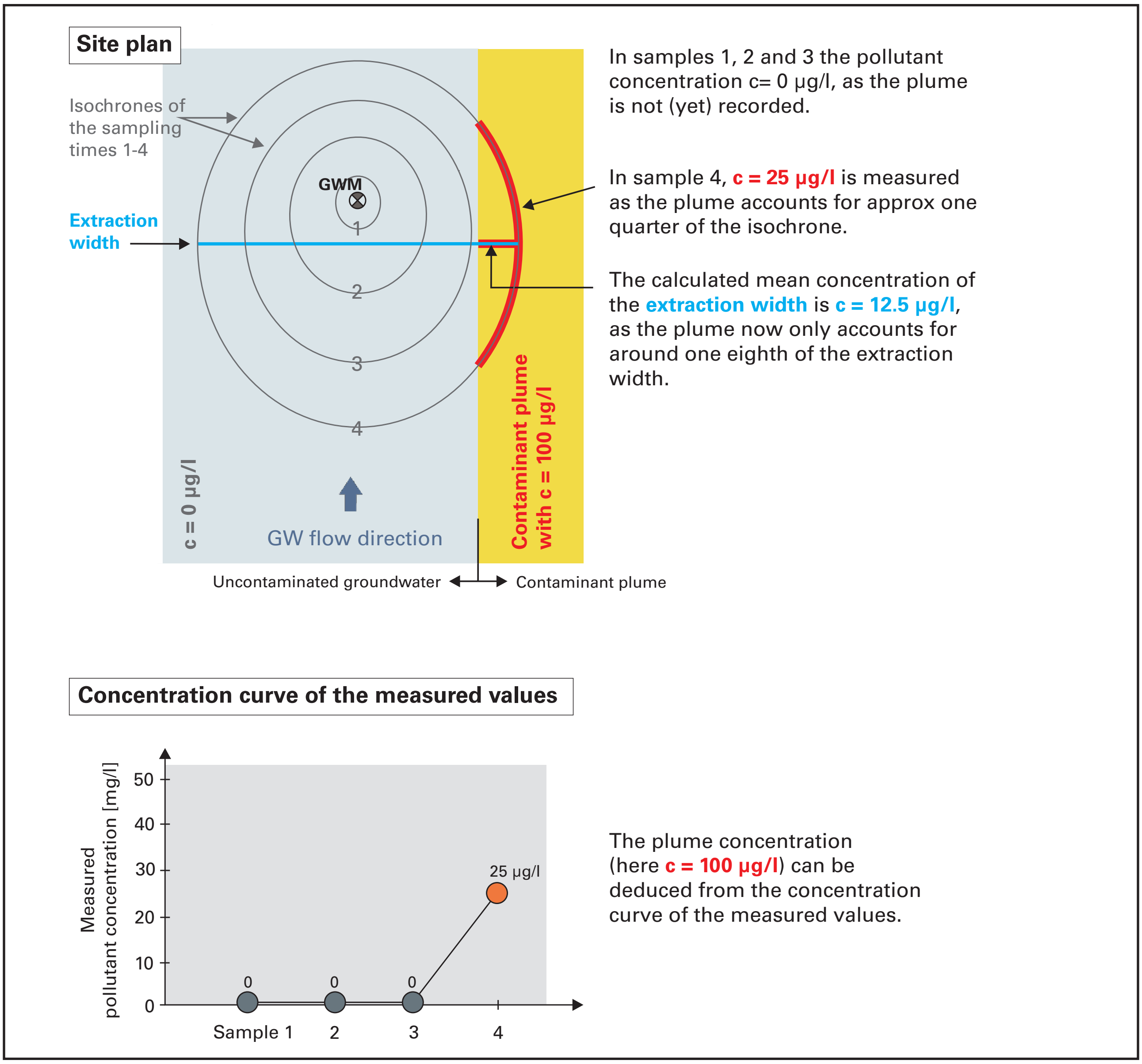


Figure 15: Simplified illustration of the relationship between measured and actual pollutant concentration using the example of an immission pumping test with increasing pollutant concentration (for explanations, refer to text)

3.4 INTEGRAL GROUNDWATER INVESTIGATION

In suitable hydrogeological conditions, integral groundwater investigation can provide a possibility

- to make decisions regarding the suspected hazard of individual areas within extensive and heterogeneous suspected contaminated areas and
- to balance the contaminant emission.

To this end the pollutant load is determined in several control levels within the contaminant plume. which are ideally perpendicular to the groundwater flow directions, by means of overlapping immission pumping tests. The following applies to the order in which the pumping tests are carried out:

1. first, start with the control level furthest away in the groundwater flow direction and then successively examine the control levels closer to the centre of pollution (rule of thumb: "from the outflow into the inflow")
2. perform adjacent pumping tests consecutively, otherwise overlapping of the extraction widths is not possible. The method of integral groundwater investigation by means of immission pumping tests is described in [3].

If the results of the integral groundwater investigation is compared to the information obtained from the survey of suspected contaminated areas or existing investigation results for the areas, individual contaminant input points can possibly localised or decisions made regarding suspected hazards [3].

3.5 HYDROCHEMICAL DATA

Apart from the hypothetical hydrogeological model (cf. section 2.2.1), which makes an essential contribution to hydraulic understanding of the system, the hydrochemical characterisation provides valuable input data and indications regarding the geogenic groundwater quality as well as regarding the structure, dynamism and interactions of the hydraulically effective units. The scope of parameters for the groundwater investigation usually consists of a combination of several, complementary parameters:

- Environmental parameters, such as electrical conductivity, Redox parameters, anions and cations, for example for general characterisation of the groundwater quality or for assessing the its suitability with respect to natural attenuation,
- industry-specific parameters, if a suspicion exists, even if there are no available screening or action levels,
- Parameters for which screening or action levels exist (see Appendix II).

The analysis of the preliminary investigations concentrates on the analysis of those parameters for which suspicion exists following completion of the survey. Lists exist for this purpose, which can be used to put together a useful selection of specific parameters. For example, the industry catalogue [38] provides information on the substances used in production and processes. Further information for industry-specific investigation parameters and their degradation products are contained in the industry guide produced as part of the BMBF funding priority research project KORA [11].

In the detailed investigation it is necessary to check on the one hand whether the scope of parameters needs to be expanded or on the other hand, especially in the case of extensive investigation series, whether it is possible to reduce them to selected parameters of concern.

Use of in-situ analysis methods should be checked, especially in conjunction with direct push technology as well as when carrying out immission pumping tests. Qualitative and semi-quantitative measuring systems can be suitable for the investigation and monitoring. Quantitative measuring systems (e.g. CHC indicators) are required to optimise the resolution of immission pumping tests in time and space. An overview of measuring systems is given in the mentioned table 6 and [4]. Use of such measuring systems requires an adapted procedure for the planning, fieldwork and quality assurance compared to conventional sampling and laboratory analysis. Measuring strategies and the corresponding procedures, including the documentation required are described in the relevant, more in-depth literature (e.g. [33]).

Forensic methods such as GC-MS fingerprinting and isotope signatures are used:

- for clear disturber identification,
- for spatial demarcation of various contaminations with identical contaminant spectra,
- for classification of contamination events in time (determination of age),
- to assess microbiological degradation [1][2][46] and their consideration in the assessment of NA processes.

GC-MS fingerprinting enables contamination of the subsoil with mineral oil products to be characterised. Typified distribution patterns can be used to determine initial products as well as their behaviour and transport in the environment. The initial products can be characterised by conditional fractioning of the products by means of distillation into a benzine fraction, middle distillate and heavy oil. If mineral oil products have got into the subsoil they are subjected to diverse physico-chemical and biological degradation processes such as evaporation, dissolving, dilution or microbial degradation as well as interaction with soil particles. The characteristics of the distribution patterns can be used to classify the degradation of mineral oil products [1][2].

Due to manufacturing methods used, industrial products such as chlorinated and aromatic hydrocarbons have different isotope signatures. As two different contaminations rarely result from the same batches, in many cases it is possible to differentiate between contaminations on the basis of their isotope signatures [2].

If the site-specific conditions and the type of contaminant allow microbiological degradation, this is mostly associated with a significant shift in the isotope signature. The bonds of lightweight isotopes of an element (^{12}C) are more quickly split than those of heavy isotopes (e.g. ^{13}C). As a consequence of this isotope fractioning the heavy isotopes accumulate in the remaining contaminant during the course of the reaction. The measured change in isotope signature can be used to verify the degradation of organic compounds in the environment. It is also possible to quantify degradation rates for individual contaminants and their degradation paths.

Assessment of natural attenuation processes requires the combination of contaminant-specific investigations to verify and quantify degradation processes (fingerprints, isotope signatures) with the investigation of so-called environmental parameters (nitrate, nitrite, ammonium, sulphate, dissolved iron, Redox potential, oxygen, etc.), which provide information regarding the basic suitability of the subsoil for contaminant degradation as well as the microbial degradation processes which actually take place. Further information is given in [9] [11][15]).

3.6 QUALITY ASSURANCE

Quality specifications are given in standards, specifications, technical rules and other methods, such as those named in BBodSchV and are declared binding for investigations within their scope or in generally recognised technical papers. Quality specifications must be defined for specific individual cases with respect to the investigation. Quality specifications concern, for example:

- delivery dates
- defects-free and reliable results useful for their intended purpose
- complete, clearly understandable documentation.

For contractors they are a means of satisfying the contractual requirements and customer wishes in order to avoid liability risks and to strengthen their market position.

The following applies regarding general responsibility for quality assurance:

- Requirement, definition of scale and brief: Client
- Completion of the project, delivery: Contractor
- Checking in accordance with the requirements and scale: Client.

Apart from the time schedule and price, the specification of works and contract must contain, in particular, details of the intended purpose and the technical requirements. In addition to general conditions of contract (basic principles, fee, termination, liability, etc.), these include:

- Description of facts and initial situation
- Description of basic conditions and time schedule
- Definition of expected work and services and investigation objective
- Summary of particular technical requirements such as compliance with specific state or national requirements, guides and recommended actions.

An engineering contract corresponding to these requirements is a basic precondition for a professional expert report tailored to the specific needs of an individual case.

The client's obligations while the investigations are being carried out include on-going monitoring and control, if necessary intervention and control of the project as well as formal checking of the contents and comparison with the objectives drawn up initially after the work has been completed (acceptance of the work and services provided). Fulfilment of these client tasks requires a high degree of expertise. Only persons familiar with the diverse specifications and aware of the critical points in practice is capable of drawing up optimum, project-specific bills of quantities and competently monitoring the project work. If this expertise is not available it is advisable to involve specialists.

Apart from personal experience, references and continued professional development and vocational training of employees, general suitability requirements for contractors include, in particular, the various approval and recognition procedures such as:

- Experts, skilled persons and examining bodies according to Art. 18 BBodSchG or Art. 36 Gewerbeordnung (Trading Regulations)
- Quality management systems and corresponding DIN accreditation for engineering service providers
- Sampler courses held by AQS Baden-Württemberg
- DIN accreditation and BAM approval for laboratories
- DVGW certificate for drilling companies.

A range of rules and aids exist for the individual steps of groundwater investigations. The whole topic is covered, for example, by the "ALA Arbeitshilfe Qualitätssicherung" [16] for quality assurance as well as the seminar series "Qualitätssicherung in der Altlastenbearbeitung" (quality assurance for contaminated sites) given by the Fortbildungsverbund boden und altlasten Baden Württemberg [23]. Both collections of documents contain overviews of individual rules and regulations to be complied with in each step of the investigation.

Errors can occur both when handling samples and with measured data. When samples are handled their properties can change, for example due to input of contaminants, cross-contaminations, gas emissions, sorption or chemical and biological reactions. In addition, measurement errors or uncertainties can occur. Mix-ups or transfer errors can occur when handling measured data. Quality assurance concepts include both preventive and controlling quality assurance measures.

When groundwater monitoring wells are built particular attention must be paid to definition of drilling methods, drill diameters and annual space, gravels and slot widths as well as material selection and construction methods for annular space seals. Drilling logs must be recorded by experts. Proper profile description must contain details of the stratigraphy, genesis, petrography and degree of weathering. In addition, fracture microstructures, colour, microstructure, consistency and other features such as contamination specific conspicuous features must also be noted. If the knowledge acquired from the drilling log is insufficient for building the monitoring wells, geophysical drillhole measurements must be taken.

New groundwater monitoring wells and existing ones must be regularly checked to ensure they are fit for their intended purpose. Basic hydraulic requirements include good contact with the filtered aquifer and absolutely no contact with unfiltered areas. To ensure hydrochemically sound conditions, monitoring wells must be free of sediments, foreign bodies and dirt. Possible effects of the drilling and construction work (flushing, cementation) must be removed or have receded. Plumbing, CCTV inspections and geophysical measurements (built condition, construction damage), hydraulic methods such as pumping or filling tests, packer tests (well condition, leaks) as well as hydrochemical investigations are suitable checking methods.

Chemical groundwater investigations should provide assured and reliable measured values. Apart from the already mentioned minimum requirements for samplers and the laboratory, especially for detailed investigations, it is advisable to arrange for random parallel investigations by a second laboratory and to carry out checks during the sampling, as the basis for difficult decisions or decisions with serious consequences. Sample material should always be put back for further or supporting investigations and the investigation findings should be checked with respect to their plausibility. The interface and coordination between the sampling and laboratory is particularly important, for example, in coordinating the sampling strategy (methods, containers), methodical approach to sampling and sample preparation as well as ensuring adequate data quality.

When drawing up and checking investigation reports, it is necessary to check whether they

- are complete, logical and conclusive, are systematically prepared
- contain analyses and investigation findings in evaluated form as tables and diagrams
- contain clear, understandable conclusions
- contain all original findings (borehole data, pumping test logs, analysis findings of the laboratory).

Further explanations are given in the requirements for an "expert contaminated site investigation report" [29] and the guide "official investigations for suspected contaminated areas" [30], the contents of which are not only limited preliminary investigations with respect to quality assurance for expert reports.

Appendix I: Definitions and abbreviations

DEFINITIONS

Outflow	A differentiation is made between the direct groundwater outflow in which the individual case related minimum requirement is checked and the outflow further downstream. → Contaminant plume
General minimum requirement	This defines a groundwater property which in general can be tolerated in groundwater sources worth using or requires remediation investigation if exceeded (VwV OW).
Detailed investigation	Detailed investigations (Detailuntersuchung - DU) also investigate whether spatially limited accumulations of contaminants result within a suspected contaminated area or hazards result within a suspected contaminated site and whether and how demarcation or containment to protect uncontaminated areas is advisable. (Art. 3 Para. 5 BBodSchV)
Direct push methods	Sampling equipment or sensors which are introduced into the subsoil in small calibre hollow rods by means of drilling, pressing or vibration and pump material samples or generate measured values.
Emission	Pollutant load from a pollution source in the groundwater (VwV OW). The usual unit is gram per day.
Individual case related minimum requirement	This defines a groundwater property which can be tolerated in groundwater sources worth using in an individual case or requires remediation investigation if exceeded (VwV OW).
Enhanced natural attenuation	Special form of in-situ remediation measures in which the natural attenuation processes are initiated, stimulated or supported (enhanced) by introducing substances into the reaction spaces of contaminant plumes.
Hazard	Condition which, if not prevented, with reasonable probability will result in the occurrence of damage to legally protected property or rights.
Risk paths	Are the different ways in which contaminants spread and, for example, can get into the groundwater or human body.
Insignificance threshold	Boundary between a slight change in the chemical quality of groundwater and harmful contamination [17]. The groundwater contamination defined with the exceeding of the insignificance threshold is synonymous with the term "disadvantageous change in the properties of groundwater" of the WHG. In Baden-Württemberg the insignificance threshold is equated to the screening levels of the BBodSchV.
Immission	Pollutant concentration in the direct groundwater outflow (depth averaged over the directly affected aquifer) (VwV OW).

Conceptual site model	The conceptual site model describes the hydrogeological situation and the presumed transfer of contaminants from the centre of pollution to the groundwater, threatened usages or sensitive receptors.
Monitored natural attenuation	Controlled natural contaminant reduction – natural contaminant reduction processes controlled by monitoring measures.
Natural attenuation	Natural contaminant reduction processes – Sum of all physical, chemical and biological processes which reduce contaminants in soil and groundwater without any human involvement and under load reduction.
Groundwater source worth using	Groundwater source from which – taking into account all the circumstances of the individual case, now and in the future – extraction, pumping to the surface, guiding to the surface or discharge of groundwater with the aim of using this water (irrespective of the type of use), can be possible and useful. The circumstances of the individual case include, in particular, the groundwater resources (available quantity) and its geogenic quality. Economic aspects, possible anthropogenically impaired groundwater quality or that usage is not intended at the present time are factors which are not usually to be taken into account.
Preliminary investigation	Within the scope of the preliminary investigation (Orientierende Untersuchung - OU) a check is carried out to examine whether specific indications or grounds exist which justify sufficient suspicion of harmful soil change or site contamination according to Art. 3 Para. 4 BBodSchV. The data situation is selective and localised, i.e. the spatial extents of the centre of pollution have not yet been determined.
Site of assessment	Transition area between the unsaturated and water saturated zone on the soil – groundwater migration path (Art. 4 Para. 3 Sentence 3 BBodSchV). The site of assessment for centre of pollution within the groundwater is the groundwater – centre of pollution contact area (contact groundwater) without dilution by the surrounding groundwater.
Screening level	Value which when exceeded, taking into account the usage, an individual case related check must be carried out to determine whether a harmful soil change or site contamination exists (Art. 8 Para. 1 No. 1 BBodSchG). The screening levels of the BBodSchV for the migration path soil – groundwater correspond to the water legislation insignificance threshold in Baden-Württemberg.
Remediation investigation	In a remediation investigation (Sanierungsuntersuchung - SU), various theoretically possible risk prevention measures are checked and compared with the aim of deducing the most suitable option for the individual case.
Contamination/Damage	According to the Water Law existing exceeding of the water legislation insignificance threshold at the site of assessment.

Contaminant plume	The contaminant plume is part of a groundwater contamination in which the contaminants are primarily dissolved [27] and exceed the insignificance threshold or screening levels.
Pollution centre (Synonym: pollution source)	Centre of pollution is the term to describe contaminants bound in the soil matrix, residual saturated areas and phase bodies in the saturated or unsaturated zone. In the groundwater the boundary between the centre of pollution and the contaminant plume can be detected by a clear change in ratio between total substance levels and dissolved fractions.
Leachate forecast	Estimate of the harmful soil change or site contamination caused by a suspected area, suspected contaminated site, harmful soil change or contaminated site or contaminant inputs into the groundwater via the leachate to be expected in the foreseeable future, taking into consideration concentrations and loads and related to the transition zone from the unsaturated to the water saturated zone (Art. 2 No. 5 BBodSchV).
Investigation plan	It contains all the necessary descriptions and work instructions for building the monitoring wells, taking and handling the samples, work scheduling, occupational safety as well as quality assurance.
Investigation strategy	It describes a basic procedure for data and information acquisition with respect to a specific investigation objective.

ABBREVIATIONS

For explanations of the abbreviations used, see also Figure 7 and Figure 8.

Indices:	A	–	Outflow, e.g. c_A, Q_A
	KGW	–	Contact groundwater, e.g. c_{KGW}, Q_{KGW}
	GW	–	Groundwater, e.g. h_{GW}
	OdB	–	Site of assessment, e.g. c_{OdB}
	Z	–	Inflow, e.g. c_Z, Q_Z
	ZT	–	Inflow fraction, e.g. Q_{ZT}
	SH	–	Centre of pollution, e.g. c_{SH}, Q_{SH}
	SiWa	–	Leachate, z. B. c_{SiWa}, Q_{SiWa}

a	–	Outflow width recorded (captured) perpendicular to the groundwater flow direction by a pumping test following the pumping test period t_{PV} [m]
A_A	–	Groundwater cross-sectional area in the direct outflow of the centre of pollution $A_A = B_A * h_{GW}$ [m²]
AF	–	Reduction factor c_{SH} / c_{OdB}, determined from the leachate forecast
A_{KGW}	–	Cross-sectional area of the centre of pollution which the contact groundwater flow rate flows through [m²]
A_{SiWa}	–	Cross-sectional area of the centre of pollution which the leachate flow rate seeps through [m²]
B_A	–	Width of the groundwater cross-sectional area A_A [m]

BAM – "Bundesanstalt für Materialforschung und –prüfung" - Federal Institute for Materials Research and Testing

BMBF – "Bundesministerium für Bildung und Forschung" - Federal Ministry of Education and Research

BN – Level of confidence

c, c* – Concentration [µg/l]; c* stands for concentrations at the site of assessment or in the direct groundwater outflow, which are recalculated or calculated taking into account dilution in the groundwater.

c_A – Pollutant concentration in the direct groundwater outflow of the centre of pollution [µg/l]

c_{Plume} – Pollutant concentration within the contaminant plume [µg/l]

$c_{KGW, OdB}$ – Pollutant concentration in the contact groundwater of the centre of pollution at the site of assessment [µg/l] (differentiation is not made between contact groundwater within the centre of pollution and contact water at the site of assessment (boundary of the centre of pollution) analogous to centres of pollution above the groundwater (c_{SiWa}).

CMT – Continuous Multi-channel Tubing

c_{OdB} – Generic term for $c_{KGW, OdB}$ and $c_{SiWa, OdB}$

CPT – Cone Penetration Test

$c_{SiWa, cSH}$ – Pollutant concentration in the leachate within the centre of pollution [µg/l]

$c_{SiWa, cOdB}$ – Pollutant concentration in the leachate at the site of assessment below the centre of pollution [µg/l]

c_{SH} – Generic term for $c_{KGW, SH}$ and $c_{SiWa, SH}$

c_Z – Pollutant concentration in the groundwater inflow [µg/l]

DIN – Deutsches Institut für Normung e.V. - German Standards Institution

DU – Detailed investigation

E – Emission or pollutant load [g/d]

E_A – Emission of contaminants out of the centre of pollution into the groundwater, calculated from the groundwater investigation [g/d]

EFA – Evanescent Field Absorbance Sensor

E_{Plume} – Pollutant load within the contaminant plume [g/d]

eM – Individual case related minimum requirement in accordance with VwV OW

E_{max}-W – Maximum allowable emission in relation to the protection of groundwater [g/d]

ENA – Enhanced Natural Attenuation

E_{OdB} – Emission of contaminants from the centre of pollution into the groundwater taking into account a possible reduction in contaminant (attenuation) within the unsaturated zone [g/d].

GFS – Insignificance threshold

GW – Groundwater

GWL – Aquifer

GWM – Groundwater monitoring well

GWN – Groundwater recharging [mm/a]

h_{GW} – Groundwater thickness [m]

h_{KGW} – Contact groundwater thickness [m]

I – Groundwater gradient [-]

IPV – Immission pumping test

k_f – Coefficient of permeability for groundwater [m/s]

KORA – BMBF funding priority: Retention and degradation processes to reduce contaminants in groundwater and soil

LfU – State Institute for Environmental Protection

LUBW – State Institute for Environment Measurements and Nature Conservation Baden-Wuerttemberg

MIP	–	Membrane Interphase Probe
MNA	–	Monitored Natural Attenuation – control of natural reduction processes
NA	–	Natural Attenuation – natural contaminant reduction processes
NAPL	–	Non-aqueous phase liquid
n	–	Number of groundwater monitoring wells [-]
n_f	–	Flow-producing porosity [-]
OdB	–	Site of assessment
OU	–	Preliminary investigation
PDB	–	Polyethylene diffusion bag collector (passive collector)
P-W	–	Screening level for the protection of groundwater against contaminant inputs from contaminated soil or deposited materials [µg/l]
Q_A	–	Groundwater flow rate over the width of the centre of pollution in its direct outflow. Q_A contains Q_{SH} [m^3/d]
Q_{KGW}	–	Contact groundwater flow rate over the width of the centre of pollution in its direct outflow [m^3/d]
Q_{PV}	–	Groundwater extraction rate during a pumping test [m^3/s]
Q_{SiWa}	–	Leachate flow rate which flows into the groundwater after percolating through the contaminated material of the centre of pollution [m^3/d]
Q_{SH}	–	Generic term for Q_{KGW} and Q_{SiWa}: Leachate flow rate Q_{SiWa} and contact groundwater flow rate Q_{KGW}, which flows into the groundwater after percolating through or following contact with contaminated material [m^3/d]
Q_Z	–	Groundwater flow rate over the width of the centre of pollution in its inflow [m^3/d]
Q_{ZT}	–	Partial flow of Q_Z, which does not flow through the centre of pollution [m^3/d]
ROST	–	Rapid Optical Screening Tool
SBV	–	Harmful soil changes/soil contamination
SU	–	Remediation investigation
T	–	Transmissivity [m^2/s]
t_{PV}	–	Pumping test duration [h]
v	–	Flow velocity [m/s]
v_f	–	DARCY specific discharge (filtration velocity) [m/s]
x, y	–	Location coordinates [m]

Appendix II: Selected background values, screening levels, insignificance threshold values and emission threshold values

Notes on use:

1. In Baden-Württemberg the tests values of the BBodSchV for the migration path soil – groundwater also define the water legislation insignificance threshold.
2. If no values are specified in the soil protection and water legislation, recognised list values can be used such as the LABO or LAWA recommendations, or individual case specific deductions can be made on the basis of the publication of the deduction methods and standards in the Federal Gazette No. 161a dated 28.08.1999. In all cases the responsible administrative authority decides whether values not specified by law can be used or not.

Inorganic parameter	Background value[1] (µg/l)	Screening level (µg/l)	GFS value (µg/l)	E_{max} value[1] (g/day)
Aluminium	100	150[1]		320
Ammonium	100	500[1]		1,100
Antimony		10	5	
Arsenic	3	10	10	22
Barium			340	
Lead	4	25	7	20
Boron			740	
Cadmium	1	5	0.5	6.5
Chloride			250,000	
Chromium tot.	2	50		90
Chromium (III)			7 (50)[9]	
Chromium (VI)	0.4	8		18
Cyanide tot.	< BG	50	5 (50)[10]	85
Cyanide easily released.		10		
Fluoride	250	750	750	1,600
Cobalt		50	8	
Copper	5	50	14	220
Molybdenum		50	35	
Nickel	3	50	14	45
Mercury	0.05	1	0.2	1.5
Selenium	4	10	7	17.5
Sulphate			240,000	
Thallium	3	8[1]	0.8	17.5
Vanadium			4[8]	
Zinc	150	500	58	3,200
Tin	2	40		20

Organic parameter	Background value[1] (µg/l)	Screening level (µg/l)	GFS value (µg/l)	E_{max} value[1] (g/day)
Aldrin		0.1	0	
Benzol	< BG	1	1	2
Σ BTEX[3]	< BG	20	20	20
Σ Chlorobenzene			1	
Σ Chlorophenol			1	
Dichloro ethane;1.2			2	
DDT		0.1		
HCB			0.01	
Σ HCH		0.1[1]		0.2
Σ VOC[4]	< BG	10	20	20
Mineral oil hydrocarbon[2]	10[7]	200	100	100
MTBE			15	
Naphthalene	0.05	2		4.5
PAH tot.[6]	0.05	0.2	0.2	0.32
PCB tot.[5]	< BG	0.05	0.01	0.1
PCDD/F (I-TEq)	< BG	0.000005[1]		0.00001
PCP	< BG	0.1[1]	0.1	0.2
Pesticide	< BG	0.1[1]	0.5[11]	0.2
Phenol	10	20	8	65
Σ Tri- and tetrachloro ethene			10	
Vinyl chloride			0.5	

1) Values not taken from BBodSchV, but instead VwV indicative values.
2) n-alkanes (C 10...C39), isoalkanes, cycloalkanes and aromatic hydrocarbons.
3) Volatile aromatic hydrocarbons (benzene, toluene, xylene, ethylbenzene, styrene, cumene).
4) Volatile halogenated hydrocarbons (sum of halogenated C1 and C2 hydrocarbons). GFS value: Incl. trihalogenomethane.
GFS of tri and tetrachloroethene, dichloroethane and vinylchloride must also be complied with.
5) PCB, tot.: Sum of polychlorinated biphenyls; usually determination via the 6 congeners according to Ballschmiter in accordance with Altöl V0 (Waste Oil Ordinance) (DIN 51527) multiplied by 5; if applicable, e.g. if known substance spectrum simple summation of all relevant individual substances (DIN 38407 3 2 and 3 3).
6) PAH, tot.: Sum of the polycyclic aromatic hydrocarbons not including naphthalene and methyl naphthalene; usually determined from the sum of 15 individual substances in accordance with list of the US Environmental Protection Agency (EPA) not including naphthalene; if applicable taking into consideration other relevant PAH (e.g. chinoline).
7) Background value for IR spectroscopy.
8) Use postponed until 31.12.2007 in order to improve the database.
9) If no chromium (VI) exists the value of the TrinkwV (50 µg/l) is used as the insignificance threshold.
10) If no free cyanide exists the value of the TrinkwV (50 µg/l) is used as the insignificance threshold.
11) Σ Agricultural pesticide + biocides (PSMBP).

APPENDIX III: ACTION MATRIX FOR THE MIGRATION PATHWAY SOIL – GROUNDWATER

BN 1: Assessment after identification/recording

BN 2: Assessment after preliminary investigation

BN 3: Assessment after detailed investigation

BN 4: Assessment after remediation investigation

BN 5: Assessment after remediation

Need for action	Criterion	BN 1	BN 2	BN 3	BN 4	BN 5	Abbreviation
A	none	x	x	x	x	x	**A**
A after control	none			x	x		**A n K**
A after remediation	none					x	**A n S**
B	Indications/grounds; no exposure at present	x					**B Aex**
B	Disposal relevance	x	x	x	x	x	**B Ent**
B	Re-assessment in case of change in use		x	x	x	x	**B New**
B	Re-assessment in case of change in exposure		x	x	x	x	**B Nex**
B	Hazardous situation acceptable/to be accepted			x	x		**B Gh**
B after control	Disposal relevance			x	x		**B Ent**
B after control	Re-assessment in case of change in use			x	x		**B New**
B after control	Re-assessment in case of change in exposure			x	x		**B Nex**
B after control	Hazardous situation acceptable/to be accepted			x	x		**B Gh**
B after remediation	Disposal relevance					x	**B Ent**
B after remediation	Re-assessment in case of change in use					x	**B New**
B after remediation	Re-assessment in case of change in exposure					x	**B Nex**
B after remediation	Hazardous situation acceptable/to be accepted					x	**B Gh**
K	Hazardous situation currently acceptable/to be accepted			x	x	x	**K Gdh**
K	Monitoring of the contamination to be accepted				x	x	**K contamination/ damage**
K	Check containment measures					x	**K S**
K	Hazardous situation can no longer be investigated			x			**K ne**
K after remediation	Hazardous situation currently to be accepted					x	**K Gdh**
K after remediation	Monitoring of the contamination to be accepted					x	**K contamination/ damage**
K after remediation	Check containment measures					x	**K S**
Self-monitoring	Hazardous situation currently acceptable/to be accepted			x	x	x	**K Gdh**
Self-monitoring	Monitoring of the contamination to be accepted				x	x	**K contamination/ damage**
Self-monitoring	Check containment measures					x	**K S**
Self-monitoring	Hazardous situation can no longer be investigated			x			**K ne**
OU	none	x					**OU**
DU	none		x				**DU**
DU	Remediation start very probable		x				**DU S**
SU	Remediation investigation			x			**SU**
S	Containment measure		x	x	x		**S S**
S	Decontamination measure		x	x	x		**S D**

No suspicion | Suspicion | Contaminated site

APPENDIX IV: CHECKLISTS FOR THE JUSTIFICATION AND DOCUMENTATION OF THE CONCEPTUAL SITE MODEL

A tabular form can be used for complete documentation and clear traceability of the conceptual site model considerations. Table A can be used to describe the manifestations, markedness, data source and assumptions for hydrogeological features in words. The result is a description of the main facts of the hydrogeological model assumption in brief form. For subsequent traceability and comprehension it is possible to give the data source in this table next to the characteristic form (e.g. "Geological map GK xxxx", "WSG report Auquelle dated xx.xx.xxxx"). If assumptions have to be made due to a lack of specific data, they are also documented in the table (e.g. "no tracer tests documented, therefore assumption for n_f 0.02, empirical value for fissure aquifer from Project xy in z").

Table A: Hypothetical hydrogeological model (the right-hand column contains key words in italic for which explanations are useful)

Characteristic features	Form, data source
Model space	*Definition/spatial demarcation*
Strata build-up, bedding	*Geol units, thicknesses, geometry, tectonics*
Unsaturated zone	*Petrographic structure, permeability*
Aquifer	*Storeys, petrographic structure, fissure/pore/Karst GWL, thicknesses, heterogeneities, relief (e.g. channels)*
Special features of the aquifer	*Damming limits, outfalls, drainage, GW extractions, subrosion, artesian wells, weathered areas*
Direction of groundwater flow	*Values with water level dependent variations*
Permeabilities, storage coefficient, flow-producing porosity, dispersivity	*Values or value intervals for all relevant units, if applicable anisotropies for hydraul. characteristics*
Groundwater recharging	*Values and their spatial variability*
Geogenic and anthropogenic groundwater quality	*Previous geogenic contaminations, typification, contaminant levels*
Existing groundwater exploration points	*Type, condition, usability for investigations*

LUBW

Table B documents the input variables of the "data sheet for determining concentrations and loads" (see Section 2.2.2). The data sheet is the central element for answering the most frequent central questions. The decision whether and which further action is to be taken is based on the input variables. Specified sources, references, etc. can be included in the following table B in order to substantiate derivation of the input variables. Documentation is useful to enable the numerical values to be traced and checked and for quality control purposes.

Table B: Documentation of the input variables in "data sheet for determining concentrations and loads"

Data origin for the "Data sheet for determining concentrations and loads" (Section 2.2.2) Examples	
A_{SiWa}	Centre of pollution investigation, see site plan …
B_A	Centre of pollution investigation, see site plan …
h_{GW}	Recording of profile GWM, see Chapter …
h_{KGW}	Recording of profile GWM, centre of pollution investigation, see Chapter …
Flow direction	LGRB report on WSG .... dated .....
T	Pumping tests, see Chapter …
k_f	Pumping tests, see Chapter …
I	Cut-off date (reference date) measurement dated …
n_f	LGRB report on WSG .... dated .....
Q_{PV}	Pumping tests, see Chapter …
t_{PV}	Pumping tests, see Chapter …
GWN	LGRB report on WSG .... dated .....
c_Z	Analysis at inflow monitoring well, see Chapter …
c_{SH}	Analysis, see Chapter …
c_{OdB}	Leachate forecast, see Chapter …
c_A	Analysis, see Chapter …

APPENDIX V: PROPOSAL FOR A PHASED APPROACH TO THE PLANNING AND IMPLEMENTATION OF INVESTIGATION STRATEGY AND PLAN

Planning stage	Examples of individual work steps
1. Identification of the question(s) to be clarified[4]	
2. Development of the conceptual site model	Determination of basic information, defining brief/framework and evaluation of existing documents or information about site history
	Drawing up a hypothetical hydrogeological model
	Estimation of aquifer data from prior knowledge, hydrogeological maps, investigations in the vicinity, etc.
	Determination of the relevant contaminant properties with respect to the propagation behaviour in saturated and unsaturated subsoil
	Identification of possibly affected sensitive receptors such as mineral or medicinal springs, public drinking water extraction plant, own or potable water extractions
3. Development of an investigation concept after carrying out a comparison of alternatives	Describe and compare basic possible alternative investigations
	Define the required measured variables such as pollutant concentrations in the soil and groundwater, material characteristic values, parameters for characterisation of the groundwater quality and sampling and sample analysis methods
	Concept with rough location of sampling points
	Concept of basic conditions for sampling such as pumping test, scooped sample, passive collector
	Definition of the requirements for accuracy and reliability of measured variables with respect to the pending decisions
4. Development of the investigation plan and quality assurance plan	Definition of the precise drilling points, drilling depths, description of drilling method (taking into account drilling obstructions such as pipes and cables, suspected munitions)
	Type and construction of the monitoring wells such as construction materials, filter sections, sealing intermediate horizons
	Description of the procedure for extraction, treatment and analysis of the samples such as sampling method, extraction depth, pumping rate, sampling intervals, pumping periods, sample stabilisation
	Type and scope of in-situ measurements such as geophysics, sensor technology
	further whereabouts of monitoring wells, such as dismantling or retention
	Description of measurements to check suitability of the monitoring wells
	Zero samples, duplicate samples and comparative analyses, calibrations
	Occupational health and safety
5. Investigation preparation and implementation	Drilling notice
	Water legislation procedure
	Fieldwork such as building monitoring wells, sampling, sample preparation, sample handover, measurements on site
	Checking construction and check measurements
	Logging/documentation
6. Evaluation, assessment and documentation	Description/presentation of results
	Plausibility check
	Evaluation of the results and development of proposals for further action to be taken

[4] Examples of questions or problems are: Decision concerning a suspected hazard, certification of lack of contaminants, demarcation between contaminated and uncontaminated areas, determination of the polluter, decision regarding action required to avert hazard, decision regarding alternative remediation methods, decision regarding use of natural attenuation

APPENDIX VI: LAWS, ORDINANCES AND REGULATIONS

BBodSchG Law on protection against harmful soil changes and the remediation of contaminated sites (Bundes-Bodenschutzgesetz) dated 17.03.1998 (BGBl. I p. 502, amended by Art. 17 Seventh Euro implementation law dated 9.9.2001(BGBl. I p. 2331) and Art.3 Law to adjust the limitation regulations to the law on the modernisation of law of obligations dated 9.12.2004 (BGBl. I p. 3214)

BBodSchV "Bundes-Bodenschutz- und Altlasten-verordnung" Federal soil protection and contaminated site ordinance, version dated 12.07.1999, (BGBl. I p. 1554)

FrAl Guidelines of the Ministry of the Environment and Transport of Baden-Württemberg concerning the promotion of measures for the identification and treatment of suspected contaminated areas and contaminated sites ("Förderrichtlinien Altlasten") dated 14.12.2004, (GABl. No. 1 p. 72).

LBodSchAG Law on the implementation of the "Bundes-Bodenschutzgesetz Baden-Württemberg" (Landes-Boden-schutz- und Altlastengesetz - State Soil Protection and Contaminated Site Law) dated 14.12.2004, (GABl. p. 908).

VwV OW Joint administrative regulations of the Ministry of the Environment and Transport and the Ministry of Social Security of Baden-Württemberg on indicative values for the handling of contaminated sites and contamination cases dated 16.09.1993, version dated 01.03.1998 (GABl. p.295) (Note: The VwV OW expired on 31.12.2005. However, there are no objections to its continued use for orientation purposes, provided its provisions do not contradict current laws or ordinances.

WHG "Wasserhaushaltsgesetz" - Water management law, version published on 19 August 2002 (BGBl. I p. 3245)

WG "Wassergesetz" - Water law for Baden-Württemberg, version published on 20 January 2005 (GBl. p. 219, amendment p. 404)

APPENDIX VII: BIBLIOGRAPHY

[1] Alimi, H.; Ertel, T. and Schug, B. (2002): Fingerprinting of Hydrocarbon Fuel Contaminants: Literature Review. Environmental Forensics 3/2003, p. 25-39.

[2] Alimi, H. and Ertel, T. (2001): Charakterisierung von organischen Schadstoffen in Boden und Grundwasser, TerraTech 5/2001, p. 32-36.

[3] Altlastenforum Baden-Württemberg e. V. (2002): Grundwasserabstromuntersuchung durch Immissionsmessung. Heft 8. E. Schweizerbart´sche Verlagsbuchhandlung. – Stuttgart.

[4] Altlastenforum Baden-Württemberg e. V. (2006): Innovative Mess- und Überwachungsmethoden. Heft 11. E. Schweizerbart´sche Verlagsbuchhandlung. – Stuttgart.

[5] ASTM: Standard Guide for Installation of Direct Push Ground Water Monitoring Wells, D 6724-01, www.astm.org

[6] ASTM: Standard Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers, D 6725-01, www.astm.org

[7] ASTM: Standard Guide Direct Push Water Sampling for Geoenvironmental Investigation, D 6001, www.astm.org

[8] ASTM: Standard Guide for Direct Push Soil Sampling for Environmental Site Characterisation, D 6282, www.astm.org

[9] Bayerisches Landesamt für Wasserwirtschaft (2004): Natürliche Schadstoffminderung bei Grundwasserverunreinigungen durch Altlasten und schädliche Bodenveränderungen - Natural Attenuation; Merkblatt 3.8/3. – München.

[10] BMBF, KORA TV8 (2005): Untersuchung der rechtlichen Rahmenbedingungen für den kontrollierten und natürlichen Rückhalt und Abbau von Schadstoffen bei der Sanierung kontaminierter Böden und Grundwässer; Schlussbericht. – Berlin.

[11] BMBF-Förderschwerpunktes KORA www.naturalattenuation.de

[12] Bracke, R.: Direct Push-Technologien (2001): Der Einsatz von Direct Push-Verfahren für Geomonitorings und baugrundtechnische Fragestellungen, ECOS – umwelttechnische und wissenschaftliche Publikationen.

[13] Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK) e. V. (2004): Erarbeitung von Leistungsbeschreibungen und Leistungsverzeichnissen zur Grundwasserprobennahme bei Altlasten im Lockergestein; Merkblatt 5 (Entwurf). – Pfullingen.

[14] Bundesamt für Umwelt, Wald und Landschaft (BUWAL) (2003): Probenahme von Grundwasser bei belasteten Standorten. – Bern.

[15] Bund/Länder-Arbeitsgemeinschaft Bodenschutz (LABO), Ständiger Ausschuss Altlasten (ALA) Ad-hoc Unterausschuss "Natural Attenuation": Berücksichtigung natürlicher Schadstoffminderungsprozesse bei der Altlastenbearbeitung; Positionspapier. (06.2005)

[16] Bund/Länder-Arbeitsgemeinschaft Bodenschutz (LABO), Ständiger Ausschuss Altlasten (ALA) Ad-hoc Unterausschuss "Natural Attenuation": Arbeitshilfe Qualitätssicherung.

[17] Bund-/Länderarbeitsgemeinschaft Bodenschutz (LABO), Altlastenausschuss (ALA): Arbeitshilfe Sickerwasserprognose bei orientierenden Untersuchungen, 07.2003

[18] Bund-/Länderarbeitsgemeinschaft Wasser (LAWA) (2004): Ableitung von Geringfügigkeitsschwellenwerten für das Grundwasser. – Düsseldorf.

[19] Bund-/Länderarbeitsgemeinschaft Bodenschutz (LABO), Altlastenausschuss (ALA): Arbeitshilfe Sickerwasserprognose bei Detailuntersuchungen, 10.2006

[20] Fachsektion Hydrogeologie in der Deutschen Geologischen Gesellschaft (2002): Hydrogeologische Modelle - Ein Leitfaden mit Fallbeispielen. – Hannover.

[21] Fehlau/Hilger/König: Vollzugshilfe Bodenschutz und Altlastensanierung: Erläuterungen zur Bundes-Bodenschutz- und Altlastenverordnung. – Berlin. Erich Schmidt, 2000.

[22] Field Analytical Technology Encyclopedia (FATE), fate.clu-in.org

[23] Fortbildungsverbund Boden und Altlasten Baden-Württemberg: Seminarreihe "Qualitätssicherung in der Altlastenbearbeitung". – Stuttgart. www.iws.uni-stuttgart.de/weiterbildung/fortbildungsverbund/index.html

[24] Gerstner, D., Scheydt, T. und Fälker, C. (2006): Untersuchung von Altlasten – Einsatzmöglichkeiten und Grenzen von Direct Push Technologien bei der Altlastenbearbeitung. In: altlasten spektrum 6/2006.

[25] Hipp/Rech/Turian: Das Bundes-Bodenschutzgesetz mit Bodenschutz- und Altlastenverordnung: Leitfaden. – 1. Aufl. – München; Berlin: Rehm, 2000.

[26] Kohler, W., Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW) (2006): Monitored Natural Attenuation - Konzepte im Rahmen der systematischen Altlastenbearbeitung in Baden-Württemberg. – Karlsruhe.

[27] Länderarbeitsgemeinschaft Wasser (LAWA), Bund-/Länderarbeitsgemeinschaft Boden (LABO) (2006): Grundsätze des nachsorgenden Grundwasserschutzes bei punktuellen Schadstoffquellen, Mainz, 05.2006

[28] Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (2007): Altlasten-Fachinformationen im WWW

[29] Landesanstalt für Umweltschutz Baden-Württemberg (2005): Anforderungen an ein Gutachten im Bereich der Altlastenuntersuchung; Sonstige Berichte Nr. 30 (Entwurf). – Karlsruhe.

[30] Landesanstalt für Umweltschutz Baden-Württemberg (2005): Die Amtsermittlung bei altlastverdächtigen Flächen nach § 9 Abs. 1 BBodSchG (orientierende Untersuchung); Altlasten und Grundwasserschadensfälle, Band 39. – Karlsruhe.

[31] Landesanstalt für Umweltschutz Baden-Württemberg (2004): XUMA-Bewertung.

[32] Landesanstalt für Umweltschutz Baden-Württemberg (2002): Altlastenbearbeitung Baden-Württemberg: Stand des Priorisierungsverfahrens und Fortschreibung für die Wirkungspfade Boden - Grundwasser, Boden - Mensch, Boden - Nutzpflanze und Gefahren durch Deponiegas. – Karlsruhe.

[33] Landesanstalt für Umweltschutz Baden-Württemberg (LfU) (2001): Handlungsempfehlung zum Einsatz von Vor-Ort-Analytik; Altlasten und Grundwasserschadensfälle, Band 33. – Karlsruhe.

[34] Landesanstalt für Umweltschutz Baden-Württemberg (LfU) (1998): Methodensammlung; Materialien zur Altlastenbearbeitung Band 20. – Karlsruhe.

[35] Landesanstalt für Umweltschutz Baden-Württemberg (LfU) (1997): Anleitung zur Probennahme von Grund-, Roh- oder Trinkwasser. – Karlsruhe.

[36] Landesanstalt für Umweltschutz Baden-Württemberg (LfU) (1997): Leitfaden fachtechnische Kontrolle von altlastverdächtigen Flächen, Altlasten und Schadensfällen; Altlasten und Grundwasserschadensfälle, Band 25. – Karlsruhe.

[37] Landesanstalt für Umweltschutz Baden-Württemberg (LfU) (1996): Leitfaden Erkundungsstrategie Grundwasser; Altlasten und Grundwasserschadensfälle, Band 19. – Karlsruhe.

[38] Landesanstalt für Umweltschutz Baden-Württemberg (LfU) (1991): Bestimmung der Gebirgsdurchlässigkeit; Materialien zur Altlastenbearbeitung, Band 8. – Karlsruhe.

[39] Landesanstalt für Umweltschutz Baden-Württemberg, Landesamt für Natur und Umwelt Schleswig-Holstein (1999): Branchenkatalog zur Erhebung von Altstandorten. – Karlsruhe/Kiel

[40] Landesgesundheitsamt und Landesanstalt für Umweltschutz Baden-Württemberg (2005): Berechnung orientierender Hinweise auf Prüfwerte für flüchtige Stoffe in der Bodenluft; Altlasten und Boden News 1/2005. – Karlsruhe.

[41] Landesumweltamt Nordrhein-Westfalen (2006): Grundwasseruntersuchungen an Altlasten im Lockergestein; Materialien zur Altlastensanierung und zum Bodenschutz (MALBO) Band 25. – Essen.

[42] Landesumweltamt Nordrhein-Westfalen (2005): Leistungsbuch Altlasten und Flächenentwicklung 2004/2005; Materialien zur Altlastenbearbeitung und zum Bodenschutz (MALBO) Band 20. – Essen.

[43] Landesumweltamt Nordrhein-Westfalen (2006): Überwachung, Nachsorge und Eigenkontrolle bei der Altlastenbearbeitung; Materialien zur Altlastensanierung und zum Bodenschutz Band 24. – Essen.

[44] Langguth, Horst-Robert und Voigt, Rudolf: Hydrogeologische Methoden, 2. überarbeitete und erweiterte Auflage 2004, Springer-Verlag

[45] Ministerium für Ernährung, Landwirtschaft und Umwelt Baden-Württemberg (1976): Arbeitsblatt Pumpversuche in Porengrundwasserleitern; Schriftenreihe Wasserwirtschaftsverwaltung Baden-Württemberg. – Stuttgart.

[46] MORRISON, R.D. & MURPHY, B.L. eds. (2006): Environmental Forensics – A contaminant specific guide, Elsevier Academic press, London.

[47] Nitsche, C. (2005): Tiefenorientierte Probennahme. Vortrag im Rahmen AQS Baden-Württemberg, Lehrgang III, 03.03.2005 (modifiziert). – Stuttgart.

[48] Umweltbundesamt (1999): Erarbeitung von Programmen zur Überwachung von altlastverdächtigen Flächen und Altlasten; UBA-Texte 96/99. – Berlin.

[49] United States Environmental Protection Agency – US EPA (2005): Groundwater Sampling and Monitoring with Direct Push Technologies, EPA 540/R-04/005, www.epa.gov.

[50] United States Environmental Protection Agency US EPA (1997): Expedites Site Assessment Tools for Underground Storage Tank Sites: A Guide for Regulators, www.epa.gov/Swerust1/sam.thm.

[51] Universität Stuttgart, Institut für Wasserbau (1997): Stand des Wissens bei der Beprobung von Grundwasser bei Altlasten. – Stuttgart.

State Institute for Environment, Measurements and Nature Conservation Baden-Wuerttemberg
P.O. Box 10 01 36 - 76231 Karlsruhe / Germany - Internet: www.lubw.baden-wuerttemberg.de