ModelPROBE final report, M. Kästner submission date 23.11.2012

4.1 Final publishable summary report

This section will be edited by the Commission as such. The length of this part should not exceed 40 pages. This report should address a wide audience, including the general public. This summary report has to be updated at the end of each reporting period.

Please provide an executive summary. The length of this part cannot exceed 1 page.

Conventional techniques for site characterisation are time consuming, cost intensive, and often do not support decision making with regard to sustainable remediation. Therefore, new techniques for step by step site characterization with smart feedback loops are necessary that are able to support a future “soil framework directive”.

Advanced geophysical site characterization techniques combined with new types of vegetation analysis were developed. Based on these non-invasive surveys, the extension of sources, contamination levels (THP, BTEX, PAH, CHC, explosives, and heavy metals) and soil heterogeneities can be localized first. Hot spots will then be investigated by new direct push probing systems integrated with geophysical & hydrogeological methods and combined with chemical & isotopic contaminant analysis for source localization and identification (environmental forensics). The actually occurring bioprocesses, such as contaminant degradation or sorption and mobilization processes, are assessed using biosensors, in situ microcosms, and stable isotope and biomarker analysis. These new techniques and tools were evaluated against best practice of conventional methods and the results are documented in the ModelPROBE handbook in addition to more than 45 scientific publications (ISI).

The ModelPROBE project provided the opportunity to test, optimize and demonstrate the proposed approach at fully equipped and characterized European brownfield reference sites in Germany, Italy, Norway and the Czech Republic. Integrating statistical analysis and modelling at different stages, the step by step approach resulted in an improved view of soil and subsurface contamination and provides a sound basis for a cost-effective risk assessment and decision in the choice of the most appropriate sustainable remediation strategy.

Please provide a summary description of the project context and the main objectives. The length of this part cannot exceed 4 pages.

Conventional techniques for site characterisation and management are mostly made of unrelated tasks (site history assessment, drilling, sampling, chemical/toxicological analysis, consulting, risk assessment, and remediation action). This approach is highly expensive, extremely time consuming and currently is not directed to supporting the decision making at an early project stage. Present techniques are not suitable to trigger effective assessment, management, and remediation actions and therefore need integration. In particular, they are mostly not compatible with a future Soil Framework Directive planned to follow up the present Soil Thematic Strategy of the EC.

In particular, current conventional site assessment techniques do not cover screening of potentially contaminated sites, source analysis regarding environmental forensics and most methods are not suitable to be extended towards remediation monitoring. In addition, the present state of the art in geological site assessment requires generally some kind of drilling with the corresponding costs and effort resulting in low area coverage. Therefore, innovative flexible and minimal invasive types of geo-sampling were required at the beginning of the project.

As a consequence, improved technologies and tools for step by step site characterisation with smart feedback loops are necessary and were developed in between by the ModelPROBE project and also outside. These new techiques support the upcoming "Soil Framework Directive" planned by the EC. Within the framework of the ModelPROBE project, a combination of advanced geophysical site characterisation techniques with new types of low-cost vegetation analysis have been developed. Based on these non-invasive surveys, the extension of sources, contamination levels and soil heterogeneities can be localised first. Hot spots will then be investigated by novel direct push probing systems including geophysical and hydrogeological methods combined with chemical and isotopic contaminant analysis for source localisation and identification (environmental forensics). Bioprocesses such as bioavailability, contaminant degradation or sorption or remobilisation processes can now be assessed by biosensors, in situ microcosms, stable isotope and biomarker analysis.

Novel techniques and tools, however, always need to be evaluated against best practice of conventional methods. Therefore, the new tools were applied in parallel at fully equipped and characterised European reference sites available for the ModelPROBE consortium (Trecate and Rho, Italy; Zeitz in Germany; Mimon/SAP, Czech Republic; Moeringa, Norway; for details see ModelPROBE homepage: www.modelprobe.eu. These sites have been equipped in previous projects or by other national sources (EU projects: BIOTOOL, WELCOME, BIOISOTOPE; German BMBF-Projects: RETZINA, SAFIRA, and several others). Integrated statistical analysis and modelling at different stages of the step by step approach resulted in an improved view of soil and subsurface contamination and provided the sound basis for risk assessment decision. The developed tools are now provided as guidelines and operation manuals and are available to industry, SME´s, consultants, and authorities for application within the framework of the ModelPROBE handbook.

Objectives. A step by step characterisation approach for contaminated sites comprise an inherent feedback loop strategy that allows referring back at each stage to the results of previous stages. This approach helps minimizing the effort and providing sufficient information necessary for a decision at each point. This approach requires operation manuals of the specific analytical tools that are related to each other and, what is more important, an integrated statistical analysis of the geological, geophysical, chemical, biotic and ecotoxicologial data aiming at a 3D modelling of the contamination at a site derived from a minimal data set. This concept provides a very high cost/efficiency ratio for site assessment.

Since new methods need to be validated properly before being considered resistant to a legal scrutiny, the developed techniques and combined tools in the ModelPROBE project are related to conventional assessment techniques. However, the effort required by such comparison would require a separate project. Therefore, the ModelPROBE approach was tested at fully equipped European reference sites that were characterized by the necessary suite of drillings, chemical inventory and hydrological modelling, and subjected to continuous monitoring or even operating remediation measures. In addition, the implementation of new approaches always required training of users, consultants, decision makers, authorities, and even of environmental lawyers. This requirement was also an inherent part of the project. General objectives of the project were:

- To develop and improve a set of new, relatively simple-to-use and minimally or non-invasive methods for the assessment of contaminated soils in the framework of the soil thematic strategy. This set of methods should provide a toolbox for future application in the planned Soil Framework directive for the general purpose of contaminated site characterisation and monitoring of remediation progress. The following issues are addressed:
    - general site characterisation and (hydro-)geology (vegetation analysis, geophysics, and direct push)
    - analysis of biogeochemical conditions (direct push with new approaches)
    - analysis of contaminants (plant based primary assessment or monitoring, direct push with new approaches, isotope analysis)
    - assessment of ecotoxicology (passive samplers, toxicity testing, effect based analysis)
    - analysis of sources (isotope analysis with environmental forensics)
    - assessment of microbial degradation activity and contaminant bioavailability (compound specific stable isotope fractionation analysis, in situ microcosms, e.g. BACTRAP and fuel cell meter)
- To evaluate the methods against conventional technologies at fully characterised sites (Zeitz, Germany; SAP, Czech Republic; Trecate and Rho, Italy)
- To evaluate the methods as appropriate information sources for long term monitoring purposes and to assist Monitored Natural Attenuation measures
- To provide additional modeling tools for integrative assessment
- To provide guidelines for applying the new tools in order to instruct decision makers, consultants and users with the chances and limitation of the new tools

Transformation of the general objectives into specific ones of the reporting periods:

The general objectives for the <u>first period</u> were to implement the project and to find the appropriate language and communication strategies for the various disciplines working together in the project. The objectives for the first reporting period are:

1. To evaluate the validity, chances and limitations of the various methods, in particular the new geophysical ones

2. To check how the methods can be applied non-invasively or be combined with Direct Push techniques
3. To evaluate how spatio-temporal statistical methods can be applied to the data of the various methods and how can they improve the overall results and their reliability
4. To start method evaluation at the reference sites and how the methods fit into the general ModelPROBE approach
5. To start the development of the overall approach in terms of guidelines and method evaluation

The general objectives for the 2nd period were to run the project and to organize the communication strategies and interaction for the various disciplines working together in the project.
The objectives for this reporting period are:

1. To validate the various methods, in particular the new geophysical ones
2. To apply the methods either non-invasively or combined with Direct Push techniques
3. To apply spatio-temporal statistical methods to the data of the various methods and to show how they improve the overall results and their reliability
4. To continue method evaluation at the reference sites and to adjust the methods to the general ModelPROBE approach
5. To develop the overall approach in terms of guidelines and method evaluation

The general objectives for the 3rd period were to continue the project and to organize the strategies and interaction for the various disciplines working together in the project.
The objectives for this reporting period are:

6. To continue validating the various methods
7. To continue method evaluation and testing at the reference sites and to adjust the methods to the general ModelPROBE approach
8. To apply spatio-temporal statistical methods to the data of the various methods and to show how they improve the overall results and their reliability
9. To develop the overall approach in terms of the guidelines and method evaluation
10. To organize the ModelPROBE handbook´s editorial process and the overall dissemination activities

Please provide a description of the main S & T results/foregrounds. The length of this part cannot exceed 25 pages.

Definition of new methods applicable at the reference sites, in comparison to conventional techniques and tools completed

The following techniques for site assessment are recommended by the different work packages of the project and are based on the maturity and applicability of the methods. The details of the applicability are provided in Deliverable 9.2 (Results of field demonstration of a set of advanced techniques for general, specific and/or detailed assessment of contaminated sites; cross validation and comparison) and the report of the 3rd period.

The methods were mostly developed or improved within the ModelPROBE project but some sound methods are also contributed from the developments of the associated project SoilCAM. All methods that can be recommended for certain tasks in the assessment of contaminated sites are documented by fact sheets (latest versions), which provide a full overview about the methods including the contact to the most experienced scientists. The list is the final list for publishing within the ModelPROBE handbook.

Self-Potential (SP) for contaminated soil characterization | Fact sheet No. 1

Main objectives

- Hydrological characterization
- Detection of contaminants
- Mapping of contaminant distribution

Brief description

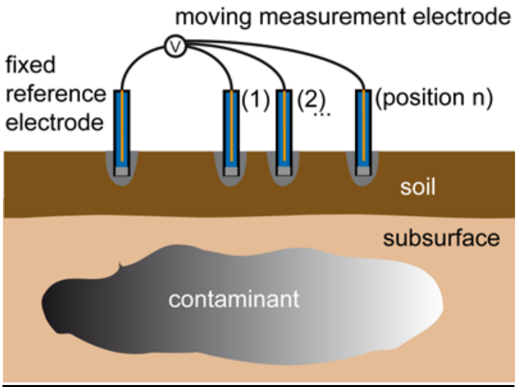
Main principle

Measurement of the natural electrical potential existing at the surface (provides profiles or maps of the electrical potential differences between a moving electrode and a reference electrode fixed far enough from the perturbed area). The signals are then inverted to retrieve the underground distribution of current generating the surface potential. Finally, this distribution is interpreted in physical/chemical terms.

Main results

The SP signals results from i) the motion of underground fluids, ii) the diffusion of ionic species, iii) the existence of a redox gradient (often the case when biodegradation is acting), iv) the diffusion of temperature. They can thus give information about the hydrology (regional flow-paths) and the contamination state and to their variations with time if an array of electrodes is installed permanently.

Sketch of measuring principle or concept

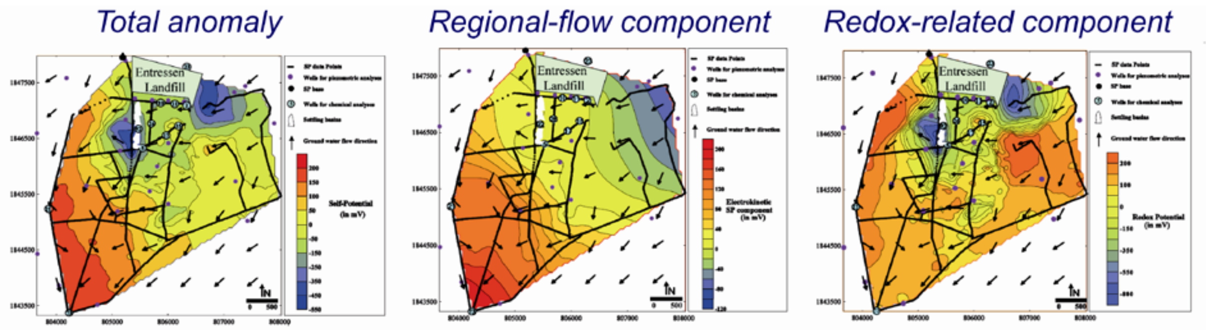


◄ Principle of measurement in the field

▼ Example of SP signals over a contaminated area (Entressen landfill, France). *From Arora et al., 2007*

Left: total SP anomaly.

Centre: SP signal linked to the local hydraulic flow, estimated from



Requirements

Site requirements (not applicable for mathematical/statistical methods)

a. Operation media: soils, sediments, rocks

b. Infrastructure requirements: none

Sample requirements (not applicable for in-situ methods)

None (in-situ application)

Data/information necessary for reliable interpretation of results

- Lithology (in particular: electrical resistivity, hydraulic permeability, porosity). Data from drilling cores is advantageous for calibration
- Hydrology: electrical conductivity of the fluid, water-level and regional hydraulic gradient.
- Contamination: chemical type of the contaminant and if available borehole chemical data could help for the interpretation

Application range ("operating windows")

- Best suited for areas without the presence of anthropogenic noise (pipes, electrical utilities, etc.).
- Unpolarisable electrodes placed on unpaved surfaces, in holes filled with a bentonite-brine mixture to ensure a good electrical contact if the soil is not moist enough
- Use of high-impedance voltmeter only
- Better to check to ground contact resistance before measurements with an alternative ohm-meter (should be less than 2000 ohm)
- Better to use shielded cables if the dipole is long

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Conventional subsoil and groundwater sampling

Advantages

- The non-invasive, passive and "low-cost" nature of the method and its capability to image the subsurface with relatively high spatial resolution (profiles or maps), and to follow the temporal evolution of the subsurface (when electrodes are installed permanently).

Limitations

- The low amplitude of the signals in some cases (usually in the range ±200 mV, but can be much lower), the sensitivity to anthropogenic electrical noise, and the difficulty of the inversion/interpretation when different sources are acting together (note that the response to bacterial activity is still poorly understood).

State of development

Field applicability state-of-the-art method

Provider Saint-Petersburg State University, Institute of Methodologies for Environmental Analysis (Italian National Council of Research), Institut de Physique du Globe de Paris,

References

Arora T., Linde N., Revil A., Castermant J., 2007. Non-intrusive characterization of the redox potential of landfill leachate plumes from self-potential data, Journal of Contaminant Hydrology 92, 274-292.

Doherty R., Kulessa B., Ferguson A.S., Larkin M.J., Kulakov L.A., Kalin R.M., 2010. A microbial fuel cell in contaminated ground delineated by electrical self-potential and normalized induced polarization data, Journal of Geophysical Research 115, G00G08, doi:10.1029/2009JG001131

Jouniaux L., Maineult A., Naudet V., Pessel M., Sailhac P., 2009. Review of self-potential methods in hydrogeophysics, Comptes-Rendus de l'Académie des Sciences de Paris Geoscience 341, 928-936.

Revil A., Mendonca C.A., Atekwana E.A., Kulessa B., Hubbard S.S., Bohlen K.J., 2010. Understanding biogeobatteries: Where geophysics meets microbiology, Journal of Geophysical Research 115, G00G02, doi:10.1029/2009JG001065

Expenditures

- Trained personnel required (2 in the field, 1 in the office for interpretation)
- Special knowledge/modeling capability needed (note that no interpretation software for SP exists)

Contact persons

- Prof. Dr. Konstantin Titov, Saint-Petersburg State University
- Dr. Enzo Rizzo, IMAA-CNR
- Dr. Alexis Maineult, IPG Paris

Remarks

none

Electrical Impedance Tomography (EIT) / Spectral Induced Polarization (SIP) for contaminated soil characterization	Fact sheet No. 2

Main objectives

- Lithological and hydrogeological characterization
- Detection of contaminants
- Mapping of contaminant distribution

Brief description

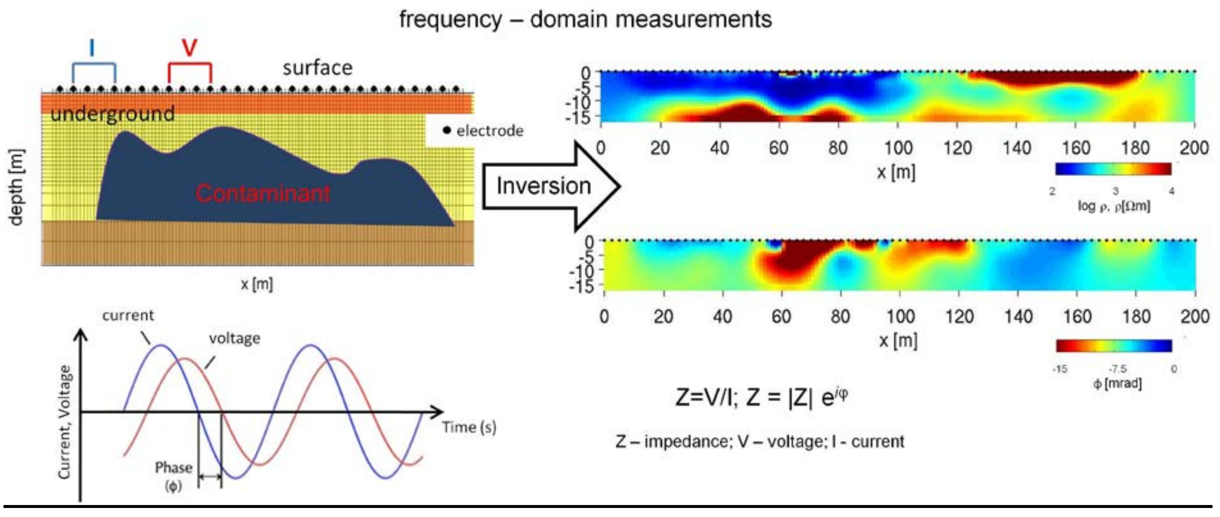
Main principle

Injection of electric currents and measurement of transfer impedances on an array of electrodes. Typically several tens to hundreds of electrodes are used, placed either at the surface or in boreholes. Each impedance measurement comprises an amplitude ratio and a phase shift between injected current and recorded voltage signals. Measurements can be performed at different measurement frequencies (spectral EIT, SIP), to gain information about the frequency dependence of the impedance.

Main results

From the overall impedance data set images of resistivity magnitude (electrical conductivity) and resistivity phase (electrical polarizability) are computed using tomographic inversion algorithms. Both 2D and 3D imaging is possible, depending on data acquisition geometry, and can be applied in monitoring mode (time-lapse measurements). In conjunction, resistivity magnitude and phase images provide spatially resolved information which can be linked to hydrogeologic properties, geochemical state (contamination), as well as corresponding changes over time (if applied in monitoring mode).

Sketch of measuring principle or concept



Requirements

Site requirements (not applicable for mathematical/statistical methods)

a. Operation media: soils, sediments, rocks
b. Infrastructure requirements: none

Sample requirements (not applicable for in-situ methods)

None (in-situ application)

Data/information necessary for reliable interpretation of results

- Lithology, hydrogeology: data from drilling cores is advantageous for calibration
- Contamination: Depending on specific application chemical data from water/soil sample analyses is required for calibration

Application range ("operating windows")

- Best suited for areas without the presence of anthropogenic noise (pipes, electrical utilities, etc.).
- Electrodes preferentially placed on unpaved surfaces, in PVC-casing wells.
- Deeper measurements related to longer electrode arrays on the surface or electrodes placed in boreholes.
- Measurements in the time domain might be used for purposes of mapping due to the robustness and relatively fast acquisition times; whereas frequency-domain measurements are necessary for improved lithological and biogeochemical characterization.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Conventional subsoil and groundwater sampling

Advantages

- The non-invasive nature of the method and its capability to image the subsurface with relatively high spatial resolution.

Limitations

- The need for calibration data to convert the imaged electrical properties into hydrogeological and/or geochemical properties.

State of development

Field applicability state-of-the-art method
Provider University of Bonn, Lancaster University

References

Kemna, A., Binley, A., and Slater, L., 2004. Crosshole IP imaging for engineering and environmental applications: Geophysics, 69, 97-107.
Binley, A., and Kemna, A., 2005. DC resistivity and induced polarization methods, *in* Rubin, Y., and Hubbard, S.S., Eds., Hydrogeophysics: Springer, 129-156.

Expenditures

- Trained personnel required (2 in the field, 1 in the office for interpretation)
- Special hardware and software needed

Contact persons

- Prof. Dr. Andreas Kemna, University of Bonn
- Prof. Dr. Andrew Binley, Lancaster University

Remarks

none

Electromagnetic Induction mapping (terrain conductivity) for contaminated soil characterization	Fact sheet No. 3

Main objectives

- Lithological and hydrogeological characterization
- Detection of contaminants
- Mapping utilities

Brief description

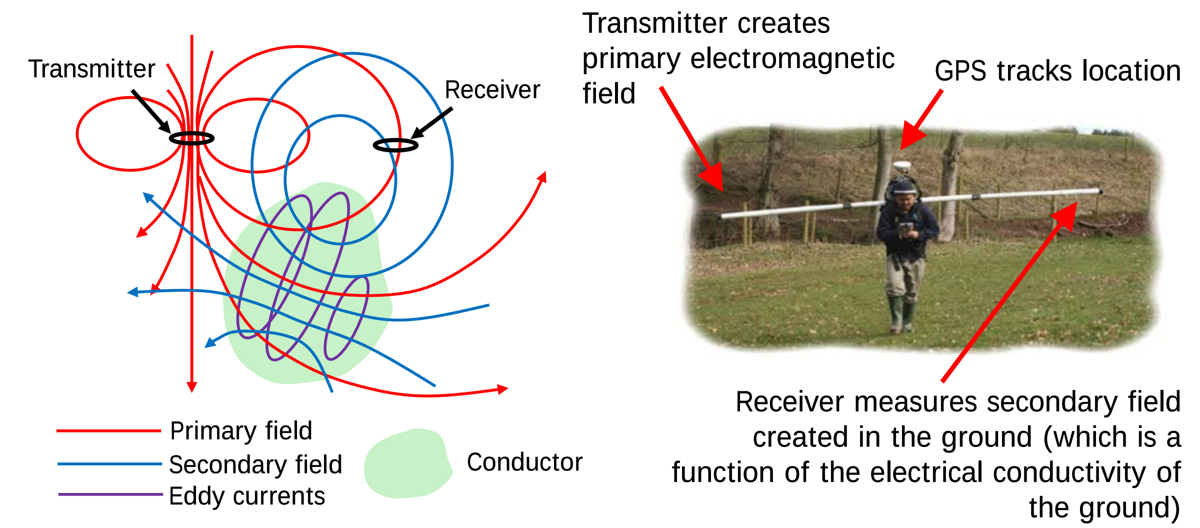
Main principle

A transmitter coil generates an electromagnetic field which induces a secondary field within the subsurface. The strength of this field is affected by the electrical conductivity of the subsurface. The sensitivity decays with depth and thus the measurement is a weighted integral measure of conductivity over some depth. The separation of transmitter and receiver coils dictates the depth of sensitivity. For practical use by one person coil separation is typically up to 3 to 4m (as shown below). This permits a depth of investigation of up to 5 or 6m. Deeper sensitivity is possible with a two man transmitter and receiver coil setup. Surveys are normally carried out with an attached GPS unit, allowing rapid surveys over relatively large areas.

Main results

Results are usually presented in terms of apparent electrical conductivity (the integral measure directly from the instrument). Multiple surveys with different coil separation allows some assessment of layering at a site. Some instrumentation permits multiple depth penetration using different operating frequencies. The surveys can be effective at identification of metallic utilities (e.g. cables, pipes) and can help in reconnaissance for more detailed investigations with tomographic imaging methods. Electrical conductivity variation may be associated with lithological variation at a site. Furthermore, in some cases high (or low) electrical conductivity may be an indicator of contamination.

Sketch of measuring principle or concept



Requirements

Site requirements (not applicable for mathematical/statistical methods)

a. Operation media: soils, sediments, rocks
b. Infrastructure requirements: none

Sample requirements (not applicable for in-situ methods)

None (in-situ application)

Data/information necessary for reliable interpretation of results

- Lithology, hydrogeology: data from drilling cores is advantageous for calibration
- Contamination: Depending on specific application chemical data from water/soil sample analyses is required for calibration

Application range ("operating windows")

- Best suited for areas without the presence of anthropogenic noise (pipes, electrical utilities, etc.) or used as a means of identifying these.
- Fast acquisition time. Measurements are instantaneous and thus large areas can be covered over short time.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Conventional subsoil and groundwater sampling

Advantages

- The non-invasive nature of the method and rapid surveying makes this excellent for reconnaissance.

Limitations

- The values are depth integrated and thus from one single measurement it is not possible to infer variation with deph.

State of development

Field applicability Basic method
Provider Lancaster University, University of Padova

References

Everett, M. and M. Meju, 2005. Near-surface controlled source electromagnetic induction: Background and recent advances, *in* Rubin, Y., and Hubbard, S.S., Eds., Hydrogeophysics: Springer, 157-183.
McNeill, J.D., 1980. Electromagnetic terrain conductivity measurement at low induction number, Geonics Ltd. Technical Note TN-6.

Expenditures

- Trained personnel required (1 in the field, 1 in the office for interpretation)
- Special hardware needed, basic software required.

Contact persons

- Prof. Dr. Andrew Binley, Lancaster University
- Prof. Giorgio Cassiani (University of Padova)

Remarks

none

Ground Penetrating Radar for contaminated soil characterization	Fact sheet No. 4

Main objectives

- Lithological and hydrogeological characterization
- Detection of contaminants if in free phase or as very conductive plumes.

Brief description

Main principle

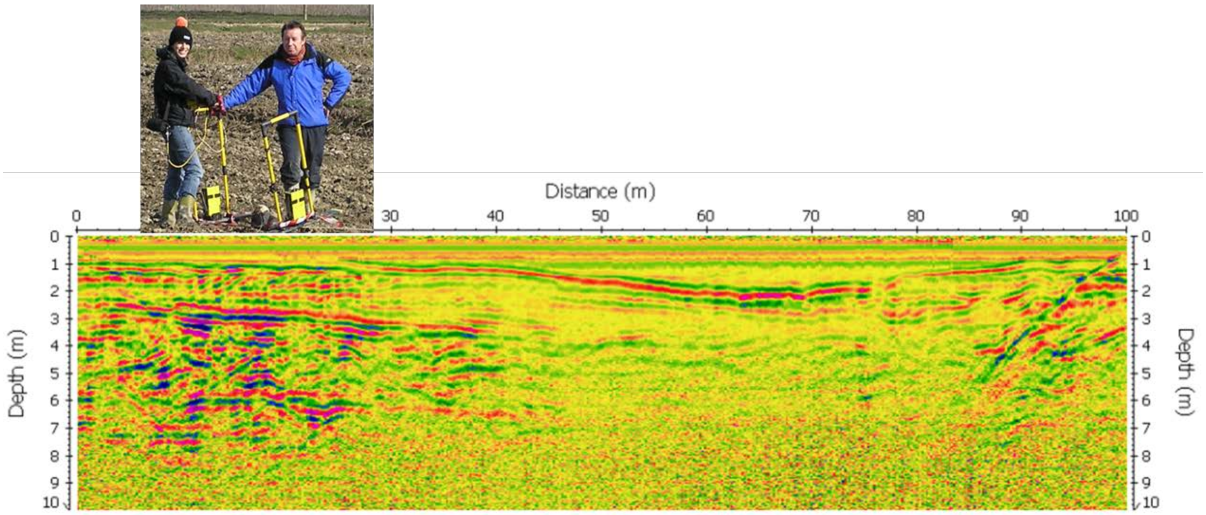
One transmitter antenna emits electromagnetic energy in the 1 MHz – 1 GHz frequency range. The emitted signal, reflected and refracted by the subsurface contrasts in dielectric properties, is recorded by a receiver antenna. Both transmitter and receiver antennas are generally electrical dipoles.

Main results

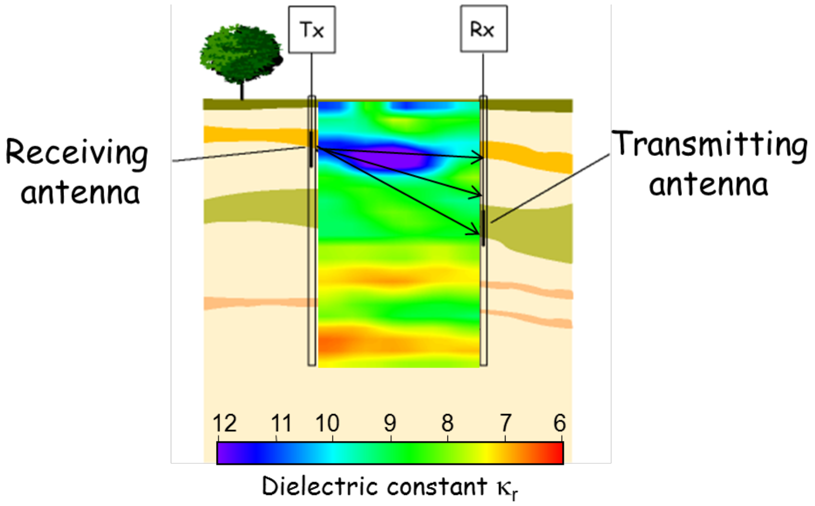
From surface measurements, and having an estimate of propagation velocity, it is possible to obtain from signal reflections an image of the main discontinuities in the subsurface, mainly linked to geological boundaries, single scattering objects, cavities etc. From borehole measurements it is possible to derive tomographic images of dielectric constant distribution. From dielectric constant it is possible to derive estimates of soil moisture content, often as a function of space and time.

Sketch of measuring principle or concept

(1) Surface-to-surface GPR reflection imaging:



(2) Cross-hole GPR transmission imaging:



Requirements

<u>Site requirements</u>

a. Operation media: soils, sediments, rocks having reasonably low electrical conductivity (not applicable in clayey or strongly saline environments).

b. Infrastructure requirements: none

<u>Sample requirements</u>

None (*in-situ* application)

<u>Data/information necessary for reliable interpretation of results</u>

- Lithology, hydrogeology: data from drilling cores is advantageous for calibration
- Soil moisture content: little need for calibration on soil samples.
- Contamination: difficult to ascertain using GPR. In case, chemical data from water/soil sample analyses is required for calibration.

Application range ("operating windows")

- Applicable to areas where soil has moderate to low electrical conductivity (resistivity above 100 Ohm m, indicatively): signal does not penetrate in clayey or saline soils.
- Penetration is often limited to the top 10 m from surface application, and to cross-hole distances of the same range.
- Higher frequencies provide better spatial resolution (e.g. 500 MHz have wavelength around 20 cm) but smaller penetration (e.g. 500 MHz penetrate 1-2 m).

Standing related to other methods (Chances and limitations for application)

<u>Substitution and complementation of conventional methods</u>

- Conventional subsoil coring and soil moisture measurements by sampling or TDR

<u>Advantages</u>

- The non-invasive nature of the method and its capability to image the subsurface with relatively high spatial resolution.

<u>Limitations</u>

- Not applicable at all sites (depending on electrical conductivity)
- Limited penetration
- Limited significance in terms of contaminant detection

State of development

<u>Field applicability</u>

State-of-the-art method

Provider
University of Padova
Lancaster University

References
Annan A.P. 2005. GPR methods for hydrogeological studies. In: Hydrogeophysics (Eds Y. Rubin and S.S. Hubbard). Springer.

Expenditures
- Trained personnel required (2 in the field, 1 in the office for interpretation)
- Special hardware and software needed

Contact persons

- Prof. Dr. Giorgio Cassiani, University of Padova
- Prof. Dr. Andrew Binley, Lancaster University

Remarks
None

Radio Magnetotelluric (RMT) for contaminated soil characterization	Fact sheet No. 5

Main objectives

- Lithological and hydrogeological characterization
- Detection of contaminants
- Mapping utilities

Brief description

Main principle

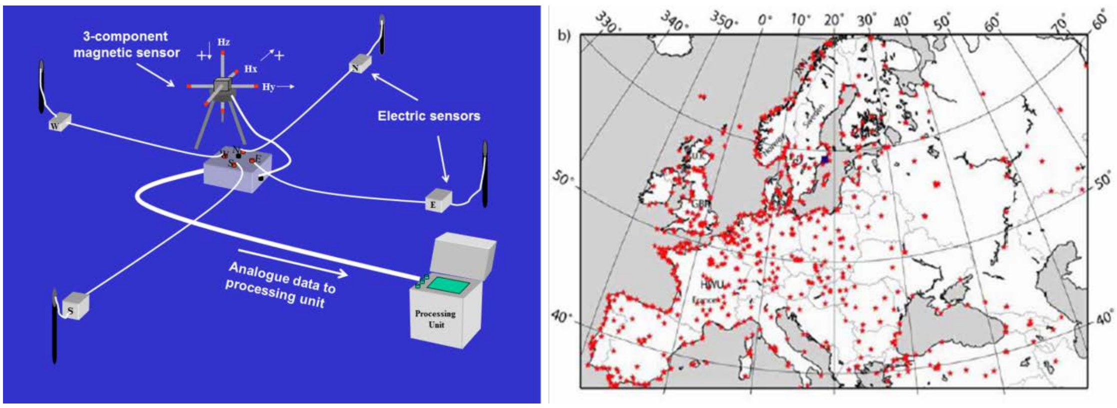
RMT is a frequency domain plane-wave electromagnetic method. The signal sources are the distant radio transmitters that operate in the frequency range 15-250 kHz and are mainly used for navigation purposes. Three components of the magnetic field and two horizontal components of the electric field are registered at the same time. The data are frequency dependent impedance tensors and tipper vectors that provide valuable information about the electrical resistivity structure below the measuring points. Depending on ground resistivity, the depth penetration can vary between 5 and 500 m.

Main results

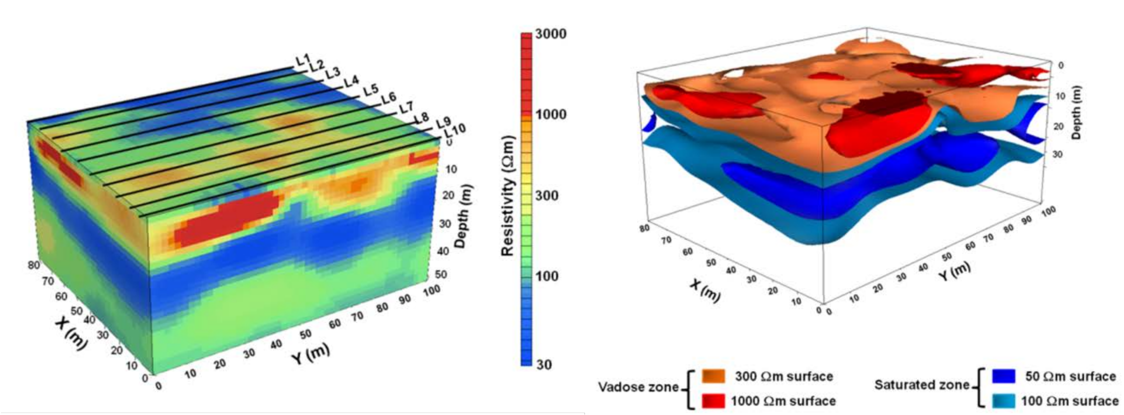
The data are usually presented as variation of apparent resistivity and phases versus transmitter frequencies at each station or along a profile. The data are inverted in 1D, 2D or 3D and presented as estimated resistivities versus depth.

Sketch of measuring principle or concept

1) RMT field setup (left) and location of radio transmitters in Europe (right)



2) 3D resistivity model from inversion (left) and hydrological interpretation (left). Example form Trecate area in Italy



Requirements

Site requirements
a. Proper geographical location to receive signal from radio transmitters.
b. Not very close to infrastructure/ anthropogenic noise sources.

Sample requirements
For 3D modeling a line spacing of one-third of depth penetration.

Data/information necessary for reliable interpretation of results
- Lithology, hydrogeology: data from drilling cores is advantageous for calibration, particularly groundwater conductivity and clay content.

Application range ("operating windows")
- Best suited for areas without the presence of anthropogenic noise (pipes, electrical utilities, etc.), or used as a means of identifying these.
- Relatively fast acquisition time depending on the terrain topography. Measurements are instantaneous and the data quality can be checked immediately at each station.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
- Can be used as an effective tool to model the electrical conductivity, especially to detect areas with high electrical conductivity.

Advantages
- Non-invasive, cost-effective and relatively fast.
- Provides information about dimensionality at each single station.

Limitations
- Low resolution for shallower structures, especially over resistive areas.
- Noise sensitive and best suited for relatively remote areas.
- Needs other data types for calibration, e.g. borehole information.

State of development

Field applicability
Basic method

Provider
Uppsala University
University of Cologne/Köln

References
Bastani, M., 2001, EnviroMT - a new Controlled Source/Radio Magnetotelluric System: Ph.D. thesis, ISBN 91-554-5051-2, Uppsala University.
Bastani, M. and Pedersen, L. B., 2001, Estimation of magnetotelluric transfer functions from radio transmitters: Geophysics, 66, 1038-1051, doi:10.1190/1.1487051.

Expenditures
- Trained personnel required (2 in the field, 1 in the office for interpretation)
- Special hardware, post processing software and 2D/3D inversion programs are needed.

Contact persons

- Prof. Laust B. Pedersen, Uppsala University
- Dr. Mehrdad Bastani, Uppsala University/Geological Survey of Sweden

Remarks
none

Name of method Geophysical data fusion	Fact sheet No. 6

Main objectives

- **Fusion of multiple geophysical methods to improve site characterization**
- **Enhancing subsurface information and reducing subsurface uncertainties**

Brief description

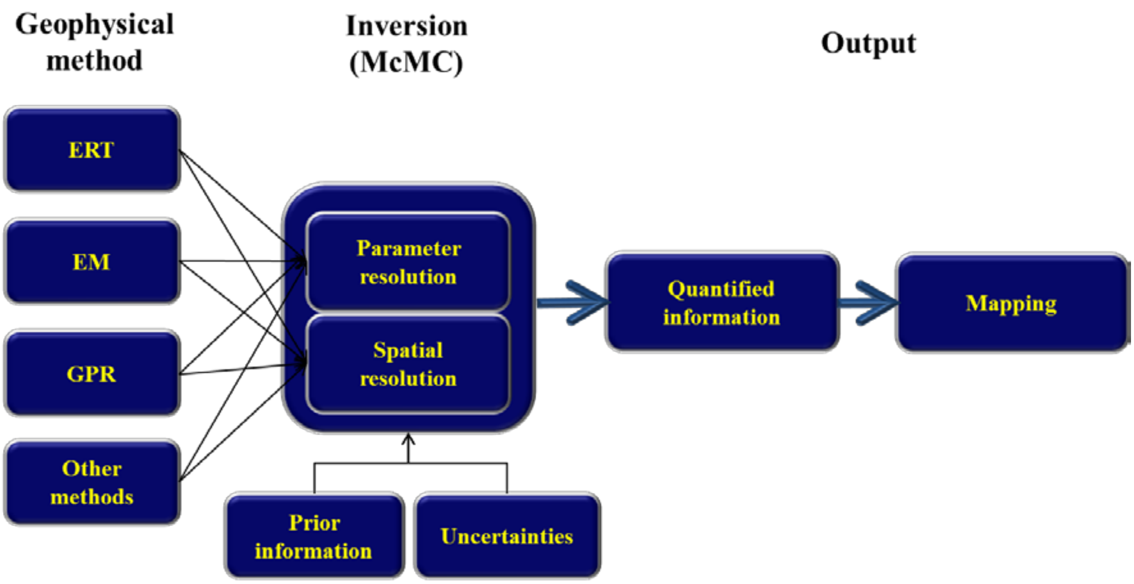
Main principle

The Bayesian fusion approach integrates multiple geophysical datasets with different spatial resolution and coverage and enhances the subsurface information. The fusion strategy is based on the capability of various geophysical methods to provide enough resolution to identify either subsurface material parameters or subsurface structure, or both. Different geophysical datasets are fed into a Markov chain Monte Carlo (McMC) joint inversion algorithm and information content of the post-inversion results are quantified. Shannon's information measure is used to quantify the information obtained from the inversion of different combinations of geophysical datasets. Information from multiple methods is brought together via introducing a joint likelihood function and/or constraining the prior information. A Bayesian maximum entropy (BME) approach is used for spatial fusion of spatially dispersed geophysical measurements and mapping of the target parameter.

Main results

- Three-dimensional distribution of the target subsurface parameter (e.g., electerical conductivity) and corresponding uncertainties.
- Identifying contribution of different geophysical methods to the overall subsurface information.

Sketch of measuring principle or concept



Requirements

Data requirements (mathematical/statistical methods)

- Measured data using multiple techniques
- An estimate of the uncertainty of the measured data
- Adequate computational resource
- A forward solution to calculate the response of each geophysical method to 1D earth-models

Data/information necessary for reliable interpretation of results

- Geology (lithology, structures, etc. including subsoil lines/installations etc.)
- Groundwater (level, flowing direction, gradient, hydraulic conductivity etc.)
- Contamination (substances likely, quality/quantity of contaminants)

Application range ("operating windows")

Any set of complementary geophysical measurements using multiple methods
(Ideal) operative range for applicability
The number of parameters at each location should be limited (typically around 5) in order to minimize computational burden.

Limits for applicability
The geophysical methods should be complementary in terms of properties and scale of measurement/depth of investigation.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

Advantages

- Dealing with multiple geophysical datasets with different spatial coverage and resolution
- Ability to incorporate multiple data types (not just geophysics).
- Incorporation of measurement uncertainty
- Applying an established information-theory based approach for information quantification
- Simplicity of parameterization, in particular avoiding computational burden of 2D and 3D solutions.
- Production of an estimate of information at a given location.

Limitations
Computational cost is high, especially for data fusion mapping

State of development

Provider
Lancaster University

References
JafarGandomi, A., and Binley, A., 2011, Enhancing subsurface information from the fusion of multiple geophysical methods, AGU Fall Meeting.
JafarGandomi, A., and Binley, A., 2011, A Bayesian approach for fusion of multiple geophysical methods to enhance the subsurface information, In preparation.

Expenditures (range of costs, personnel needed, special skills of personnel)

- A degree of knowledge of geophysical methods
- Basic computer programing skills
- Adequate computational resource

Contact person

Dr. Arash JafarGandomi, Lancaster University
Prof. Andrew Binley, Lancaster University

Remarks

Tree Core Monitoring | **Fact Sheet No. 7**

Main objectives

- Rapid screening of sub-surface pollution
- Delineation of plumes
- Rapid monitoring of natural attenuation, qualitatively

Brief description

Main principle

Vegetation samples (typically wood cores) are taken (typically with a core borer) and analyzed as indicator for subsurface contamination. The occurrence of compounds like chlorinated solvents in vegetation is mapped. There is a relation, but not necessarily a linear correlation, between concentrations of chemicals in vegetation samples and subsurface concentrations.

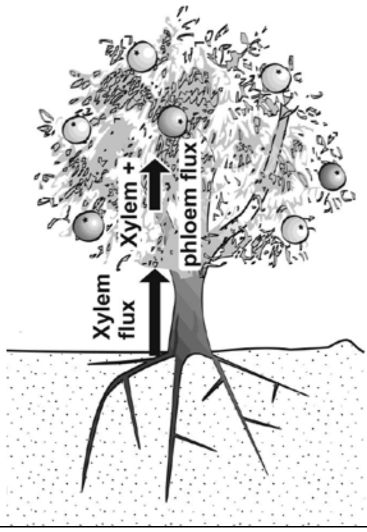
Main results

Elevated concentrations of chemicals in vegetation usually indicate elevated soil- or groundwater concentration.
The method may be used as an exploratory method, and also for monitoring of plume movement and natural attenuation.

Sketch of measuring principle

- Trees root into groundwater
- Trees transport water upwards
- Wood adsorbs and stores compounds.

It follows that each tree is a combination of well, pump and passive sampler.



Requirements

Site requirements

Vegetation required (best: trees).
For volatile or degradable organics: during vegetation period only.
For heavy metals, a reference site with similar soil conditions and vegetation is required.

Sample requirements

Samples (about 1 g) are taken with an increment borer and placed into vessels for analyses.
Conserving agents should be added for biodegradable compounds (organics).
Conservation with acid (0.01 M HNO_3) was successful for PCE, TCE and DCE.
Vessels with volatile compounds (VOC) should be cooled after sampling.
Replicate sampling is recommended (4 per tree from 2 holes).

Data/information necessary for reliable interpretation of results

Tree species and age should be recorded because differences in uptake between species have been observed. Coordinates of sampled trees must be available for mapping.

Application range ("operating windows")

Depth of contamination < 8 m (optimal is 0 - 6 m), i.e. only for shallow groundwater.
The method has been applied successfully for chlorinated solvents (PCE, TCE, DCE). It is expected that it also works for chloroform, trichloroethane, tetrachlorocarbon (CCl4), perchlorate and some explosives (e.g., RDX). BTEX only under good conditions; MTBE not yet tested but could work. For heavy metals, the results were variable. Best was copper. Research is ongoing.

Non-successful for cyanide, iron cyanide; petroleum products (diesel and PAH); long-chain alkanes.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
Initial identification, screening and delineation of subsurface pollution.
Primarily used to optimize drilling of observation wells (or direct push)
Also as rapid method for mapping large-scale subsurface contamination

Advantages
Cheap, rapid, suitable for large areas
Can also be used in inner cities (gardens, alleys)
No heavy equipment required, thus also feasible in swamp areas and moorlands, off-road, in forests

Limitations
Only for certain types of indicator compounds (see above)
Only for shallow groundwater
Semi-quantitative (no linear relation between tree and subsurface concentration)
non-standardized
Results vary with season and weather, tree species, tree size
Permission required in some countries for bore holes in trees

State of development

Field applicability:
Widely applied for PCE, TCE

Provider:
Olaf Holm, TU Berlin; Stefan Trapp et alii, Technical University of Denmark; Daniel Nordhorn, Sweden; HP Consult, Freiburg, Germany; Ellen Graber, Tel Aviv; Joel Burken, Missouri, USA; Daniel Vroblesky, USA; and others

References:
Gopalakrishnan G, Negri MC, Minsker BS, Werth CJ. Monitoring subsurface contamination using tree branches. *Ground Water Monitoring & Remediation* **2007**, *27*, 65-74.
Larsen M, Burken J, Macháčková J, Karlson UG, Trapp S. Using tree core samples to monitor natural attenuation and plume distribution after a PCE spill. *Env. Sci. Technol.* **2008**, 42, 1711–1717.
Ma X, Burken JG. VOCs fate and partitioning in vegetation: Use of tree cores in groundwater analysis. *Environ. Sci. Technol.* **2002***, 36,* 4663-4668.
Vroblesky DA, Nietch C., Morris JT. Chlorinated ethenes from groundwater in tree trunks. *Environ. Sci. Technol.* **1999***, 33,* 510-515.

Expenditures:
Efforts: 2 persons 1 day sampling for 50-100 samples; 2 days analysis for 100 samples;
no standard prices, ask.

Contact person

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Remarks

Get the "guide to vegetation sampling" here: homepage.env.dtu.dk/stt/

Direct Push (general description of technology) (Specific applications: see facts sheets no. 9-13, 16	**Fact Sheet No 8**

Main objectives (objectives depend on specific probe)

- Determination of physical parameter distributions along vertical profiles
- Detection and identification of contaminants
- Contaminant distribution
- Identification of migration / migration paths

Brief description

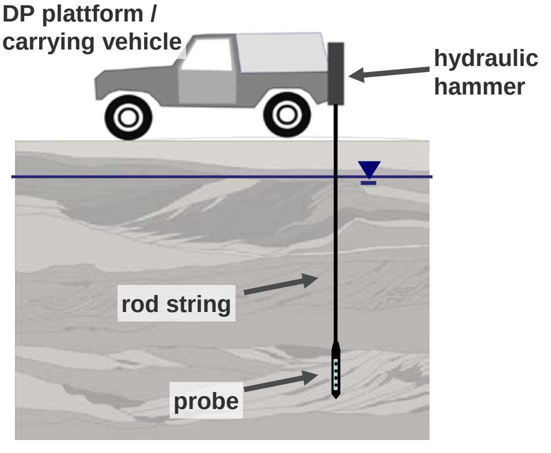
Main principle
Direct push technology (DP) refers to a family of tools used for performing subsurface investigations by driving, pushing, and/or vibrating small-diameter hollow steel rods into the ground. By attaching sampling tools to the end of the steel rods, the technique can be used to collect soil, soil-gas, and groundwater samples. DP rods can also be equipped with probes that provide continuous in-situ measurements of subsurface properties (e.g. geotechnical characteristics and contaminant distribution) (US EPA, 1997, Dietrich & Leven, 2006). In addition DP is capable for installations of groundwater observation wells (max. 2” diameter) and other subsurface applications (subsurface electrodes, borehole logging tubes, fiber optics etc.).

Specific applications of DP are described in Fact Sheets No X, X and x.

Main results
Depending on specific application, following results can be obtained:

- In situ measurement (vertical profiles) of
  - hydrogeological parameters (e.g. hydraulic conductivity, groundwater contamination)
  - geophysical parameters (e.g. natural gamma, electrical conductivity)
  - geotechnical parameters that are indirectly related to several geotechnical factors
  - geochemical parameters (e.g. proxies for soil contamination)
- Sampling of soil, groundwater and soil-gas

Sketch of measuring principle



Requirements

Site requirements
- Operation media: unconsolidated sediments (saturated/unsaturated)
- Infrastructure requirements: accessibility for DP platform / carrying vehicle, technical staff (2 technicians), further requirements depending on used application (e.g. water)

Sample requirements

None (in-situ application)
Data/information necessary for reliable interpretation of results
- Geology: data from drilling cores is advantageous for cross-correlation of DP results
- Contamination: Depending on specific application chemical data from water/soil samples or hydraulic data is advantageous for cross-checking

Application range ("operating windows")

- unconsolidated sediments, applications in claystones and weathered sandstones are reported
- probing depth: typical operation range: 20 – 35 m, max. 50 m – 60 m
- probing diameter: typically 1.5" to 3.25", max. 4.5" = ca. 114 mm

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
- drilling
- depending on specific application, other (hydro)geological or chemical investigation methods (e.g. pumping tests, slug tests, groundwater/soil sampling, installation of permanent observation wells)

Advantages
- minimal-invasive method (minimal changes of in-situ conditions)
- fast sampling und data acquisition (feasible for on-site analysis and decision-making)
- very flexible and mobile equipment
- large variety of different tools and samplers are available
- cost reduction (usually more measurement points at a given budget)

Limitations compared to conventional methods
- limited application range compared to drillings in terms of available diameters and maximum penetration depths (see above)
- limited sampling volumes (for groundwater and soil sampling) due to max. probing diameter
- only capable for low flow groundwater sampling

State of development

Field applicability: state-of-the-art method, some tools are partly in a development stage
Equipment provider (selected): AMS Inc., AP Vandenberg, GeoMil,, Geoprobe®, Geotech AB, MPBF Mess- u. Probenahmetechnik / Terra Direct, Nordmeyer Geotool und Geotechnik Dunkel, Röhrenwerk Kupferdreh Carl Hamm GmbH, SonicSampDrill
References (general overview):
Dietrich, P., Leven, C. (2006): Direct push-technologies. In: Kirsch, R. (Ed.): Groundwater geophysics. A tool for hydrogeology. Springer, Berlin, 321-340.
McCall, W., Nielsen, D.M., Farrington, S.P., and Christy T.M. (2005): Use of Direct-Push Technologies in Environmental Site Characterization and Ground-Water Monitoring. In Nielsen, D.M. (Ed.): Second Edition of the Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring, CRC Press, Boca Raton, 345-471.
Expenditures: dependent on the tools to be applied

Contact person

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L. Zschornack (UFZ), ludwig.zschornack@ufz.de; T. Vienken (UFZ), thomas.vienken@ufz.de

Remarks

Specific applications for direct-push technology: see fact sheets no. 9-13, 16

Direct Push tools for geophysical measurements	Fact Sheet No. 9

Main objectives

- Vertical profiling of geophysical parameter distributions as proxies for further subsurface information such as lithology, hydrogeological and geotechnical parameters
- flexible and mobile installations for subsurface geophysical measurements e.g., for tomographic measurements

Brief description

Main principle

The main principle is based on the vertical profiling of geophysical parameter distributions. The application of petro-physical relationships allow to transfer these geophysical parameters into parameters relevant for site characterization (e.g., lithology, hydrogeological parameters). In general, the concepts of either surface or borehole geophysics are adopted and integrated into Direct Push (DP) probes or similar tools. Examples for available Direct Push tools for geophysical measurements are:

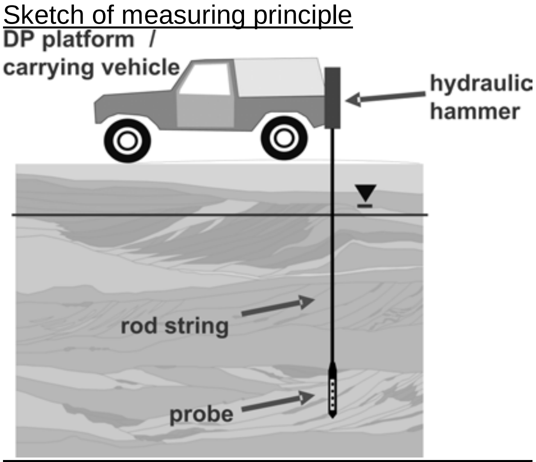
- Electrical conductivity logging (EC) tool, based on geoelectrical measurements
- Soil moisture probe/ Water content profiler, based on the measurement of soil permittivity with high frequency electro-magnetic waves
- Nuclear logging tools, based on detection of natural γ-radiation or the response of artificially induced γ- and neutron radiation of soil
- Tools for seismic measurements, based on the detection of acoustic wave velocities
- Permanent or temporary installations for the application in geophysical tomography (e.g., subsurface electrodes for electrical resistivity tomography)

Main results

Depending on specific application and target, following results can be obtained:

- Depth discrete, in situ measurements (vertical profiles) of geophysical parameters and related subsurface parameters
  - o electrical conductivity as proxy for changes in clay content
  - o soil permittivity, related to soil moisture (unsaturated zone) or porosity (saturated zone)
  - o natural or response to artificially induced γ-radiation as proxies for e.g., changes in clay content and/or water content, bulk density
  - o soil response to artificially induced neutron radiation which allows estimation of hydrogen content (e.g., water or hydrogen-containing contaminants) and porosity
  - o seismic wave velocity distribution: delineation and mapping of lithological units and dynamic elastic modules
- tomographic datasets of different geophysical parameters using permanent or temporary Direct Push installations (e.g., Electrical Resistivity Tomography)

Sketch of measuring principle



Requirements and Application range ("operating windows")

see Fact Sheet X.X Direct Push technologies

Standing related to other methods (Chances and limitations for application)

Substitution and complement to conventional methods

- drilling
- depending on specific application, other geophysical, (hydro)geological and chemical investigation methods (e.g. surface geophysics, slug tests, groundwater/soil sampling, permanent observation wells or geophysical subsurface installations)

Advantages

- fast data acquisition compared to e.g., soil sampling or hydrogeological measurements
- higher vertical resolution compared to surface geophysics
- combination of DP tools for geophysical measurements with surface geophysics can help to improve the lack in depth resolution of surface geophysics
- reliability and accuracy check for geophysical subsurface measurements and assistance for further interpretations or improvements of inversion results

Limitations compared to conventional methods

- measurement of parameter proxies (geophysical parameters) instead of parameters of concern (e.g. geology, lithology, contamination)
- often unknown support/measurement volume (the e.g., volume of soil that is actually measured)
- relatively low robustness of certain applications
- as with all geophysical methods, expert knowledge is necessary for an appropriate data interpretation

State of development

Field applicability: most of the mentioned tools are fully field applicable and commercially available

Equipment provider (selected):

Direct Push EC logging:

- Terra – Direct GbR (Germany)
- Envi (Sweden), provided as resistivity cone
- Geoprobe® (USA)

Seismic Cone:

- Envi (Sweden)
- Geomil (Netherlands)

Soil Moisture Probe

- Geomil (Netherlands)
- Vertek (USA)

References:

Beck, F. P., Clark, P. J., & Puls, R. W. (2000): Location and Characterization of Subsurface Anomalies Using a Soil Conductivity Probe. Ground Water Monitoring & Remediation 20 (2): 55-59.

Jarvis, K. D. and R. Knight, 2000, “Near-surface VSP surveys using the seismic cone penetrometer.” Geophysics, 65, 1048–1056.

Kim, Y., Oh, M., & Park, J. (2007): Laboratory study on the dielectric properties of contaminated soil using CPT deployed probe. Geosciences Journal 11 (2): 121-130.

Paasche, H., U. Werban, et al. (2009). "Near-surface seismic traveltime tomography using a direct-push source and surface-planted geophones." Geophysics 74(4): G17-G25.

Robertson, P. K., R. G. Campanella, et al. (1986). "Seismic CPT to measure in situ shear wave velocity." Journal of Geotechnical Engineering 112(8): 791-803.

Schulmeister, M. K., Butler, J. J., Healey, J. M., Zheng, L., Wysocki, D. A., & McCall, G. W. (2003): Direct-Push Electrical Conductivity Logging for High-Resolution Hydrostratigraphic Characterization. Ground Water Monitoring & Remediation 23 (3): 52-62.

Expenditures: depends on the tools to be applied

Contact person

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L. Zschornack (UFZ), ludwig.zschornack@ufz.de; T. Vienken (UFZ), thomas.vienken@ufz.de

Direct Push tools for sampling of soil, soil gas and groundwater	**Fact Sheet No: 10**

Main objectives

- Sampling of soil for e.g., characterization of lithology, contaminant type and distribution
- Sampling of ground water for qualitative and quantitative estimation of contaminant type and concentration, as well as the spatial distribution and temporal variability (monitoring) of contamination
- Sampling of soil gas for delineation of contaminant distributions

Brief description

Main principle

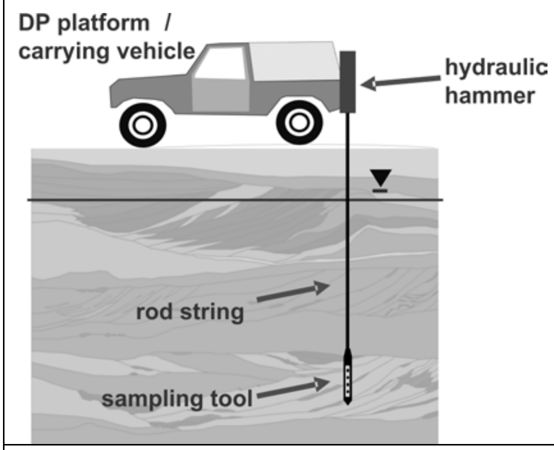
Direct Push technologies (DP) provide an extensive number of different tools for the sampling of soil, soil gas and groundwater. In the simplest form soil samples are taken with hollow sampling tools that are filled with soil material during the advancement of the tool into the ground. For the sampling of soil gas the sampling tools usually consists of a probe with a slotted or filtered section. The soil gas is then pumped to the surface through the perforated probe section using tubes within the rods or the rods itself. Groundwater sampling is usually performed with similar tools as they are common for soil gas sampling. A slotted or filtered probe is advanced to the desired depth and groundwater is pumped at the surface or collected in a small chamber (Smolley & Kappmeyer, 1991; Pitkin et al., 1999; Hoffmann et al., 2010; Leven et al., 2011).

Main results

The use of DP sampling tools can provide depth discrete or continuous (along a vertical profile) samples of soil, soil gas or groundwater. In general, the gathered samples are further analysed in the field or in the laboratory. In this regard, the information that can be obtained from the samples may vary depending on the subsequent analyses. Typical results that can be achieved with DP sampling tools and subsequent analyses are:

- distribution and lithological characterization of subsurface units
- delineation and characterization of contaminants in soil, soil gas and/or groundwater
- characterization of geochemical conditions (e.g., pH, redox potential)

Sketch of measuring principle



Requirements and application range ("operating windows")

see Fact Sheet 8: Direct Push: General description of technology

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- drilling
- installation of permanent groundwater observation wells

Advantages

- minimal-invasive method (minimal changes of in-situ conditions)
- fast depth discrete or continuous sampling (depending on the used tools)

- very flexible and mobile equipment
- large variety of different tools and samplers are available to meet site specific requirements
- cost reduction (usually more measurement points at a given budget accompanied with an increased spatial resolution due to more sampling points and higher data density at a site)

Limitations compared to conventional methods

- limited application range compared to drillings in terms of available diameters and maximum penetration depths
- limited to unconsolidated sediments (not applicable in hard rock)
- limitations in sampling volumes (for groundwater and soil sampling) due to max. probing diameter
- only capable for low flow groundwater sampling

State of development

Field applicability: commercially available sampling tools are generally well developed; some tools are more common than those designed for special applications regarding the type of contamination or specific site conditions

Equipment provider (selected): Röhrenwerk Kupferdreh Carl Hamm GmbH (Germany), Eijkelkamp Agrisearch Equipment (Netherlands), Solinst Canada Ltd. (Canada), Geoprobe® (USA), AMS Inc. (USA)

References (general overview):

Dietrich, P. & Leven, C. (2006): Direct push-technologies. In: Kirsch, R. (Ed.): Groundwater geophysics. A tool for hydrogeology. Springer, Berlin, 321-340.

Hofmann, T., Darsow, A., Groning, M., Aggarwal, P., & Suckow, A. (2010): Direct-push profiling of isotopic and hydrochemical vertical gradients. Journal of Hydrology 385 (1-4): 84-94.

Jacobs, J.A., Kram, M., & Lieberman, S. (2000): Direct-push technology sampling methods. In: Lehr, J. (ed.): Standard Handbook of Environmental Science, Health, and Technology, McGraw Hill, New York, pp. 11.151–11.163.

Leven, C., Weiß, H., Vienken, T., & Dietrich, P. (2011): Direct Push technologies—an efficient investigation method for subsurface characterization. Grundwasser 16 (4): 221-234.

McCall, W., D.M. Nielsen, S. Farrington, & T.C. Christy (2005): Use of direct-push technologies in environmental site characterization and ground-water monitoring In: Nielsen, D.M. (ed.): The Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring, 2nd ed., CRC Press, Boca Raton, pp. 345–472.

Pitkin, S. E., Cherry, J. A., Ingleton, R. A., & Broholm, M. (1999): Field Demonstrations Using the Waterloo Ground Water Profiler. Ground Water Monitoring & Remediation 19 (2): 122-131.

Smolley, M., & Kappmeyer, J. C. (1991): Cone Penetrometer Tests and HydroPunch® Sampling: A Screening Technique for Plume Definition. Ground Water Monitoring & Remediation 11 (2): 101-106.

Tillman, N., Leonard, L. (1993): Vehicle mounted direct push systems, sampling tools and case histories: an overview of an emerging technology - Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration. Ground Water Management 17: 177–188.

U.S. Environmental Protection Agency – U.S. EPA (1997): Office of Underground Storage Tanks: Expedited Site Assessment Tools for Underground Storage Tank Sites: A Guide for Regulators. EPA 510-B-97-001.

U.S. EPA (2005): Office of Solid Waste and Emergency Response: Ground Water Sampling and Monitoring with Direct Push Technologies. EPA 540/R-04/2005.

Expenditures: dependent on the tools to be applied

Contact person

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Direct Push tools for hydrostratigraphic characterisation	**Fact Sheet No: 11**

Main objectives

- Delineation and characterisation of small scale hydrogeological structures based on vertical profiles of the hydraulic conductivity (K) distribution

Brief description

Main principle

All Direct Push (DP) methods for hydrostratigraphic characterisation are based on the measurement of fluxes into or out of the aquifer system causing a (temporary) alteration of natural aquifer conditions by measuring the related or induced response (e.g., changes in pressure heads). In this regard, some methods are based on the commonly applied well based methods which were adopted or integrated into DP technologies.

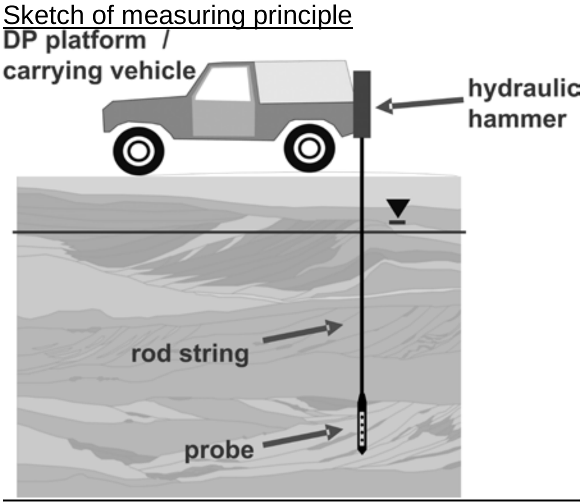
In combination with well pumping tests, temporary DP wells can be used to increase the number of observation points leading to a higher certainty concerning the estimation of K. The DP slug test (DPST; Butler, 2002) an adoption of the multilevel slug tests to DP technologies is able to provide K estimates on a high vertical resolution. The injection based methods such as the DP Injection Logging (DPIL) approach and the DP Permeameter (DPP) are based on water injection into the aquifer system by measuring either the pressure that is required for the injection or the induced pressure head changes in the tested aquifer section. Both methods are still under development but were already proven in several field tests and fundamental investigations (e.g., Butler et al., 2007; Dietrich et al. 2008; McCall et al., 2009)

Main results

Depending on the specific tools the following results can be obtained:

- information about relative vertical variations in K (DPIL approach)
- semi-continuous (vertical profiles of depth discrete measurements) or depth discrete estimation of absolute K values (DPST, DPP)

Sketch of measuring principle



Requirements and Application range ("operating windows")

Site requirements

- Operation media: unconsolidated sediments, all measurement methods are predominantly designed for applications in the saturated zone
- Infrastructure requirements: water supply for injection methods, power supply for e.g., pumps used for the water injection

Data/information necessary for reliable interpretation of results

- Lithological information e.g., from drill cores (sieve analysis) and/or information from other hydrogeological methods (e.g., well based slug tests, flow meter measurements) can be advantageous for cross-checking or interpretation of DP results

- Depth to water table is required for data analysis

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Drilling and/or soil sampling and consecutive sieve analysis
- other (hydro)geological well based investigation methods (e.g., pumping tests, flow meter measurements)

Advantages

- in situ measurements of hydraulic parameters without installation of permanent wells (reduction of time and effort compared to core drilling, sieve analyses and well installation)
- provides estimates of K on a high vertical resolution due to small integral scales (measurement or support volumes)

Limitations compared to conventional methods

- if injection and pressure (heads) are measured at the same point the estimates of K can be significantly underestimated due to a compaction zone caused by the advancement of the DP probe
- the DPIL approach does not provide absolute values of K, which may limit the worth of datasets for site characterisation
- the vulnerable equipment of the DPP (pressure transducer) may decrease the applicability in rough environments

State of development

Field applicability: especially the DPST is well developed, DPIL and DPST are fully field applicable, robust and commercially available, whereas the DPP is still in development status

Equipment provider (selected):

Terra – Direct GbR (Germany):

- Direct Push Slug Test
- Direct Push Injection Logging
- Direct Push Permeameter currently in development in collaboration with the Helmholtz Centre for Environmental Research – UFZ (part of the ModelPROBE project)

Geoprobe® (USA):

- Direct Push Slug Test
- Direct Push Injection Logging – labeled as Hydraulic Profiling Tool (HPT)Geoprobe®

References (selected):

Butler, J. J., Healey, J. M., McCall, G. W., Garnett, E. J., & Loheide, S. P. (2002): Hydraulic tests with direct-push equipment. Ground Water 40 (1): 25-36.

Butler, J.J. Jr., Dietrich, P., Wittig, V., & Christy, T. (2007): Characterizing hydraulic conductivity with the Direct-Push Permeameter. Ground Water 45 (4): 409-419.

Dietrich, P., Butler, J.J. Jr., & Faiß, K. (2008): A Rapid Method for Hydraulic Profiling in Unconsolidated Formations. Ground Water 46 (2): 323-328.

Geoprobe® (2006): Hydrostratigraphic characterization using the Hydraulic Profiling Tool (HPT): Standard operating procedure. Technical Bulletin: MK3099.

Liu, G., Butler, J., Reboulet, E., & Knobbe, S. (2012): Hydraulic conductivity profiling with direct push methods. Grundwasser 17 (1): 19-29.

McCall, W., Christy, T. M., Christopherson, T., & Issacs, H. (2009): Application of Direct Push Methods to Investigate Uranium Distribution in an Alluvial Aquifer. Ground Water Monitoring & Remediation 29 (4): 65-76.

Expenditures: dependent on the tools to be applied

Contact person

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Direct Push tools for geotechnical applications	Fact Sheet No: 12

Main objectives

- Definition and delineation of subsurface stratigraphic and lithological units
- estimation of geotechnical parameters

Brief description

Main principle

The main principle is based on the vertical profiling of parameters related to the static (Cone Penetration Test) or dynamic (Standard Penetration Test) advancement of standardized probes. The static advancement during a Cone Penetration Test (CPT) is based on pushing the probe with a constant penetration rate by using the static weight of the penetration vehicle. During the advancement the forces on the probe tip (tip resistance) and the friction sleeve (sleeve friction) are measured continuously and simultaneously. In contrast, the standard penetration test is based on the dynamic advancement with strokes from a falling weight. The number of strokes that is required to advance the probe over a predefined length is then used to obtain the vertical distribution of geotechnical parameters. CPT is generally more common in environmental site characterisation, the SPT (not a focus of this Fact Sheet) is more common in subsoil investigations. A wide range of additional probe extensions and integrated sensors are available for CPT probes which can provide further information about the following subsurface parameters:

- pore water pressure (Piezocone – CPTu)
- electrical conductivity (Resistivity Cone – RCPT)
- seismic wave velocities (Seismic Cone – SCPT)
- chemical parameters (e.g., pH and redox potential)
- natural γ radiation
- temperature

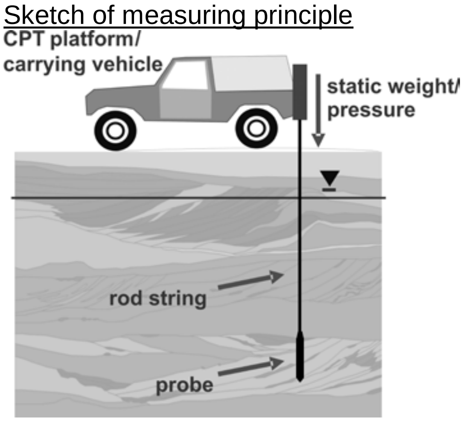
Main results

High resolution (cm scale) vertical profiles of the main parameters, sleeve friction and tip resistance, provide:

- location and characterization of subsurface units along vertical profiles
- further characterization and classification of these subsurface units in terms of several soil types/characteristics generally based on empirical relationships
- a rough estimation hydraulic conductivity based on empirical relationships with grain size distributions
- estimation of geotechnical parameters, such as undrained shear strength (s_u) or the effective inner friction angle (ϕ')

The uses of additional probe extensions allow for measurements of e.g., pore water pressure (CPTu) or electrical conductivity (RCPT) which generally assist the interpretation of CPT data.

Sketch of measuring principle



Requirements and Application range ("operating windows")

Site requirements

- Operation media: unconsolidated sediments (saturated/unsaturated), application of CPT in sediments containing coarse gravel or cobbles/boulders is not recommendable due to the high risk of probe loss or damage

Data/information necessary for reliable interpretation of results

- Geology: data from drilling cores and/or sieve analysis is advantageous for cross-correlation or site specific calibration of DP results

Standing related to other methods (Chances and limitations for application)

Substitution and complement to conventional methods

- drilling
- depending on specific application (hydro)geological investigation methods (e.g. surface geophysics, soil sampling and sieve analysis)

Advantages

- compared to core drilling and soil sampling time and effort for the delineation of subsurface structures is generally reduced
- high vertical resolution (down to the cm-scale)
- measurements of parameters are performed in situ
- capable for real time measurements, useful for on site decision making
- compared to other DP applications CPT is more standardized accompanied with a higher regulatory acceptance and a vast number of commercial service
- a wide range of different probe extensions and configurations are available that allow for the determination of numerous parameters with only one probing

Limitations compared to conventional methods

- parameter estimations based on empirical relationships can be non-unique, site specific or to complex for an on-site interpretation
- CPT is a push only application which may require more specific or heavier equipment
- the use of CPT in sediments containing coarse gravel or cobbles/boulders is not recommendable due to the high risk of probe damage or loss

State of development

Field applicability: state-of-the-art method, well standardized application

Equipment provider (selected): GeoMil (Netherlands), Envi (Sweden), Geoprobe® (USA)

References and external standards (excerpt):

DIN EN ISO 22476-1 (2009): Geotechnical investigation and testing - Field testing - Part 1: Electrical cone and piezocone penetration tests. Deutsches Institut für Normung e.V., Berlin.

International Society for Soil Mechanics and Geotechnical Engineering - ISSMGE (1999): International Reference Test Procedure for the Cone Penetration Test (CPT). In: Swedish Geotechnical Society (ed.): Cone Penetration Tests - Recommended Standard, Appendix A: Tyck-Center, Linköping.

Lunne, T., Robertson, P.K., & Powell, J.J.M. (1997): Cone Penetration Testing in Geotechnical Practice. Spon Press, New York, 312 pp.

Meigh, A.C. (1987): Cone Penetration Testing: methods and interpretation. Butterworths, London, 144 pp.

Schmertmann, J.H., 1978. Guidelines for cone penetration test, performance and design. In: U.F.H. Administration (Ed.), Washington D.C., pp. 145.

Expenditures: dependent on the tools to be applied

Contact person

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Direct Push tools for hydro-geochemical screening	Fact Sheet No: 13

Main objectives

- qualitative and semi-quantitative screening of volatile and semi-volatile organic compounds in the subsurface along vertical profiles

Brief description

Main principle

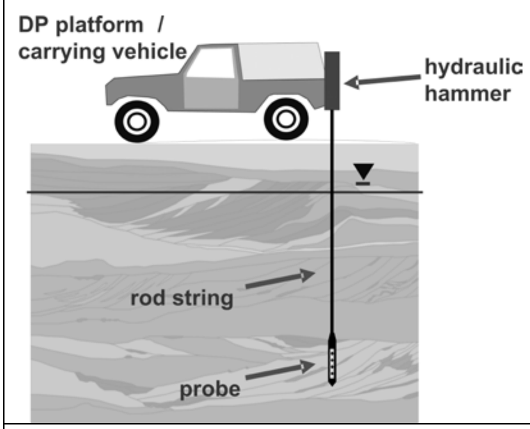
Two major principles are used for the Direct Push (DP) tools for hydro-geochemical screening. The first principle is based on Laser Induced Fluorescence (LIF) spectroscopy. These tools use ultraviolet light pulses to stimulate the fluorescence of petroleum hydrocarbons. By measuring the fluorescence response the LIF based tools are able to detect the occurrence of petroleum hydrocarbons such as diesel, kerosene and gasoline. Since the intensity of the fluorescence is proportional to hydrocarbon concentrations the tools allow for an estimation of the contaminant amount (e.g., Kenny et al., 2000; Kram et al., 2001a; Grundl et al., 2003). Examples for LIF tools are the Rapid Optical Screening Tool (ROST™), the UV-based Optical Screening Tool (UVOST®) tool and the Tar-specific Green Optical Screening Tool (TarGOST®).
The second approach used is based on the mobilization and capture of volatile organic compounds (VOC). In this regard, the Membrane Interface Probe (MIP) can be used for the detection of chlorinated hydrocarbons and BTEX compounds (e.g., Kram et al., 2001b; U.S. EPA, 2004). A heating element in the MIP allows for the mobilization and diffusion of VOC such as PCE, TCE or BTEX through a small semi-permeable membrane located in the sleeve of the probe. A carrier gas stream (e.g., Nitrogen or Helium) behind the membrane transports the mobilized VOC to the surface. At the surface a gas chromatograph (GC) and additional detectors, such as flame ionization detectors (FID) or a photo-ionization detector (PID) are used to detect the VOCs from the gas stream. Further available tools based on a similar approach are the Hydrosparge™ system and the Thermal Desorption Sampler (TDS).
Besides these two main principles further analytical systems for the detection of inorganic contaminants in the subsurface are available (such as e.g., a metal sensor).

Main results

Depending on specific application, following results can be obtained:

- In situ screening (along vertical profiles) of volatile or semi-volatile organic compounds
- depending on the used tool, delineation of several contaminants e.g., PAH

Sketch of measuring principle



Requirements and application range ("operating windows")

Site requirements

- Operation media: unconsolidated sediments (saturated or unsaturated zone)
- Infrastructure requirements: power supply for field laboratory analysis (e.g., GC)

Data/information necessary for reliable interpretation of results

- Geology: lithological data is advantageous for the further interpretation of measurements

- Contamination: Depending on specific application chemical data from water/soil samples or hydraulic data is advantageous for cross-checking and assessment of site specific validity of the used method

Standing related to other methods (chances and limitations for application)

Substitution and complementation of conventional methods

- Soil, soil gas and groundwater sampling

Advantages

- minimal-invasive method (minimal changes of in-situ conditions)
- contaminants are mobilized directly from the soil matrix (in-situ measurement or extraction)
- fast sampling and data acquisition (feasible for on-site analysis and decision-making)
- no drill cuttings are generated, which reduces costs accompanied with regulatory treatment of contaminated samples

Limitations compared to conventional methods

- only qualitative or semi-quantitative analyses are possible
- the performance of the MIP system depends on the condition of the membrane (e.g., damaged or attrited)
- carry over effects (contaminant retention time in the MIP transfer line after passing of e.g., source zones) needs to be recognized in the data interpretation
- the contaminants that can be detected with these tools are limited e.g., LIF tools are not capable for the detection of chlorinated hydrocarbons

State of development

Field applicability: commercially available

Equipment provider (selected): Dakota Technologies, Geoprobe®

References (selected):

Bumberger, J., Radny, D., Berndsen, A., Goblirsch, T., Flachowsky, J., & Dietrich, P. (2012): Carry-Over Effects of the Membrane Interface Probe. Ground Water: in press.

Grundl, T. J., Aldstadt, J. H., Harb, J. G., St. Germain, R. W., & Schweitzer, R. C. (2003): Demonstration of a Method for the Direct Determination of Polycyclic Aromatic Hydrocarbons in Submerged Sediments. Environmental Science & Technology 37 (6): 1189-1197.

Kenny, J. E., Pepper, J. W., Wright, A. O., Chen, Y. M., Schwartz, S. L. & Shelton, C. G. (2000): In: Balshaw-Biddle, K., Oubre, C.L. & Ward, C.H. (eds.): Subsurface monitoring using laser fluorescence, Lewis Publishers, Boca Raton, 2000, 162 p.

Kram, M. L., Keller, A. A., Rossabi, J., & Everett, L. G. (2001a): DNAPL Characterization Methods and Approaches, Part 1: Performance Comparisons. Ground Water Monitoring & Remediation 21 (4): 109-123.

Kram, M. L., Lieberman, S. H., Fee, J., & Keller, A. A. (2001b): Use of LIF for Real-Time In-Situ Mixed NAPL Source Zone Detection. Ground Water Monitoring & Remediation 21 (1): 67-76.

U.S. EPA (1995): Rapid Optical Screen Tool (ROST). — Innovative Technology Verification Report EPA/540/R-95/519.

U.S. EPA (2004): Site Characterization Technologies for DNAPL Investigations. Publications on Characterization and Monitoring EPA/542/R04/017.

Expenditures: dependent on the tools to be applied

Contact person

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Compound specific isotope analysis (CSIA)	Fact sheet No. 14

Main objectives

a. Identification of contaminant degradation and degradation pathways
b. Quantification of contaminant degradation
c. Identification of contaminant distribution (sources and sinks of contaminants)

Brief description

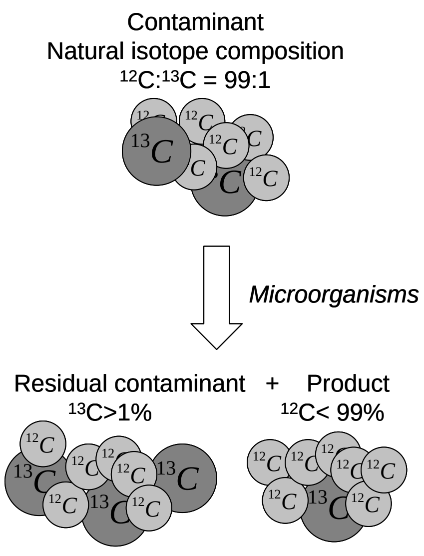
Main principle

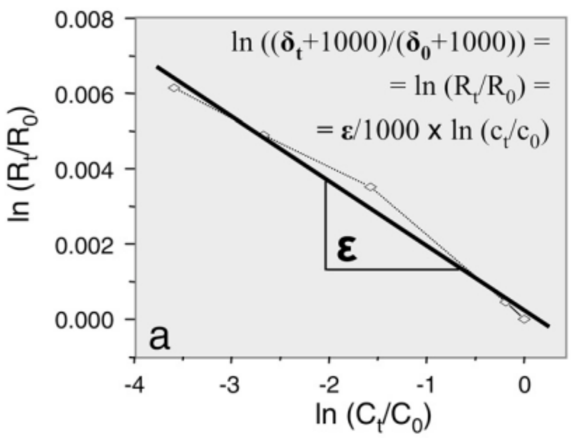
In situ microbial degradation of organic contaminants in the subsurface is assessed by measuring the concentration of a contaminant, and the stable isotope ratio of carbon, hydrogen, chlorine and/or nitrogen atoms in the contaminant molecules. The method is based on the fact that many microbial contaminant degradation reactions result in enrichment of the heavier isotopes in the residual contaminant fraction, and the depletion in the degradation product. The enrichment of stable isotopes compared to the natural/initial isotope ratio is detected by Gas Chromatography coupled to Isotope Ratio Mass Spectrometry (GC-IRMS), and provides information on the extent and nature of ongoing *in situ* microbial contaminant degradation.

Main results

The method can be used to prove and quantify *in situ* microbial degradation, and therefore active Natural Attenuation or Enhanced Natural Attenuation during biostimulation of target contaminants. Furthermore, microbial degradation pathways are characterized via 2D CSIA. CSIA can also be successfully applied for the identification of contaminant distribution, sources and sinks (environmental forensics, plume mapping).

Sketch of measuring principle or concept





Contaminant specific isotope enrichment factors ε for defined degradation conditions are determined in laboratory experiments using the graphic representation of the **Rayleigh equation**. (Eisenmann and Fischer, 2010)

Requirements

Site requirements

a. Operation media: groundwater, surface water, sediments and soil.
b. Infrastructure requirements: subsurface/groundwater has to be accessible either via installed wells or via direct push technologies (see Factsheet No. XX). Usually electricity is required for sampling.

Sample requirements

a. Minimum volume of samples: depending on contaminant concentration and sample preparation, in the range of several mL to a few L.
b. Type of samples: liquid (solid material if the contaminants are sorbed)

c. Handling of samples: inhibition of microbial activity (e.g. NaOH), cooling

Data/information necessary for reliable interpretation of results

a. Geology: information on properties and depths of layers necessary for identifying the sampling points and interpretation of the results
b. Groundwater: basic information on level and flow direction, plume extension, information on gradients, groundwater flow velocity
c. Contamination: basic information on contaminants; enrichment factors for the biochemical pathways are necessary for quantification of degradation
d. Basic biogeochemical data (redox, electron accepting processes) are advantageous for choice of appropriate enrichment factors and interpretation of results

Application range ("operating windows")

(Ideal) operative range for applicability:
List of compounds: BTEX, MTBE/ETBE, chlorinated VOC, RDX, naphthalene, HCHs
Contaminant concentrations > 1 □g/l up to hundreds of mg.
Down gradient sampling locations (wells) are necessary, covering at least one order of magnitude differences in contaminant concentrations
Sample volume: low contaminant concentrations may require sample volumes of ≥ 1 L

Limits for applicability:
Degradation of only minor fractions of the total contaminant load may not be detectable with this method.
CSIA is not applicable if degradation reactions yield only minor isotope fractionation, thus is not suitable for all contaminants and situations.
CSIA is difficult if contamination is present in a NAPL phase or highly concentrated source areas

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
Geochemical approaches
Tracer tests
Metabolite analysis
Biased lab-scale degradation experiments with material from the field (lab-scale microcosms)
In situ-microcosms (BACTRAPs)

Advantages
Evidence and Quantification of *in situ* degradation and Natural Attenuation
Identification of microbial degradation pathways
Groundwater samples can easily be obtained from existing wells or through DP sampling
Sample storage and preparation is easy (gas tight, head-space free, e.g. NaOH stabilized)
Direct sampling and measurement without delay

Limitations
Analytical equipment: GC-IRMS is relatively expensive and requires specific know-how and maintenance
CSIA can be biased by mixing of different groundwater streams and NAPLs
Uncertainty may be introduced by application of laboratory derived enrichment factors

State of development

Field applicability: state of the art for BTEX, chlorinated VOC, HCHs and MTBE/ETBE; all main approaches including 2D CSIA, modelling and pitfalls are already published. Application for other contaminants, e.g. heteroaromatics and RDX, is currently developed.

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Isodetect GmbH
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E-Mail: eisenmann@isodetect.de

References:

Journal publications:

Fischer et al. (2007) Applicability of Stable Isotope Fractionation Analysis for the Characterization of Benzene Biodegradation in a BTEX-contaminated Aquifer. Environ. Sci. Technol. 41:3689-3696.

Fischer et al. (2008) Combined carbon and hydrogen isotope fractionation investigations for elucidating benzene biodegradation pathways. Environ. Sci. Technol. 42:4356-4363.

Fischer et al. (2009) Carbon and hydrogen isotope fractionation of benzene during biodegradation under sulfate-reducing conditions: a laboratory to field site approach. Rapid Commun. Mass Sp. 23:2439-2447.

Manuals, Handbooks and Guidelines:

Eisenmann and Fischer (2010) Isotopenuntersuchungen in der Altlastenbewertung. Handbuch Altlastensanierung und Flächenmanagement: 60. Aktualisierung der 3. Auflage, Januar 2010. Franzius, Altenbockum, Gerhold (Eds.); Verlagsgruppe Hüthig Jehle Rehm, München.

US EPA (2008) A guide for assessing biodegradation and source identification of organic ground water contaminants using Compound Specific Isotope Analysis (CSIA). EPA 600/R-08/148, Office of Research and Development, National Risk Management Research Laboratory, Ada(OK), USA. http://www.epa.gov/nrmrl/pubs/600r08148/600r08148.pdf

Expenditures: GC-IRMS and trained personnel for maintenance and analysis needed;
Prices for CSIA from commercial providers: ca. 200-500 USD per sample

Contact person

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Remarks

Classical BACTRAPs (in situ microcosms)	Fact sheet No. 15

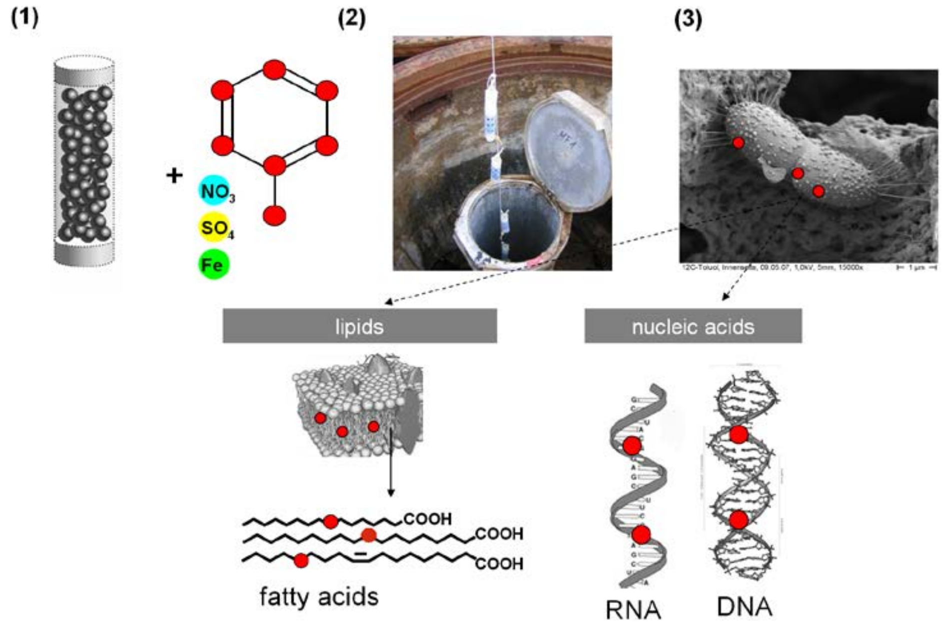
Main objectives * (max. 3; see annex)
Identification of contaminant degradation
Assessment of microbial activity
Quantification of microbial activity

Brief description

Main principle
Assessing the potential for microbial contaminant degradation at contaminated field sites is crucial for the evaluation of remediation options. Therefore, the in situ microcosm system (BACTRAP®) has been developed. These in situ microcosms consist of a perforated Teflon tube filled with an activated carbon matrix and closed by glass wool stoppers. ^{13}C labelled contaminants are loaded on the activated carbon and the microcosms are then exposed in groundwater wells. Following a usually 6 week long exposure, the microcosms are taken out again and the composition of the colonising bacteria on the activated carbon matrix is analysed by means of phospholipid fatty acid (PLFA) analysis.

Main results
Evidence for microbial contaminant degradation activity can be provided by the method. Furthermore, by supplying BACTRAPs with terminal electron acceptors (Fe, NO_3, SO_4), degradation potentials under various redox conditions can be evaluated. In addition, the microcosms can be used for continuous monitoring during a monitored or enhanced natural attenuation site remediation approach.

Sketch of measuring principle or concept



Picture modified from Stelzer (2008)

1. BACTRAPs are loaded with ^{13}C enriched substrate (and terminal electron acceptors)
2. exposure inside the contaminated aquifer
3. ^{13}C label is integrated into degrading microbes and can be identified by phospho-lipid-fatty-acid (PLFA) analysis using gas chromatography-mass spectrometry (GC-MS), (or DNA/RNA analysis for specific microorganisms)

Requirements

Site requirements (not applicable for mathematical/statistical methods)
a. Operation media: groundwater

b. Infrastructure requirements: groundwater monitoring wells

Sample requirements (not applicable for in-situ methods)
None

Data/information necessary for reliable interpretation of results

e. Geology: -
f. Groundwater: level and flow direction
g. Contamination: main contaminants which are likely, plume extension
h. Basic biogeochemical data: data on electron acceptors

Application range ("operating windows")

(Ideal) operative range for applicability

- Applicable in all aquifers accessible by groundwater monitoring wells
- Applicable for BTEX, MTBE, MCB and all compounds available with stable isotope labels (^{13}C, ^{15}N)

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Geochemical approaches
- Tracer tests
- Metabolite analysis
- Lab-scale microcosms

Advantages

- Less bias compared to off-site lab microcosms
- No bias introduced resulting from taking soil or water samples
- No need for taking sediment samples for lab microcosms

Limitations

- Need for exposure in already installed wells
- Long exposure times needed
- Isotope ratio MS needed
- Expensive stable isotope labeled compounds needed

State of development

Field applicability fully applicable and accepted by German and international authorities

Provider Department Environmental Biotechnology, UFZ

Commercial Provider: Isodetect GmbH, Ingolstädter Landstr. 1. D-85764 Neuherberg
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E-Mail: eisenmann@isodetect.de

References

- Geyer R, Peacock AD, Miltner A, Richnow HH, White DC, Sublette KL, Kästner M (2005) Environ Sci and Technol 39:4983-4989.
- Kästner M, Fischer A, Nijenhuis I, Geyer R, Stelzer N, Bombach P, Tebbe CC, Richnow HH (2006) Eng Life Sci 6:234–251
- Kästner M, Richnow HH (2010) in: Timmis KN, McGenity T, van den Meer JR, de Lorenzo V (Hrsg.): Experimental protocols and appendices Handbook of hydrocarbon and lipid microbiology Vol. 5, Part 1, Springer, Berlin, S. 3504-3511

Expenditures 480-580€ per sample

Contact person

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(Department Environmental Biotechnology, UFZ)

Remarks

Also see fact sheet 16 for adaptation of the concept to Direct Push

Direct-Push BACTRAPs (in situ microcosms)	**Fact sheet No. 16**

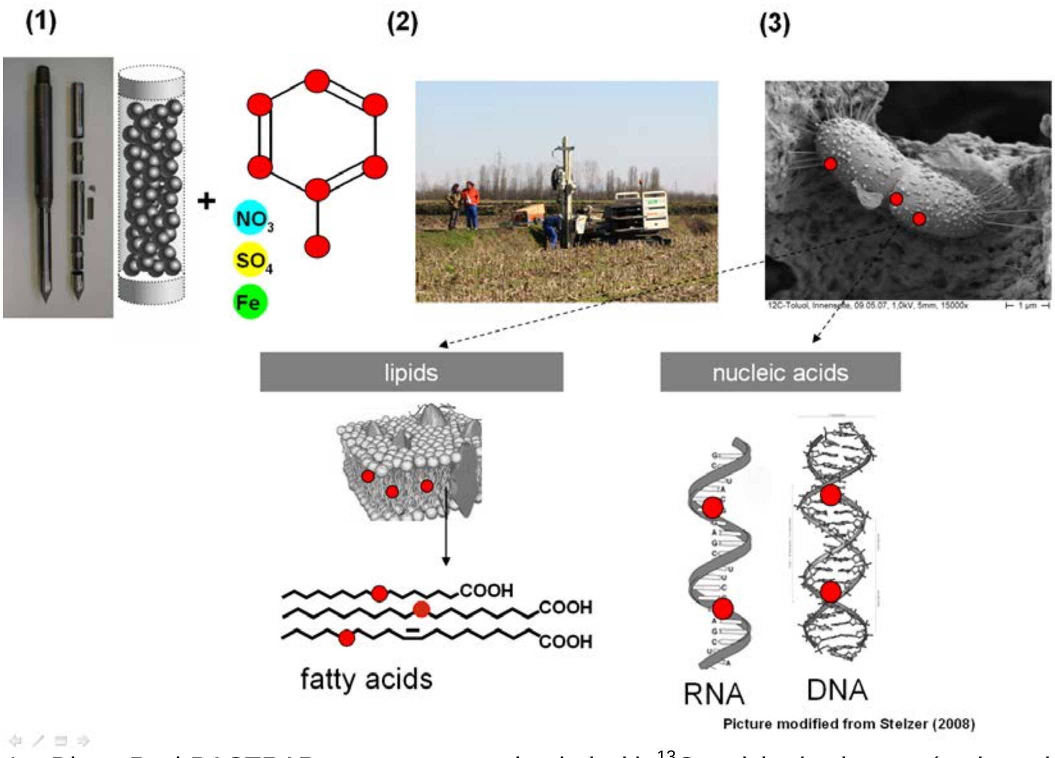
Main objectives * (max. 3; see annex)
Identification of contaminant degradation
Assessment of microbial activity
Quantification of microbial activity

Brief description

Main principle
Assessing the potential for microbial contaminant degradation at contaminated field sites is crucial for the evaluation of remediation options. Therefore, the in situ microcosm system (BACTRAP®) has been developed. In order to overcome some limitations of the "classical" BACTRAP approach (need for established wells, no access to the vadose zone), the system has been adapted to the Direct-Push technology. This allows for applicability at field sites without monitoring wells and also inside the vadose zone.

Main results
Evidence for microbial contaminant degradation activity inside aquifers as well as in the vadose zone can be provided by the method. Furthermore, by supplying DP-BACTRAPs with terminal electron acceptors (Fe, NO_3, SO_4), degradation potentials by various redox processes can be evaluated. Also, the microcosms can be used for repeated monitoring during a monitored or enhanced natural attenuation site remediation approach.

Sketch of measuring principle or concept



4. Direct-PushBACTRAPs prototypes are loaded with ^{13}C enriched substrate (and terminal electron acceptors)
5. exposure inside the contaminated aquifer/soil by means of Direct-Push rod probe (prototype)
6. During microbial degradation the ^{13}C label is integrated into degrading microbes, which can be identified by phospholipid fatty acid (PLFA) or DNA/RNA analysis for specific groups of microorganisms

Requirements
Site requirements (not applicable for mathematical/statistical methods)

a. Operation media: unconsolidated material, aquifer and vadose zone
b. Infrastructure requirements: energy supply (electricity or fuel), Direct-Push machine and tubing

Sample requirements (not applicable for in-situ methods)

None

Data/information necessary for reliable interpretation of results

i. Geology: -
j. Groundwater: level and flow direction
k. Contamination: main contaminants which are likely, plume extension

Basic biogeochemical data: data on electron acceptors (inside aquifer)

Application range ("operating windows")

(Ideal) operative range for applicability

- Applicable on all sites in all depths accessible by Direct-Push device
- Applicable for BTEX, MTBE, MCB and all compounds available with stable isotope labels (13C, 15N)

See also "classical" approach (fact sheet # 15)

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Geochemical approaches
- Tracer tests
- Metabolite analysis
- Lab-scale microcosms
- Classical BACTRAPs

Advantages

- Less bias compared to off-site lab microcosms, avoiding bias resulting from obtaining soil or water samples
- No need for obtaining soil samples by drilling and consequently no need for lab microcosms anymore
- No wells or infrastructure necessary at the site
- As many BACTRAPs as desired are easily installed
- Installation of BACTRAPs can be done simultaneously with water level determination

Limitations

- Direct push machine is needed
- Pushing rod has to stay at the site for the exposure time
- Long exposure times needed
- Isotope ratio MS needed
- Expensive stable isotope labeled compounds needed

State of development

Field applicability prototype field ready, is currently tested

Provider Department Environmental Biotechnology, UFZ

References (from classical BACTRAPs)

- Geyer R, Peacock AD, Miltner A, Richnow HH, White DC, Sublette KL, Kästner M (2005) Environ Sci and Technol 39:4983-4989.
- Kästner M, Fischer A, Nijenhuis I, Geyer R, Stelzer N, Bombach P, Tebbe CC, Richnow HH (2006) Eng Life Sci 6:234–251
- Kästner M, Richnow HH (2010) in: Timmis KN, McGenity T, van den Meer JR, de Lorenzo V (Hrsg.): Experimental protocols and appendices Handbook of hydrocarbon and lipid microbiology Vol. 5, Part 1, Springer, Berlin, S. 3504-3511

Expenditures to be determined

Contact person

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Remarks

Also see fact sheet 15 for classical BACTRAPs

Monitoring of dechlorinating microorganisms by FISH and Real Time PCR	Fact sheet No. 17

Main objectives

- Assessment of microbial activity
- Identification of contaminants distribution by identification/quantification of key-degrading microorganisms

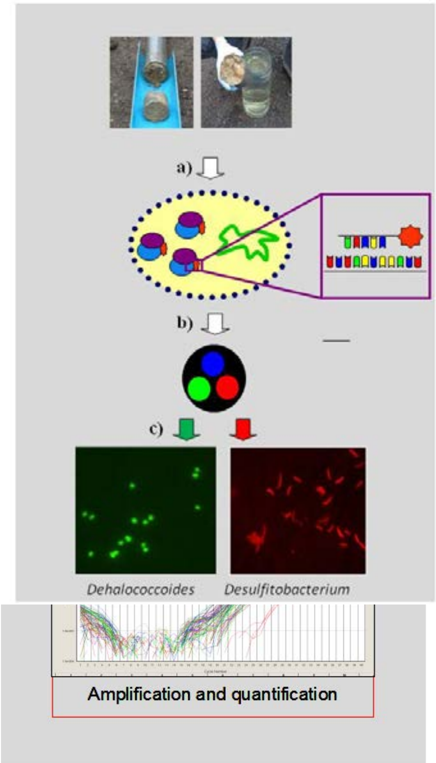
Brief description

Main principle

a) Fluorescent in situ hybridization techniques (FISH and CARD-FISH) have proven to be a powerful molecular method for identification, visualization, and quantification of organisms of interest in microbial communities. They allow for the identification, performed in the laboratory, of individual microbial cells in their natural habitat (for which the term “in situ” has been coined) and rely on the specific hybridisation of the nucleic acid probes to the intracellular ribosomal RNA.
b) Quantitative real-time polymerase chain reaction (qPCR) for nucleic acid analysis is applied for determining gene and transcript numbers within environmental samples. Differently from the traditional PCR, qPCR is a quantitative tool and quantification is achieved by detection of a fluorescent dye that accumulates in direct proportion to the yield of amplified PCR products. A statistically significant increase of target 16S rRNA gene would be therefore indicative of an increase in the number of target organisms.

Main results

- Assessment of microbial degradation activity by defining the distribution of dechlorinating microorganisms, in both contaminated groundwater and soil.
- The distribution of key-degradative bacteria in the aquifer provides a mapping potential for the contamination and gives a direct insight on the presence of favourable conditions for natural attenuation.



Sketch of measuring principle or concept

FISH (Fluorescence In Situ Hybridization) uses fluorescently-labeled nucleic acid probes targeting to complementary rRNA within cells. Water or soil samples are fixed in formaldehyde to keep cell integrity and RNA content (a). The cumulative signal from multiple probe-target binding events after hybridization (b) provides the basis for sequence-specific fluorescence of target cells which are visualized by epifluorescence microscopy (c).

CARD-FISH (CAtalysed Reported Deposition–FISH) CARD is a variant of conventional FISH and is based on the deposition of a large number of labeled tyramine molecules by peroxidase activity. If fluorochrome-labeled tyramides are used, numerous fluorescent molecules can be introduced at the hybridization site *in situ*. This results in greatly enhanced FISH sensitivity compared to probes with a single fluorochrome.

Sketch of measuring principle or concept

Polymerase Chain Reaction (PCR) approach allows specific DNA/RNA sequences, representing target microorganisms or catabolic genes, to be detected in environmental samples. The method requires the nucleic acids extraction from filtered groundwater (or directly from soil samples) followed by their amplification by PCR.

Real Time PCR allows the sensitive, specific and reproducible quantification of nucleic acids from key-degrading bacteria by targeting 16S rRNA gene or specific functional genes involved in contaminant biodegradation process (i.e. reductive dehalogenase).

The method is also used to monitor the expression level of specific functional genes and provides the direct evidence of the occurrence of contaminant degradation processes in environmental samples.

Requirements

Site requirements (not applicable for mathematical/statistical methods)
a. Infrastructure requirements (e.g. electricity for water sampling and filtration)

Sample requirements (not applicable for in-situ methods)
a. Water and soil samples (~ 20-30 ml or 1-5 g respectively) need to be fixed in formaldehyde for FISH/CARD-FISH analysis. Larger groundwater volumes are required for qPCR (1-2 L)
b. Samples need to be stored at -20°C after the sampling.

Data/information necessary for reliable interpretation of results
a. Contamination: chemical data from water/soil samples can be advantageous for cross-checking.

Application range ("operating windows")

- Both methods can be easily applied on either water or soil samples
- Limits for applicability: qPCR application may be limited by drawbacks due to DNA extraction and PCR inhibition

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
The available methods (i.e. DGGE, PLFA) are not quantitative or not provide specific/reliable information. Their application is declining due to the largest employment of qPCR.

Advantages
Compared to conventional methods, the in situ molecular tools provide the quantitative estimation of the target microorganisms and provide additional information on cell activity and on the actual biodiversity and structure of the whole mixed microbial communities.

Limitations
Some limitations can be due to the presence of high particulate loads, that highly interfere with visualization by epifluorescence microscopy, and to the usual low activity state of bacteria (low ribosome content and consequently low fluorescence signals). However these limitations have been shown to be adequately circumvented by introducing samples pre-treatments (i.e. cell extraction method) and by utilizing methodological improvements of FISH (i.e. CARD-FISH).

State of development

Field applicability Both techniques have been already applied on field samples within the project.

References

- Rossetti S., Aulenta F., Majone M., Crocetti G., Tandoi V. (2008). "Structure analysis and performance of a microbial community from a contaminated aquifer involved in the complete reductive dechlorination of 1,1,2,2-tetrachloroethane to ethane". *Biotechnology and Bioengineering* 100 (2), 240-249.
- Fazi S., Aulenta F., Majone M., Rossetti S. (2008). "Improved quantification of *Dehalococcoides* species by fluorescence in situ hybridization and catalyzed reporter deposition". *Systematic and Applied Microbiology*, 31(1), 62-67.

- Matturro B., Rossetti S. (2011) "Biomonitoring of key-degrading bacteria in a chlorinated solvents contaminated aquifer". Submitted to *Journal of Biotechnology*.

Expenditures (range of costs, personnel needed, special skills of personnel)

Skill on microscopic analysis and cell counting are required for FISH analysis. However, the quantification can be further simplified by analyzing the hybridized liquid samples by adopting an automated counting procedure (i.e. by flow cytometry).

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Bioassays for the Assessment of Ecotoxicity	**Fact sheet No. 18**

Main objectives

- Identification of contaminants distribution (source, unsaturated zone or groundwater);
- Identification of contaminants degradation or retention;

Brief description

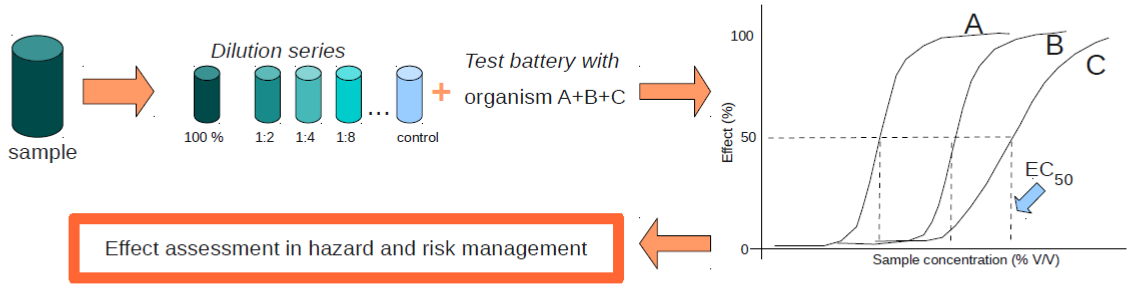
Main principle

The major aim of ecotoxicity assessment is the provision of tools such as bioassays for the detection of effects from contamination, and the assessment of effects as deleterious to ecological systems. Bioassays complement chemical analytical data in that chemical exposure is typically not directly linked to biological effects, while biological responses mostly do not reveal the causing agents. If the intention of risk assessment lies in the protection of goods such as toxicologically acceptable water for human consumption, functioning ecosystem services (biodegradation) or production and utilization of animal and plant products, short-term bioassays might prove useful. Since different organism may respond with varying sensitivity to different chemicals, it is common to apply test batteries with organisms representing different trophic levels or physiological competences. Different ecotoxicological assays such as the luminescent bacteria assay, the fish egg toxicity assay and the phytotoxicity assay with unicellular green algae provide reliable responses upon exposure to organic groundwater pollutants.

Main results

Given a standardised test protocol and sufficient controls to exclude confounding factors, results depend only on the contaminant or mixture of contaminants present in the sample of interest. The observations of bioassays are typically presented as impairment of the observed biological property, and vary between 0% (no effect) and 100% (full effect compared to a negative control). Causal relationships and thus extrapolation between chemical information (compounds present) and biological effects can be established if concentration-effect-relationships are available. Establishment of causality may require additional information in the case of mixtures (Altenburger et al. 2004).

Sketch of measuring principle or concept



EC50 or LC50: the concentration of contaminant or sample which affects 50% of the test organisms (effect could be anything from growth to death)

Requirements

Site requirements

- Operation media: surface- and groundwater, soils or sediments
- Infrastructure requirements: depending on sampling technique, e.g. direct push/ ground water pump; the only requirement is that a sufficient sample volume for analysis can be obtained

Sample requirements

- Minimum volume of samples depends on the test design; 0.5 to 1 L is recommended for a single testing of a water sample with a battery of the above mentioned assays.
- Type of samples: surface- and groundwater, soils or sediments

- Handling of samples: depends on contamination and sampling site, typically only short-term storage is recommended

Data requirements for reliable interpretation of results

- Geology: Depends on sample type: For groundwater samples mineralogy and particle density is highly important; for solid test materials, soil characteristics need to be known
- Groundwater: flow direction, flow velocity, plume characteristics
- Contamination: quality and quantity of substances/contaminants which are likely to occur
- Basic biogeochemical data: redox potential, pH, organic matter, oxygen and carbon dioxide, conductivity

Application range (Limits for applicability)

Confounders (e.g. H_2S, extreme pH regimes or high salt concentrations) may influence test results, but corrections may be feasible.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
Ecotoxicological assessment may complement or substitute chemical analysis, depending on the aim of the study.
Advantages
Results directly indicate bioavailability and biological activity of contaminants. Not only single substances arer detected, but rather combined effects of compound mixtures are observed. The measured effects may be used directly for the prediction of effects on the biotic environment in hazard or risk assessment or in process control, e.g. the quality evaluation of management measures.
Limitations
Organisms always have specific sensitivity profiles for different chemicals (comparable to chemical analytical techniques which are only able to quantify specific chemicals). Thus, false negative indication of toxicity may occur when relying on a too limited range of assays. The identification of chemicals causing the toxicity is rather laborious.

State of development

Field applicability: Assays are developed for standard laboratory experiments
Provider: Specialized ecotoxicology laboratories are providers of most standardized bioassays
References: Middaugh et al. 1991, Altenburger et al. 1990 & 2004, Küster et al. 2003 & 2004
Expenditures: Specifically trained personnel for sample provision, bioassay performance and data interpretation is required

Contact person

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Remarks

For a specific description of bioassays adapted for the study of volatile or sorptive organic compounds in groundwater samples, see Manual XX.

Cyclodextrin extractions for the determination of bioaccessible contaminants in soil	Fact sheet No. 19

Main objectives

Quantification of the microbially degradable fraction of organic pollutants in soil

Brief description

Main principle

The quantification of organic contaminant bioaccessibility in soils and sediments is essential for the risk assessment and remediation of contaminated land. Within this framework, practitioners require standardised protocols. Cyclodextrins are a group of macrocyclic compounds that can form inclusion complexes with organic xenobiotics. This occurrence can be exploited to measure the labile/rapidly desorbable compound fraction, which correlates with microbial degradation (Fig 1).

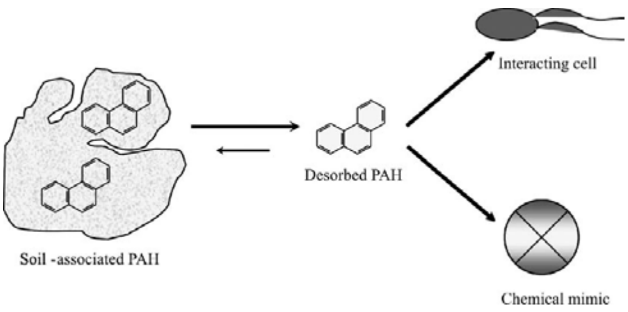

Figure 1. Theoretical mechanisms for the biodegradation of phenanthrene and a putative chemical mimic allowing the determination of biodegradation end-points

We present a rapid and easily reproducible hydroxylpropyl-β-cyclodextrin (HPCD) shake extraction technique (Fig 2) that has been experimentally demonstrated to directly predict microbial availability and degradation in soil.

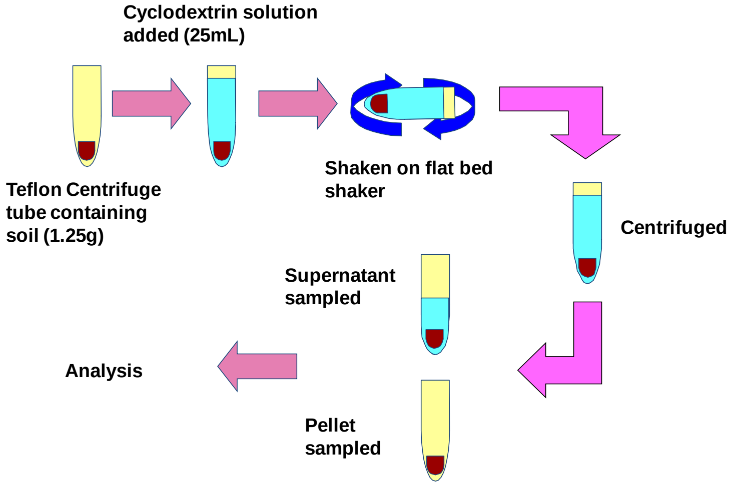

Figure 2. Schematic of HPCD extraction method

Following extraction and sample clean-up, the pollutant concentration can then be measured analysing (i) the HPCD solution directly or (ii) the residual soil concentration following the HPCD extraction, using an appropriate solvent extraction on the soil pellet and then quantified by GC-MS, GC-ECD, HPLC-Fluorescence or HPLC-MS. This method can provide practitioners with both an indication of bioremediation end-points and may be valuable in the risk assessment of contaminated land.

Main results

The following results are key results:

1. the HPCD extraction directly describes the amount of pollutant that may be biodegraded in soil;

2. the biodegradable fraction is described the rapidly desorbable fraction of organic pollutants in soil, as described by the HPCD extraction;
3. the assessment of bioremediation endpoints.

Requirements
1. The methods require typically sample masses of 1-10 g or sieved soil
2. Samples must be shaken for a minimum of 6 hours

Application range ("operating windows")
1. Concentration of cyclodextrin solution should be ~60 mM
2. The cyclodextrin extraction technique is most applicable to PAH contaminated soils
3. The method is not suitable for highly volatile organic contaminants

Standing related to other methods (Chances and limitations for application)

This method may be used in place of aqueous extractions, such as $CaCl_2$' polar solvents, such as methanol and hydrophobic resin extraction, such as Tenax or XAD, as a measure of pollutant bioaccessibility in soil. The HPCD extraction technique is a more reliable predictor of microbial degradation of organic pollutants in soils than aqueous, polar solvent and XAD extractions; however, the Tenax method has been shown to be equally as effective.

Advantages: The method is a simple aqueous-based shake extraction. Separation of the HPCD solution and soil is achieved by centrifugation. It is can be used with many soil types, across a large range of concentrations and is highly reproducible.

Limitations: The method is not applicable to (1) very volatile analytes (e.g. BTEX compunds), (2) very unstable chemicals and (3) large molecular weight pollutants (heavily halogenated compounds, very large PAHs).

State of development
Field applicability: The HPCD extraction technique has been tested on a number field contaminated soils over a range of PAH concentrations and, even in theses chemically complex systems, maintains its predictive capacity for biodegradation. It has recently been offered commercially in the UK by Alcontrol Geochem to contaminated land consultants, particularly those considering bioremediation.

Selected References
McAllister, L. and Semple, K.T. 2010. Bioavailability of organic pollutants in the environment. *In* Methods in Molecular Biology – Bioremediation. Edited by Stephen Cummings. Humana Press, New Jersey, pp 1-14.
Rhodes, A.H., McAllister, L.E., Chen, R. and Semple, K.T. 2010. Linking desorption kinetics to phenanthrene biodegradation in soil. *Environmental Pollution* 158, 1348-1353.
Stroud, J.L., Paton, G.I. and Semple, K.T. 2009. Prediction of hexadecane and phenanthrene degradation in the presence of mixed hydrocarbon contaminants in soil using aqueous cyclodextrin extractions. *Chemosphere* 74, 563-567.
Rhodes, A.H., Carlin, A. and Semple, K.T. 2008. Impact of black carbon in the extraction and mineralisation of phenanthrene in soil. *Environmental Science and Technology* 42, 740-745.

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Contaminant Trap - Isolating and Measuring the Desorption Resistant Pool of Soil Pollutants	Fact sheet No. 20

Main objectives

- Quantification of “desorption resistant” contaminant concentration in a soil sample
- Prediction of the lower boundary of pollutant level, which can be reached by (bio)remediation
- Research tool for the investigation of exposure and risk originating from desorption resistant soil pollutants

Brief description

<u>Working principle</u>
A soil suspension is incubated in a contaminant trap glass (Figure 1) for the continuous trapping of contaminants during their desorption from the soil matrix. Cyclodextrin serves here as a diffusive carrier, and a composite of activated carbon and silicone as a diffusive sink. The remaining contaminants in the soil can then be measured by conventional extraction and instrumental analysis.

<u>Main results</u>
- The contaminant trap provides fast trapping kinetics and a high trapping capacity.
- PAH contaminated soils have been incubated in the traps and the PAH concentrations remaining in the soil were determined by exhaustive extraction and compared with a biodegradation experiment. The halting of the biodegradation process before reaching the legal threshold level was well indicated by the contaminant trap.
- The contaminant trap proved to be a practical approach to the isolation and quantification of the desorption-resistant PAH fraction.
- The exposure and toxicity originating from the desorption-resistant PAH fraction, which has been isolated during the incubation in the contaminant traps, is presently under investigation in various exposure and toxicity tests.

Figure 1. The contaminant trap glass. A composite of the silicone PDMS and activated carbon is cast into the bottom of a glass, where it acts as an infinite diffusion sink for polycyclic aromatic hydrocarbons.

Requirements

3. The method requires a very small soil sample (e.g. 5 gram), which however should be representative for the polluted soil under consideration.
4. The contaminant traps need to be made in the laboratory or might be provided by the inventor (presently possible within collaborative research at cost price).
5. The contaminants remaining in the soil can be measured with conventional extraction and analytical techniques including international guidelines.

Application range ("operating windows")

The contaminant trap is applicable to all types of small soil samples. It is crucial to ensure that the soil sample is representative for the polluted soil or site under consideration.

The contaminant trap has been developed and tested with a range of polycyclic aromatic hydrocarbons. The contaminant trap is further expected to be applicable to many other hydrophobic pollutants, for which cyclodextrine works as diffusive carrier and activated carbon as diffusive sink. This is likely the case for instance for several dioxins, brominated flameretardants and organachlorine pesticides.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods. The contaminant trap is designed to isolate and measure the "desorption resistant" fraction (non-accessible). It thus complements other extraction and sampling methods that were designed to measure (bio)accessible concentrations, freely dissolved concentrations and chemical activities.

Advantages. The contaminant trap is designed to determine desorption resistant concentrations, which are difficult to determine with other methods. When using the contaminant trap, no subtraction of concentrations is needed and the method ensures also that a full gradient for diffusion can be maintained. Finally, the method is suited for long term incubations of months or even years.

Limitations. The method is currently tested only for PAHs. It will certainly also work for some of the other soil pollutants, but this requires additional research.

State of development

The contaminant trap glass is fully developed and tested for a range of polycyclic aromatic hydrocarbons. For these pollutants the traps should be ready to be used in research, monitoring and project work.

Field applicability: The method is not meant for *in situ* applications, but it is certainly applicable to field samples.

Provider and Expenditures: The contaminant traps are not yet commercially available. They can be made easily in any laboratory with materials that will cost less than 10 Euro per glass. Within collaborative research they might also be provided at cost price by the inventor (presently possible).

Selected References

- Mayer P, Olsen JL, Gouliarmou V, Hasinger M, Kendler R and AP Loibner. A contaminant trap as a tool for isolating and measuring the desorption resistant fraction of soil pollutants. Environmental Science & Technology 45: 45: 2932–2937.
- Reichenberg F and P Mayer. 2006. Two complementary sides of bioavailability: accessibility and chemical activity of organic contaminants in sediments and soils. Environ Toxicol Chem 25:1239-1245
- Reid, B. J.; Stokes, J. D.; Jones, K. C.; Semple, K. T., Nonexhaustive cyclodextrin-based extraction technique for the evaluation of PAH bioavailability. Environmental Science & Technology 2000, 34: 3174-3179.

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Acknowledgements

The contaminant trap was developed at the National Environmental Research Institute at Aarhus University. This work was financially supported by the European Commission (MODELPROBE, no. 213161) and the Danish Council for Strategic Research (REMTEC).

Equilibrium sampling of organic soil pollutants	Fact sheet No. 21

Main objectives

- Quantification of pollutant freely dissolved concentrations
- Quantification of pollutant chemical activity
- Quantification of pollutant fugacity

Brief description

Main principle

The pollutants are equilibrated between the soil and a micrometer thin layer of silicone polymer. Such equilibrium sampling is normally done in the laboratory but can in principle also be done in the field. The pollutant concentration is then measured by for example GC-MS, GC-ECD, HPLC-Fluorescence or HPLC-MS.

The concentration in the polymer is finally translated into:

- freely dissolved concentration (C_{free}, effective concentration for toxicity and bioconcentration)
- chemical activity (a, energetic state of pollutant, closely linked to baseline toxicity also known as non-polar narcosis)
- fugacity (f, escaping tendency into ideal gas, particularly suited for volatile pollutants)

The best suited equilibrium sampling technique depends on the target analytes:

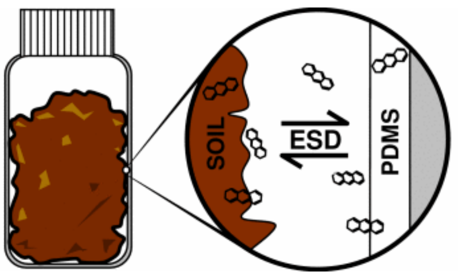
- Silicone coated vials or jars are particularly suited for hydrophobic organic pollutants.
- Headspace Solid Phase Microextraction (HS-SPME) is particularly suited for (semi) volatile pollutants. It can be fully automated and is thus suited for high throughput sampling.

Main results

A range of equilibrium sampling techniques have been developed during the last years. Depending on the specific applications, the following results can be obtained:

- freely dissolved concentrations can be measured and related to toxicity data and threshold levels for soil organisms.
- chemical activities can be measured and related to the empirical level required for baseline toxicity (0.01-0.1). Further these measurements can be used to determine the direction and extent of mass transfer (diffusion and partitioning) within the soil column and also into other media.
- fugacities can be measured to quantify the pollutant partitioning into the gaseous phase. This can be used in venting technologies and in the modeling and prediction of diffusive mass transfer of volatile organic pollutants into buildings.

Sketch of measuring principle:



Drawing of equilibrium sampling device (ESD) for determination of thermodynamic activity by partitioning to micrometer thin polydimethylsiloxane (PDMS).

Requirements

6. The methods require typically sample masses of 5 to 100 gram.
7. The exact mass does not need to be determined.
8. The stability of the sample depends on the properties of the pollutants to be analyzed, and the samples should in some case be stabilized by poisoning of native microorganisms.

Application range ("operating windows") The coated vials technique is particularly suited for highly hydrophobic organic pollutants (Log K_{OW} 3 – 8). Typical analytes include: polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated benzenes, organochlorine pestices (e.g. DDT isomers and lindane) as well as brominated flameretardants. The HS-SPME technique is particularly suited for semi-volatile organic pollutants. Typical analytes include BTEX, alkanes, PCBs, chlorinated benzenes and 2 - 3 ringed PAHs. These methods are not suited for highly volatile pollutants such as chloroethanes and volatile fluorocarbons (CFC, HCFC). SPME methods with adsorptive coatings, headspace sampling methods and purge and trap methods might be applied for such highly volatile analytes.
Standing related to other methods (Chances and limitations for application) Substitution and complementation of conventional methods. Equilibrium sampling techniques can measure C_{free}, a and f. They thus complement conventional analytical methods based on exhaustive extractions that are directed at the measurement of total pollutant concentrations. Advantages. Equilibrium sampling methods provide new and crucial information for the assessment and management of organic soil pollutants, when sorption, diffusion and partitioning are the dominating processes. C_{free} and chemical activities can be used in risk assessment. Chemical activity and fugacity can be used to determine direction and extent of diffusive mass transfer. Limitations. The methods are not applicable to (1) very volatile analytes (e.g. PCE and CFC), (2) very unstable chemicals and (3) large molecular weight pollutants (polymers, proteins and nanoparticles).
State of development Field applicability: Equilibrium sampling techniques have been applied also in the field, but this is normally not operational for the assessment and management of soil pollution. However, some sensors are based on equilibrium sampling into polymer (e.g. E-nose). Such sensors are highly suited for field application but they have generally a much lower sensitivity and/or selectivity. In most cases, a field sample should be brought to the laboratory for equilibrium sampling and analysis. Provider and Expenditures: The coated vials are not yet commercially available, but they can be made easily in any laboratory. The obtained extract can be measured by conventional GC and HPLC methods. SPME devices are available from SUPELCO (approximately 100 Euro per device, which can be used for e.g. 100 samples). Autosamplers to operate SPME are available from e.g. CTC and GERSTEL and they cost generally more than 25 000 Euro. Selected References - Mäenpää K, Leppänen M, Reichenberg F, Figueiredo K & P Mayer. 2011. Equilibrium sampling of persistent and bioaccumulative compounds in soils and sediment - comparison of two approaches to determine equilibrium partition concentrations in lipids. In press in Environ Sci Technol. 45: 1041–1047. - Reichenberg F, Smedes F, Jönsson JÅ & P Mayer. 2008. Vials with polymer coatings of multiple thicknesses for equilibrium sampling of hydrophobic organic compounds in soil. Chem Centr J. 2008, 2:8. - Legind CN, Karlson U, Burken JG, Reichenberg F and P Mayer. 2007. Determining chemical activity of (semi)volatile compounds by headspace solid phase microextraction. Anal Chem 79: 2869-2876. - Reichenberg F and P Mayer. 2006. Two complementary sides of bioavailability: accessibility and chemical activity of organic contaminants in sediments and soils. Environ Toxicol Chem 25:1239-1245 - Mayer P, Tolls J, Hermens JLM and D Mackay. 2003. Equilibrium Sampling Devices: An Emerging Strategy for Monitoring Exposure to Hydrophobic Organic Chemicals. Environ Sci Technol 37: 184A-191A.
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Suction cups	Fact sheet No. 22

Main objectives
Identification of migration paths, i.e. (preferential) flow paths, aquicludes
Quantification of migration
Identification of contaminants degradation or retention

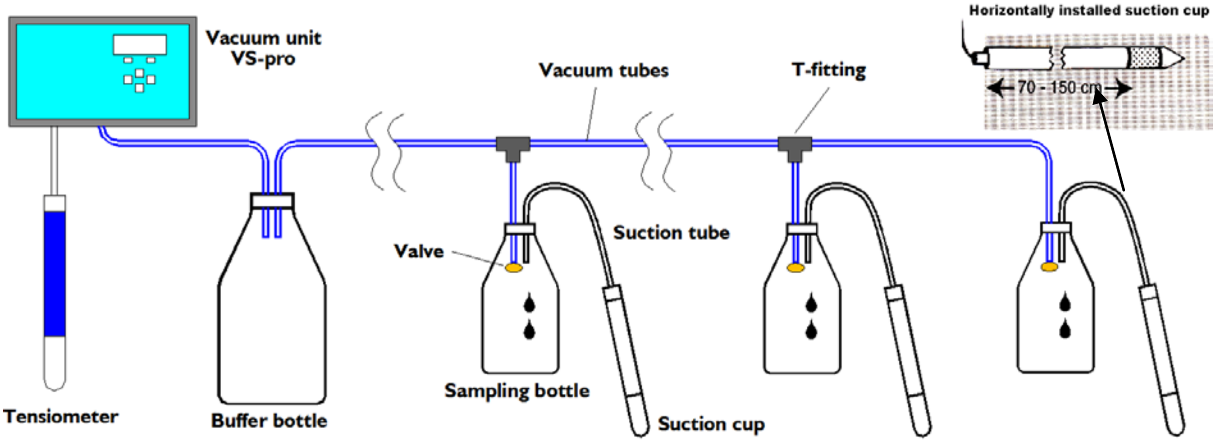
Brief description

Main principle
A porous filter material, such as ceramic, porcelaine or Teflon mixed with quartz, is inserted into undisturbed soil to obtain hydraulic connection between water in the filter material and the soil. The system is closed, and exerting suction to the tube which enters the filter allows continuous sampling of soil water in the unsaturated zone.

Main results

Gives the opportunity to analyze soil water for contaminant concentrations and general soil water chemistry. A multiple set of suction cups can provide information about the spatial distribution of a contaminant and how it changes in time.

Sketch of measuring principle or concept



Horizontally installed suction cup with connection to sampling bottle and vacuum pump. Suction can also be controlled by measurements of soil tension naturally existing at the same depth in order to minimize interference with natural flux in the system. The pump is then connected to a logger which controls the exerted suction of the pump.

Requirements

Site requirements (not applicable for mathematical/statistical methods)
a. Suction cups can operate in any kind of soil where capillary contact between filter and soil can be obtained (up to gravelly sand)
b. Requires power supply (from mains or battery) to drive suction pump

Sample requirements (not applicable for in-situ methods)
a. Minimum volume of samples depends on the list of contaminants and solutes to be analyzed. Depending on the water content of the soil, about 10 ml can be collected in 3-4 hours.
b. Method provides soil water samples
c. Handling of samples depends on the list of contaminants and solutes to be analyzed. Adding acid to sampling bottles for conservation prior to sampling is not recommended as it may disintegrate the tubing. Cold temperatures are mostly sufficient in case samples are collected at least once a week. Longer storage usually requires conservation with acid or freezing.

Data/information necessary for reliable interpretation of results
Depending on which questions are asked the following information is useful:
a. Geology (lithology, structures, including subsoil lines/installations etc.)

b. Groundwater level, hydraulic conductivity, porosity
c. Contamination (substances likely)
d. Basic biogeochemical data (redox, pH, organic matter, mineralogy etc.)

Application range ("operating windows")

(Ideal) operative range for applicability
Unsaturated zone, for negative pressures less than the air entry value of the suction cup. Can be turned off during extremely dry conditions.

Limits for applicability
Mainly applicable for shallow subsurface systems, top 5 m. Sensitive to preferential flow, install several points at each depth.

Standing related to other methods (Chances and limitations for application)

<u>Substitution and complementation of conventional methods</u>
Multi-compartment sampler, porous plates, wick samplers

<u>Advantages</u>
The installation of the suction cup is easy and disturbance of the soil profile is minor.

<u>Limitations</u>
Uncertainties about sampling volume, various pore volumes may be sampled depending on suction applied. No mass balance for entire soil profile.

State of development

<u>Field applicability</u>
Can be applied in most shallow soil systems. Clogging of filters has been observed in systems with high organic loads and degradation activity which may form biofilms and clog pores of filter material.

<u>Provider</u>
Several companies exist. In the SoilCAM project, Prenart instruments and UMS have provided the suction cups.

<u>References</u>
Curley, E.M., M.G. O`Flynn and K.P. McDonnell, 2011. The use of Porous Ceramic Cups for Sampling Soil Pore Water from the Unsaturated Zone. *International Journal of Soil Science, 6: 1-11.*

French, H. K., Swensen, B., Englund, J.-O., Meyer, K.-F. and van der Zee, S.E.A.T.M. (1994): A lysimeter trench for reactive pollutant transport studies. In: Soveri, J. and Suokko, T. (eds.) Future Groundwater Resources at Risk. International Association of Hydrogeological Science (IAHS), 13-16 June, Helsinki, Finland IAHS Publication (1994) 222: 131-138.

<u>Expenditures</u>
In 2012, the cost of a single suction cup from UMS including 1 L sampling bottle varied between 100-180€. A 2-channel vacuum unit for two adjustable vacuum circuits (0-85 kPa), one controllable with an optional tensiometer, is about 1,700€. A setup of about 12 sampling points costs about 5,800€.
The most time-consuming part of installing a large set-up of horizontally installed suction cups is to excavate and secure the trench, some days to a couple of weeks.

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Remarks

Multilevel samplers (MLS)	Fact sheet No. 23

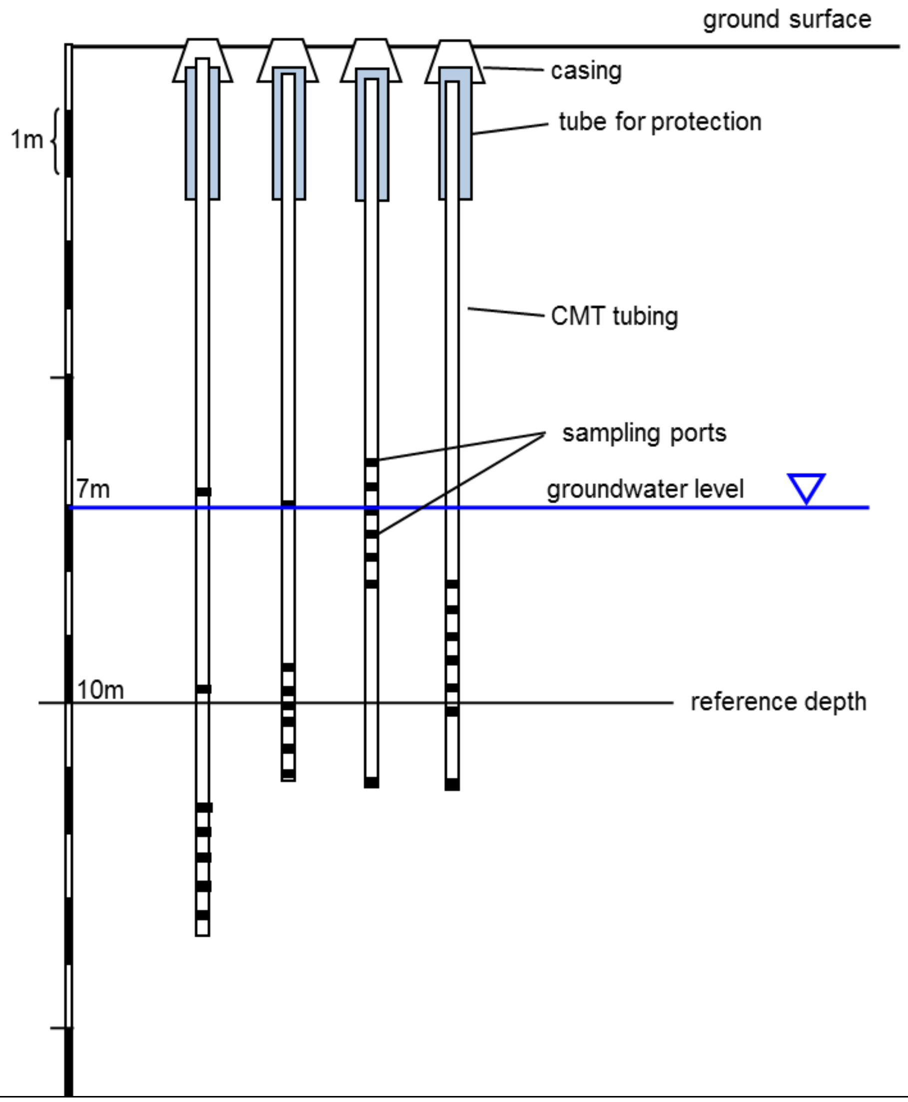
Main objectives
Identification of contaminants
Quantification of contaminants
Identification of contaminants distribution (source, unsaturated zone or groundwater)

Brief description

Main principle
The multilevel sampling system is used to sample water (and soil gas) at multiple isolated horizons in a single borehole. For each well a multiple set of tubing is connected to sampling locations at different levels in the groundwater zone. Each tubing and hence isolated horizon can be sampled to separate sampling bottles.

Main results
Gives the opportunity to delineate the top or base of a contamination plume, as well as spatial distribution between the outer boundaries, depending on how many wells are installed. If a number of wells are installed the contamination can be outlined in a three dimensional volume.

Sketch of measuring principle or concept
The figure below shows the setup of multilevel samplers used by SoilCAM at the Trecate site, where the main interest is in the depth where the groundwater level fluctuates.



Requirements

Site requirements
a. Groundwater and phreatic zone
b. Energy source for pump, could be battery driven.

Sample requirements
a. Sampling volume depends on list of contaminants and solutes in question. Under ideal conditions sampling system yields 200ml/min
b. Provides groundwater samples
c. Handling of samples depends on the list of contaminants and solutes to be analyzed, see Annex, chapter A.1.

Data/information necessary for reliable interpretation of results
a. Geology (lithology, structures, etc.)
b. Groundwater (level, direction of flow, gradient, hydraulic conductivity etc.)
c. Contamination (substances likely)
d. Basic biogeochemical data (mineralogy)

Application range (“operating windows”)

(Ideal) operative range for applicability
Saturated zone, depending on the pumping system multilevel samplers can provide samples from depths up to 300 m.

Limits for applicability
Not relevant for fractured rock

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods
Standard groundwater wells

Advantages
Can supply space- and time-resolved chemistry information from an aquifer.
Lower cost than multiple sets of wells

Limitations
Gives less water per time unit than normal groundwater wells
Requires expert knowledge for placing wells and determining filter, material and pumping options.

State of development

Field applicability
Has already been tested at a number of locations, Borden aquifer (landfill lechate), DuPont Belle, West Virginia (volatile chemicals), Gardermoen (jet fuel contamination)

Provider
Several, for example: Solinst Canada Ltd., Flexible Liner Underground Technologies, LLC, Schlumberger Water services
Provider for SoilCAM project: ecoTech Umwelt-Meßsysteme GmbH, Nikolausstraße 7, D-53129 Bonn

Self-made systems are also possible, the required number of sampling tubes with a filter at the lower end can be connected to a metal core (e.g. stainless steel) and inserted into a predrilled hole with a casing and backfilled with local soil, well sorted sand or similar.

References
Cherry, J.A., R.W. Gillham, E.G. Anderson and P.E. Johnson, (1983) Migration of contaminants in groundwater at a landfill: a case study, 2. Groundwater monitoring devices, Journal of Hydrology, 63, 31-49.

Wilson, R.D., Thornton, S.F. & Mackay, D.M., (2004). Challenges in monitoring the natural attenuation of spatially variable plumes. Biodegradation, 15(6): 359-369.

Expenditures

The Solinst CMT system shown in the figure above was 10,000€, including control unit for pumps and 5 pumps. Setup was done in 1 day: Project manager 1 day, Assistant 1 day, Geoprobe team who conducted the drilling: 1 day.

Contact person

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Remarks

Spatial statistics, data comparison and assimilation	Fact sheet No. 24

Main objectives

- Data assimilation and spatial mapping of a contamination plume;
- Performance evaluation of various indirect and/or non-invasive measurement methods for site assessment;
- Feedback and recommendations for on-site pollution assessment and site characterization with respect to the indirect measurement techniques at hand.

Brief description

Main principle

Data assimilation, evaluation and standardisation are necessary to provide a higher degree of specificity and reliability from the primary data as coming from the various indirect measurement techniques. Statistical data evaluation is a cornerstone for the assimilation of data of different nature.

A mathematically consistent way of assimilating data is proposed to account for various data sources in order to reach a better assessment of the site and to improve the evaluation of the pollutant plume. It is based on stochastic modeling tools built on spatial statistics and geostatistical concepts (i.e., spatial dependency quantification, optimal mapping, etc.) that are methodologically implemented as Matlab computer routines. The final aim is an improved mapping of the contaminant plume, based on the spatial assimilation of these data with results coming from more conventional/direct techniques.

The techniques and methodology is general enough to allow it to be applied to a wide array of indirect measurement techniques, with the final aim of improving the modelling of the contamination plume at a given site.

Based on this methodology, clear feedbacks and recommendations can be provided to the users about the benefit of each indirect method that can be involved for on-site measurements, in order to identify the most efficient subset of these methods to be used as a substitute for more conventional sampling and modelling techniques.

Main results

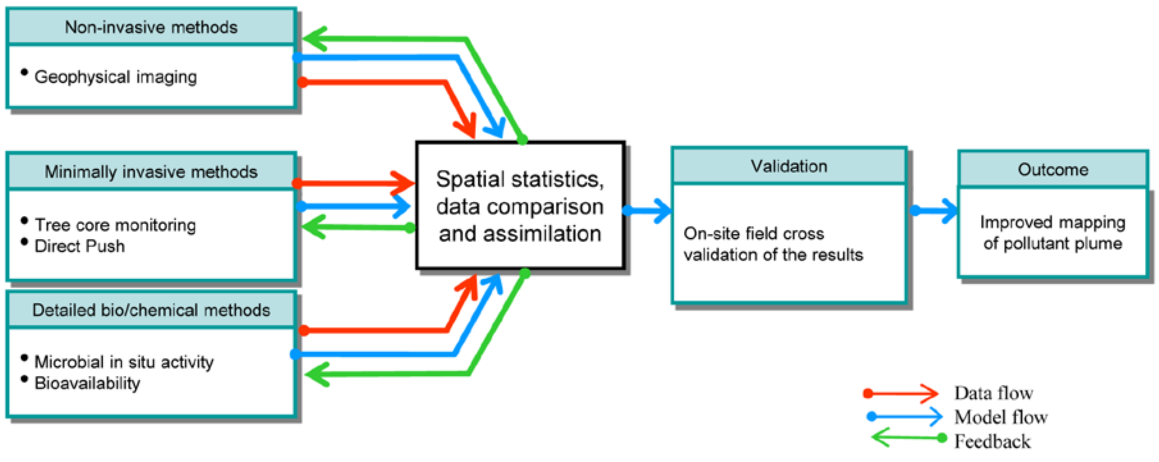
Depending on the measurement techniques (either directly related to the contaminant itself or to the geophysical structure of the site) and using this operational methodology and mathematical tools, the results will be:

- An improved mapping with respect to the delineation of the contamination plume, in order to assess the importance and the extent of the contamination;

- A quantitative assessment of the relative benefits of using each indirect measurement techniques when the final goal is to obtain an improved mapping of the contamination plume;

- A quantification (partial or total) of the uncertainty attached with the final estimation of the concentration levels as obtained from the combination of the various measurement techniques at hand.

Sketch of measuring principle or concept



Requirements

Data requirements (mathematical/statistical methods)

e. Data input from indirect measurements techniques & conventional methods

Data/information necessary for reliable interpretation of results

f. Site characterization from pre-existing data sources or from geophysics
g. Data interpretation linked to the various measurement techniques that are used and results that are obtained from these methods

Application range ("operating windows")

Spatial delineation/mapping of a contamination plume; data assimilation; reliability assessment of indirect measurement techniques.

Limits for applicability

Methodology could be limited or might be not applicable when site description, some data interpretation and calibration/validation with conventional direct measurements are not available.

Standing related to other methods (Chances and limitations for application)

Substitution and complementation of conventional methods

- Direct sampling of the contaminant based on conventional methods
- Alternate mechanistic models or geophysical data fusion methods, when relevant

Advantages :

- General methodology which is relevant for a wide variety of indirect measurement techniques
- Ability to assimilate various indirect measurements at the same time, along with more conventional ones
- Easy to implement with the help of available computer routines.

Limitations

- Some modeling assumptions that might prove to be partly invalidated
- Limited to a statistical approach of data assimilation (no mechanistic views of the problem)

State of development

Provider : Catholic University of Louvain, Louvain-la-Neuve, Belgium References : see published papers on applications and description as provided in technical report Expenditures : 1 specialist and sufficient computing resources
Contact person Patrick Bogaert (UCL)
Remarks None

Please provide a description of the potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results. The length of this part cannot exceed 10 pages.

The ModelPROBE project was dedicated to the development and improvement of innovative investigation techniques and methods to be used at the assessment of contaminated sites, in particular in Europe but also worldwide. These techniques and methods focus on the detection of (hydro)geological site characteristics, contaminants and subsurface processes by geophysical and biogeochemical means. The techniques and methods covered by ModelPROBE rely on a cyclical cost and time saving overall approach for contaminated site management, which allows for short-term (on-site) decisions ("ModelPROBE overall approach").

Besides introducing the ModelPROBE overall approach, the recommendations for dissemination, harmonisation and implementation, which are part of the guideline chapter of the ModelPROBE handbook (see added file), are mainly dedicated to presenting the investigation techniques and methods that have been developed and improved within the project ("tool-box"). The recommendations were already considered for the validation activities at the reference sites and the outcome and experience are directly incorporated into the final recommendations within the handbook. They are intended for environmental practitioners engaged in the investigation of contaminated sites including engineers as well as representatives of authorities. It addresses both, (i) an overview on techniques and methods and how and when (at which stage of investigation) to apply them ("Guideline": Part 1 of the Handbook) and (ii) detailed technical information on the techniques and methods ("Manuals": Part 2 of the ModelPROBE handbook). In the latter part there is also a section providing easy-to-understand descriptions for each technique and method ("Fact Sheets"), which can be used by site-owners or potential investors as well. The handbook is regularly published under:

M. Kästner, M. Brackevelt, G. Döberl, G. Cassiani, M. Petrangeli Papini, C. Leven-Pfister & D. van Ree (Eds.). MODEL-DRIVEN Soil probing, site assessment and evaluation – Guidance on technologies. ISBN 978-88-95814-72-8. Printed in Italy by Centro Stampa Università, Sapienza University of Rome;

and can be ordered via the project homepage. For enabling the users to consider the details, an e-learning course was also developed and is provided by a DVD within the handbook or at http://modelprobe.dissemination.org.

The detailed analyses of administrative and legal constraints as well as the recommendations for dissemination, harmonisation, and implementation of the ModelPROBE approach and toolbox are presented in in the guideline of the handbook. A brief guidance of the practical use for all potential users (authorities, stakeholders, and consultants/engieers) is presented below:

1 *A brief guidance to the practical use of the techniques covered by ModelPROBE* How to integrate ModelPROBE within an overall site investigation frameworks

1.1 ModelPROBE within a tiered investigation approach

Since contaminated land management is to a large extent a regulator- and authority-driven process, many countries have implemented more or less complex and extensive schemes and procedures to support decision making in this field. Most of these schemes or procedures are based on a tiered approach in order to identify contaminated sites and the impacts originating from them in a systematic way. In Fig. 4, a generalised framework for a tiered approach is sketched. It represents a condensed scheme based on common frameworks applied in a similar way by many countries across Europe and North America (e.g. ISO 10381-5 (2005); United States: US EPA (2010); United Kingdom: UK UA (2008); Germany: e.g. LFU (2001); Austria: OENORM S 2085 (2009); etc.). The framework integrates four tiers, including all relevant investigation and assessment steps in contaminated site management. Besides, the tier-specific state of the CSM (Level 1 to Level 3) and typical questions to be addressed at different tiers are covered. It has to be underlined that this framework is conceptual and idealised; hence, in practice neither the investigation tiers nor the levels of the CSM can be separated distinctly but are overlapping in most situations. Nevertheless, in Tab. 1 some clues on typical levels of site-specific information are given, whereas Tab. 2 at the end of this chapter sketches a corresponding general overview on the potential application of the techniques and methods covered by ModelPROBE at different levels of the CSM.

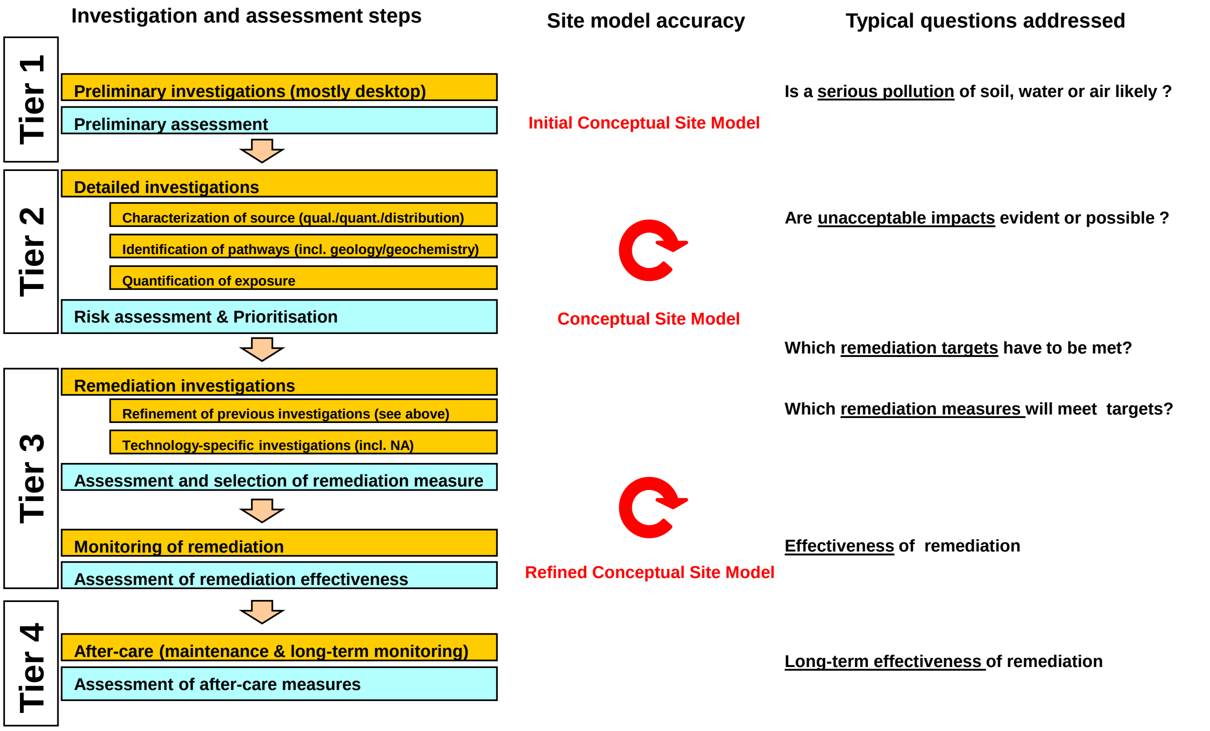


Fig. 4: Generalised tiered framework in contaminated site management as it is in use in similar ways in many countries (Environment Agency Austria, 2012)

Tab. 1: Levels of site-specific information ("Levels of Conceptual Site Model" – CSM)

	Level 1 ≈ Initial CSM	Level 2 ≈ CSM	Level 3 ≈ Refined CSM
Groundwater	Level and flowing direction	Quantity (hydraulic cond., gradient); geogenic background	Seasonal and long-term variability
Geology	Regional geology	Local geology	Local geology refined
Contamination	Main contaminants, which are likely	Main cont.: quality and quantity Minor cont.: quality	Quantity refined (e.g. mass-flow in groundwater); distribution in detail; NA processes

1.2 Tier 1: Sketching an Initial Conceptual Site Model (Level 1)

Tier 1 consists of preliminary investigations including desktop-based investigations focusing on the question whether a pollution of the environment is likely. To figure out the main environmental issues of a site, typical information and data needed at this tier include:

- Type of industrial or commercial activities on the site (historically and recently)
- Information regarding possible impacts on the environment (e.g. operation period of relevant activities; accidents, extent of (soil or groundwater threatening) activities, i.e. type and size of technical installations, number of employees etc.)
- Basic information on
    - Geology and hydrogeology: depending on availability on local and on regional scale
    - Contaminants: Which contaminants are likely?

First field investigations typically are intended to give a rough overview on geology and hydrogeology. If at all, sampling takes place at e.g. existing wells or by cost-effective screening methods.

<u>Contribution of the techniques covered by ModelPROBE at Tier 1</u>

Although ModelPROBE techniques are mostly focused on Tier 2 and Tier 3, some of them might be considerably useful at this tier in order to screen the site surface-based for potential geological "anomalies" or pollutants with geophysical techniques and/or tree core monitoring, and to get a first rough insight into subsoil conditions with classical Direct Push applications. Besides, this investigation step is crucial to all further investigations since the Initial CSM (Level 1) developed at this tier is the (only) information basis when it comes to extended field investigations at Tier 2.

1.3 Tier 2: Creating a Conceptual Site Model (Level 2) as a basis for risk assessments

Based on the initial site model, Tier 2 is dedicated to detailed site investigations in order to characterise the contaminants' source(s), their potential migration and their potential impacts. The latter includes environmental media such as ambient air, soil, or groundwater as well as receptors such as humans, animals, plants or ecosystems, which are or might be affected by the contamination.

The investigation results at this stage typically lead to a CSM (Level 2), serving as a basis for the risk assessment to be followed. Based on the risk assessment, it has to be decided whether risks to humans or the environment originating from a specific site are acceptable or whether there is a need for measures to lower the risk, e.g. by remediation measures or use restrictions.

At this tier the questions to be addressed in particular largely depend on the type of risk assessment to be applied, but typically include:

- Type of contamination
- Extent of contamination (e.g. delineation of contaminants' source and plume or contaminants' distribution)
- Mobility, transport and degradation of contaminants
- Impact on affected media or receptors

Besides further desktop-based historical investigations, among typical Tier 2 field and laboratory investigations are:

- Geological, hydrological and hydrogeological investigations
- Sampling and analysis of air/gas, soil and (ground)water at the site and determination of biogeochemical conditions
- Laboratory tests regarding availability of contaminants (leaching tests, column tests)
- Toxicity assessment

Contribution of ModelPROBE at Tier 2

The ModelPROBE approach and its techniques and methods are tailored to answer the questions addressed at this tier. By its cyclical approach, in many cases allowing for short-term feedback loops including on-site data assessment and decision making, the CSM can be updated regularly with structured data and information in order to get an appropriate basis for the next investigation steps. As mentioned before, the application of ModelPROBE's non-invasive or low-invasive investigation techniques in particular for screening purposes helps to support or substitute classical investigation techniques such as drilling, sampling and laboratory analyses in a time and cost saving way.

Particularly,

- the interaction of geophysical and classical Direct Push techniques will contribute significantly to a complete geological, hydrogeological and contaminant related picture of the subsoil. This is also crucial to the appropriate planning of expensive drilling campaigns.

Geotechnical and chemical data from Direct Push investigations (including sampling of soil, gas and groundwater) should be used to calibrate the results of geophysical measurements in order to separate "geological" from "chemical" signals. After calibrating, geophysics consequently serve to fill inevitable spatial gaps left by Direct Push investigations. On the other hand, these methods may be applied for initial screening to identify anomalies at the respective site.

- Tree Core Monitoring may be performed for initial screening or to complement investigations focussing on the delineation of plumes in shallow groundwater (e.g. in order to optimise the positioning of further drillings, Direct Push investigations or monitoring wells).

- conventional pumping tests to assess the hydraulic conductivity can be supported (or partially substituted) by hydraulic Direct Push (hydraulic head measurements) investigations.
- Compound Specific Isotope Analysis (CSIA) can be used to detect and quantify in situ microbial degradation of organic contaminants or to map degradation pathways in plumes.
- assessment of impacts on ecosystems can be based on Bioassays as indicators for ecotoxicity.
- for assessing the bioavailable fraction of persistent contaminants like PAH, innovative laboratory methods such as Contaminant Trap, HPCD-Shake Extraction Technique or Equilibrium Sampling can be performed to support conventional techniques like leaching or column tests.
- to support an overall assessment of results and allow for an appropriate data management, methods of spatial statistics, data comparison and data assimilation should be applied from the very beginning of the investigation campaign.

1.4 Tier 3: Refining the Conceptual Site Model (Level 3) when it comes to remediation

Tier 3 is only relevant to sites where (remediation) measures have to be performed to lower the risks originating from a site. The main questions to be addressed at this tier are:

- Which remediation goals/targets have to be met?
- Which remediation technology will meet the goals/targets?

Generally, the remediation goals depend on technical, environmental and economic feasibility, i.e.:

- The goal should be "environmentally sound",
- a technology to meet the goal should be available and
- the corresponding costs can be covered.

Based on the CSM, investigations at Tier 3 ideally lead to a Refined CSM (Level 3) and mostly address the following two issues:

- refinement of the CSM, i.e. assessing quality and quantity of the contamination more precisely in order to be able to pre-select appropriate remediation technologies (see above); generally, the same investigation techniques are used as at Tier 2
- investigations specific to pre-selected remediation technologies (e.g. specific hydraulic and geotechnical investigations or biogeochemical investigations to assess or to proof the effectiveness of natural attenuation processes)

During and after remediating a site, the effectiveness of remediation measures has to be monitored and assessed ("final risk assessment") at Tier 3. Monitoring includes sampling and analysis of air/gas, soil and (ground)water on the site and its surroundings, but also maintenance of technical installations. To ensure comparability, assessing the effectiveness of remediation measures should be performed in a similar way as the risk assessment prior to the remediation measures.

Contribution of ModelPROBE at Tier 3

As with Tier 2, the ModelPROBE approach as well as its techniques and methods are dedicated to be applied extensively at Tier 3. Again, the cyclical approach will allow for a continuous update of the CSM, resulting in its final version – a Refined CSM (Level 3).

In addition to their use at Tier 2, the techniques and methods covered by ModelPROBE can be performed at Tier 3 as follows:

- A combination of geophysical and all kinds of Direct Push techniques can be performed to refine the CSM – e.g. to get detailed geotechnical or hydrological information necessary for the pre-selection or the planning of remediation measures. After an appropriate calibration, geophysical techniques may be used as cost-effective (long-term) monitoring tools (see Tier 4). This applies for Direct Push investigations as well: They can be used either for assessing the effectiveness of remediation measures in-situ or for sampling purposes.
- Compound specific isotope analysis (CSIA) contributes to the assessment of the effectiveness of on-going Natural Attenuation processes or of remediation measures to stimulate (bio)degradation (e.g. all kinds of Enhanced Natural Attenuation).[1]
- BACTRAPs, either installed in groundwater wells or used as a Direct Push probe, are applied to evaluate biological degradation potentials or remediation options under various redox conditions (pre-selection of remediation measures). 1
- If dechlorinating processes need to be assessed, Fluorescent In-Situ Hybridization techniques (FISH and CARD-FISH) should be applied for the quantification of dechlorinating microorganisms, which directly corresponds to the effectiveness of dechlorinating processes. The assessment of the distribution of key degrading bacteria in the aquifer can be used to assess whether conditions for natural attenuation are favourable. 1
- Bioassays are used to complement chemical data when assessing the effectiveness of remediation measures or monitoring. 1
- Laboratory methods such as Contaminant Trap, HPCD-Shake Extraction Technique or Equilibrium Sampling can be used to assess the effectiveness of measures to reduce the bioavailable fraction of contaminants.

1.5 Tier 4: Post-remediation monitoring and maintenance

Besides classical maintenance works, long-term monitoring at **Tier 4** should ensure long-term effectiveness of after-care measures and, especially, of long-lasting safeguarding measures or enhanced/monitored natural attenuation.

Contribution of ModelPROBE at Tier 4

Basically, all techniques proposed for monitoring purposes at Tier 3 can be applied at Tier 4 as well.

Special attention should be given to geophysical and biogeochemical techniques, which, once calibrated or proved to be effective at the tiers before, may have a high potential to substitute classical techniques for long-term monitoring purposes at Tier 4.

1.6 Summary

Tab. 2 summarizes the goals of typical applications of the techniques and methods covered by ModelPROBE at different levels of the CSM. In addition, investigation steps to be followed (or to be performed in parallel) are proposed for each application.

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[1] *In addition, this technique can be used for continuous monitoring during a monitored or enhanced natural attenuation site remediation approach (see Tier 4).*

Tab. 2: Overview on goals and next (or parallel) steps of typical applications of the techniques covered by ModelPROBE (levels of the CSM correspond to Fig. 5 and Tab. 1)

	Level 1	Level 2	Level 3
Geophysical techniques SP, SIP/EIT, EM, GPR, RMT	**Goal**: Screening of "anomalies" **Next steps**: historical investigations, DP, D+S	**Goal**: "separation of geology and contamination" ; pre-selection of remediation measures (combined with DP) **Next steps**: verification/refinement by DP, D+S	**Goal**: long-term monitoring of pollution (dynamics of hydraulic system)
Tree Core Monitoring	**Goal**: screening of pollutants **Next steps**: verification/refinement by DP, D+S	**Goal**: delineation of plume **Next steps**: verification/refinement by DP, D+S	-
Direct Push "Classical applications"	**Goal**: screening of (hydro)geology, pollutants **Next steps**: additional DP; additional applications; (verification by D+S)	**Goal**: refinement of (hydro)geology, quant./qual. of pollutants; pre-selection of remediation measures **Next steps**: additional DP; additional DP applications; (verification by D+S)	-
Biogeochemical techniques CSIA, (DP-) Bactrap, (CARD-) FISH, bioassays, lab techniques	-	**Goal**: supporting DP or D+S investigations; exposure analyses; pre-selection of remediation measures **Next steps**: additional DP; (verification by D+S)	**Goal**: long-term monitoring of (enhanced) natural attenuation; analysis of degradation processes/microbial activity
Mathematical - statistical methods	**Goal**: supporting the creation of an appropriate CSM at all levels by comparing, interpreting and assimilating data gained by multiple techniques		

SP Self Potential
SIP/EIT Electrical Spectroscopy / Electrical Impedance Tomography
EM Electromagnetic Induction Mapping
GPR Ground Penetrating Radar
RMT Radio Magentotelluric
CSIA Compund Specific Isotope Analysis
FISH Fluorescent In-Situ Hybridization techniques
DP Direct Push
D+S conventional Drilling and Sampling

Please provide the public website address (if applicable), as well as relevant contact details.

ModelPROBE website: http://www.modelprobe.ufz.de/

Attached documents : Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc...), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

ModelPROBE logo

Final report

4.2 Use and dissemination of foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 - G). plan should consist of:

- Section A

This section should describe the dissemination measures, including any scientific publications relating to foreground. Its content will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

Accompanying to the ModelPROBE project a series of training and dissemination activities were scheduled to:

- promote practical applications of novel strategies and approaches in the characterization and monitoring of contaminated land and groundwater;
- transfer existing and emerging knowledge to the scientific community and potential (end)-users, such as SME´s technical consultants, regulators, policy makers, problem owners, and the public.

Beside the edition of the proposed guidelines for integrated site assessment, which are the outcomes of WP 10, an efficient knowledge and information dissemination were achieved by the following measures:

- Courses for professional training and education taking into account the interests of the different needs of involved scientists and end-users. The training and education program includes: (1) training for scientists using the different disciplinary results achieved in the different work packages, (2) training for consultants and stakeholders from practice to demonstrate the application of monitoring strategies and tools, (3) thematic training for national/local authorities on global issues (e.g. impact on policy implementation), (4) civic meetings at local level for specific end-users such as municipalities, and water supply services;
- Case Studies to demonstrate the implementation of the novel site characterization strategies and techniques under real conditions;
- Regular dissemination courses for transfer of information and knowledge on emerging RTD results produced by ModelPROBE;
- Maintenance of a web based information system and an e-learning course.
- Final publishing of the methods and tools developed in form of a guideline including a method handbook (ModelPROBE handbook, for details see below).

The activities were closely connected to an outreach program that is performed by the UFZ since the second half of 2007 called TASK. This program was funded by the German Ministry for Education and Research (BMBF) and provided financial and logistic support for the utilization of emerging technologies in the area of contaminated soil and groundwater management. For that purpose measures were performed that (i) demonstrate at real field sites the applicability of new technologies, (ii) create references for a standardization of innovative methods, and (iii) produce digested information (e.g. handbooks, guidelines, fact sheets) for practitioners, in order to improve the visibility and acceptance of scientific products on the market. The linking up with the UFZ outreach program induces valuable synergy effects that were used by ModelPROBE for highly effective dissemination and exploitation of the project outcomes.

The consortium had defined clear deliverables and their level of dissemination (see Deliverables). The internal rules of exploiting findings, concepts and technologies will be put down in the Consortium Agreement. The chances of any discovery or development to be patentable were discussed and decided on the basis of the Consortium Agreement and in the plenary meetings. SMEs partners took over the lead in recognizing commercial dissemination plans and articulating them for the whole consortium. For all tools, models and protocols developed during the ModelPROBE project, which in the end appeared to have no direct market potential, the concepts and the deliverables were transmitted to potential end-users and became public domain by publishing the ModelPROBE handbook.

Dissemination activities on the scientific level were the production of scientific peer-reviewed manuscripts, which is of critical necessity for all research and higher education partners. This was basically the responsibility of each partner or ideally partner group. Plans for scientific manuscripts have been circulated among the consortium and confidentiality items defined in a premature state did not provide conflict potentials on commercial exploitation. More popular presentation of the ModelPROBE project work was performed through press releases, popular articles, and public seminars or on the internet. An important dissemination activity in the later phase of ModelPROBE was performed by two advanced courses, in which concepts of the developed tools and techniques were presented and practical demonstrations will be performed. The target audience of the courses were governmental or private environmental laboratories, consultants, governmental agencies or NGOs. Tutors and lecturers of the courses were the partners of the consortium.

The ModelPROBE handbook:

ModelPROBE e-learning-tool: the DVD is provided with the Handbook and at http://modelprobe. dissemination.org

Preface of the ModelPROBE handbook. The book you hold in your hands has been written in order to publish the final outcome of six years of research activities dedicated to both the primary development of emerging (mostly geophysical) methods, and the improvement and combination of previously developed methods, for the investigation and assessment of contaminated sites. The research presented in this handbook was centred around two European Commission 7th Framework program projects: 'ModelPROBE - Model driven Soil Probing, Site Assessment and Evaluation' (Grant agreement No. 213161; www.modelprobe.eu) and, to a much lesser extent, 'SoilCam – Soil Contamination: Advanced Integrated Characterisation and Time Lapse Monitoring' (Grant agreement No. 212663; www.soilcam.eu). The methods presented in this handbook are 'non- to low-invasive', aim for cost-effectiveness, and comprise advanced geophysical site characterization techniques, new types of vegetation analysis, and improved or new biogeochemical methods, mostly combined with direct push applications.

When we started planning the project in late 2006, conventional techniques for site characterization were often applied with limited strategic planning, resulting in time-consuming and cost-intensive investigation campaigns, which did not effectively support decision making. Therefore, the need for new techniques and improved approaches was identified by the US EPA and by the European Commission, to be based on step-by-step site characterization strategies allowing for smart feedback loops. The identified needs were laid down in a call in the FP 7 program which then acted as the starting point for the overall project approach. Initially, there was a core group of scientists from the Helmholtz-Centre for Environmental Research (UFZ) and other institutions, with specific expertise in site assessment, biogeochemical plus toxicology-related methods, and direct push applications in general. In the search for complementary partners, another European core group focusing more on geophysical method development and data fusion was identified. Combining the expertise of both core groups resulted in a perfect match for the consortium, finally leading to the top-ranked project proposal ModelPROBE in 2007. Negotiations with the European Commission started in 2008, and led to association of the two projects (ModelPROBE and SoilCAM) selected in the competitive call for proposals, in order to make use of the possibly synergistic approaches and to ensure the transfer of knowledge between the projects. The overlap of personnel within the partners of both consortia facilitated the collaboration. However, due to the different approaches in SoilCam with less advanced development stages of the methods with respect to their implementation in practice, only a few specific contributions could be incorporated in the present book as ready-for-use method descriptions.

One of the leading ideas of the ModelPROBE project was to evaluate the techniques against the best practise of conventional methods at fully equipped and characterized European reference sites. However, due to the large variety of methods and their specific results, this idea was recognised as being very ambitious, and finally it turned out that the evaluation goal could only be achieved in a limited set of cases. The simple reason for this lower-than-expected outcome was that techniques which are based on different physical or biogeochemical principles cannot be directly compared in all details. Another basic idea of the project was to develop and apply integrated statistical analysis and modelling at various stages of the approach in order to extract as much information as possible from the raw data. However, owing to a general limitation, which is inherent to multi-partner and multi-method projects, some partners could not efficiently work hand-in-hand because delays and revisions adversely impacted the project time schedule. Some work packages needed to rely on results and input from others, which were able to provide data of appropriate quality only in the later stages of the project. This was particularly the case for the interaction of the statistical analysis work package with other partners in ModelPROBE focused more on technical developments. This work suffered from the late inputs in the project's time frame, since many methods were still under development. Finally, the statistical methods were developed as stand-alone tools based on assumptions and hypotheses about the expected final outcomes from most of the site assessment methods. Nevertheless, we kept track of the developed methods and approaches, ensuring their applicability related to the overall goals of the project.

Six years later, after some changes of partners (particularly related to processing the outcome), we can now state that the majority of the development goals have been achieved. Nevertheless, developments outside of the project also evolve, so the outcomes of several developments are punctual but no longer totally new in the field of site assessment. The reason for publishing the developments of the project is to make the outcomes understandable and available to all potential users: stakeholders, consultants and authorities, and, last but not least, scientists.

Therefore, due to the wide potential readership, this book contains general introduction chapters concerning the principles of site assessment as well as the application of the geophysical methods, which cannot always provide direct information related to contaminants and their distribution. In order to promote easy access and to provide overviewsof the methods, the general chapters are accompanied by a set of brief fact sheets summarizing the principles of the methods and highlighting their advantages, followed by extensive method application manuals, all with a uniform organisation scheme. The Annex provides additional information of general relevance.

We ensured quality control of the manuscripts by organising peer-reviews of each part of the handbook by external evaluators who are experts in the field but not involved in ModelPROBE or SoilCAM, as well as by internal reviewers from both projects.

The editorial committee considers the structure they arrived at to be the most appropriate way to provide access to the methods and to contribute to a more sustainable, cost effective site assessment. It also supports general progress in contaminated site investigation and assessment, which is often neglected due to financial issues, for example in Eastern European countries. We hope to meet the expectations of the readers and we welcome feedback, in particular concerning the experience in method application or failures. Although the proposed methods did not undergo 'technology evaluation' in a classical sense, we are confident that this book will provide a useful site assessment approach with an appropriate toolbox.

We hope that you find reading the book a pleasant and informative experience, and also hope that you may consider applying some of the described methods for site assessment tasks in your own day-to-day practice,

Matthias Kästner, Mareike Brackevelt, Gernot Döberl, Giorgio Cassiani, Marco Petrangeli Papini and Derk van Ree (on behalf of the editing committee)

According to the public nature of the EU funding, this handbook is free of charge in terms of publishing the results of the project, and was produced as inexpensively as possible. However, any reprints of the book or of parts of its content are still subject to the copyright of the authors.

This handbook can be ordered at the Helmholtz-Centre for Environmental Research, Department of Environmental Biotechnology and at the La Sapienza University of Rome and will be distributed after the finalization of the project for a charge of about 25 € to cover shipping and administration costs.

- Section B

This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

All main S & T results and foregrounds from the project in particular the methods, tools and prototypes are provided in a comprehensive way within the ModelPROBE handbook and are thus fully available to the public. In particular, the deliverables D 9.3, D 9.2, and D 9.1.2 provide the downloadable version of the most important chapters of the handbook.

List of Deliverables – to be kept confidential by the EC[2]

Del. no[3]	Del. no[4]	Deliverable name	WP no	Lead bene-ficiary	Estimated indicative person months	Nature[5]	Dissemi-nation level[6]	Delivery date (proj. month)
D.1.1	1	SIP spectrum signature of contaminants, microbial activity and relevant database development	WP 1	IPGP	18.7	R	CO	14, 46
D.1.2	2	Design of electrodes for SP measurements and relationship of SP signals to microbial activity	WP 1	USP (Spb SU)	17	R	CO	24
D.1.3	3	Quantification of other effects on SIP/SP response and mapping of water presence and link to microbial activity	WP 1	UPD	19	R	CO	46
D.1.4	4	Identification of key parameter combinations to map soil contamination	WP 1	UPD	11	R	CO	46
D.5.1.1	17	Applicability of Spectral Induced Polarisation (SIP)-probe, Direct Push permeameter, multifunctional probes; prototypes	WP 1, 2, 3, 9	Met-UFZ	7	P	PP	28
D.5.1.2	18	Applicability of biosensors and microbial fuel cell	WP 6	Bio-UFZ	7	P	PP	28

2 In a project which uses 'Classified information[2]' as background or which produces this as foreground the template for the deliverables list in Annex 7 has to be used

3 Deliverable numbers in order of delivery dates. Please use the numbering convention <WP number>.<number of deliverable within that WP>. For example, deliverable 4.2 would be the second deliverable from work package 4.

4 Deliverable numbers in order of delivery dates: D1 – Dn

5 Please indicate the nature of the deliverable using one of the following codes:
R = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

6 Please indicate the dissemination level using one of the following codes:
PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

D.5.2	19	Extensive data sets for evaluation of geophysical methods	WP 1, 2, 3	UBO	6	R	RE	34
D 6.2.3	27	Report on factors and conditions affecting the applicability of the biolelectrochemical device for in situ determination of CAH concentration and/or biological reactivity	WP 6	URom	4	R	CO	16, 28
D 8.1	34	Methodology and theory	WP 8	UCL	10	R	CO	12
D 8.2	35	Source of responses	WP 8	UPD	12	R	CO	18
D 8.4	37	Computer routines	WP 8	UPD	21	P	CO	28
D 8.5	38	Quality assessment	WP 8	UCL	10	R	CO	34