City Chlor

Direct-Push Technology

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

NWE INTERREG IVB

Summary

Direct-Push Technology (DPT) refers to a group of techniques used for subsurface investigation by driving, pushing and/or vibrating small-diameter rods into the ground. By attaching tools to the end of the rods, they can be used for in-situ measurements or for the collection of samples from soil, groundwater or soil air. DPT holds a group of a versatile techniques that aid in cost-efficient and flexible soil investigation.

DPT are being applied in environmental soil investigation since 20 years, but there is a big difference in the status of these techniques within Europe. The CityChlor project offers an excellent opportunity to exchange experiences with DPT and to eliminate these dissimilarities.

This document addresses to consultants, contractors and authorities. The goal of this document is to enhance the knowledge on DPT by giving a balanced overview of advantages and drawbacks, focussing on tools relevant for pollution with chlorinated solvents. As the equipment is still rapidly evolving, this document does not include a complete overview of all tools manufactured by specific companies. Not only are new tools being developed, but existing equipment is being used in creative ways to meet the needs of site-specific conditions.

The chapters 2 and 3 of this report are based on the publication ‘Direct-Push-Verfahren’ by Carsten Leven, Hansjörg Weiss, Hans-Peter Koschitzky, Philipp Blum, Thomas Ptak and Peter Dietrich (Heft 15: Schriftenreihe Altlastenforum Baden-Württemberg e.V., E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 2010) with kind permission of the authors.

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1 Introduction

1.1 CityChlor and the integrated approach

Space is scarce in Europe. Even in the subsurface it is getting busier. Large-scale soil and groundwater contamination with chlorinated solvents are often an obstruction for urban developments. The traditional way of dealing with polluted soil and groundwater does not work in all cases and is not economically and sustainable feasible. In urban environments multiple contaminations with chlorinated solvents are often mixed with each other and spread underneath buildings. This not only leads to technical problems for remediation, but also to liability and financial discussions and hence has an impact on society. An integrated approach and area-oriented approach is needed to tackle the problems. The CityChlor project has demonstrated that remediation and sustainable development can evolve on a parallel timescale.

An integrated approach combines all aspects that are relevant to tackle the problems that pollution with VOC in urban environment causes. Depending on area, site and context different aspects together or parallel to each other can be used. Not only technical solutions are included, but also socio-economical aspects as urban development, communication, financial and legal aspects, time, space, environment and actors (active & passive) have to be handled.

CityChlor did not remain at single case remediation, but looked at the area as a whole in a bigger context: the area-oriented approach. A technical approach that makes it possible to remediate, monitor and control multiple groundwater sources and plumes within a fixed area.

1.2 CityChlor and technical innovations

The managing of knowledge and technical innovations are one of the key to achieve a sustainable city development. A development project has to cope with loads of information coming from different disciplines in different (technical) languages and with different uncertainties. With chlorinated solvents, the knowledge about the pollution will always have a certain uncertainty that can have an impact on the course and the costs of the remediation. An efficient 'managing of knowledge' will try to decrease this degree of uncertainty.

CityChlor therefore also worked on the technical aspects of characterization and remediation. The conventional techniques that are applied for investigation and remediation have their limitations dealing with chlorinated solvents. Promising innovative techniques exist, but do not easily find their way to current application. This barrier is often caused by lack of knowledge on different levels. Experts and contractors do not always have the means to invest in experiments with new techniques, authorities are reluctant to accept techniques of which the results may be uncertain and clients aren't eager to pay for experimental techniques.

Dissemination of knowledge can break this deadlock. CityChlor therefore collected experiences from field application of innovative techniques and implemented itself a number of techniques in pilot projects. For the detailed outcomes, the reader is referred to the specific reports.

CityChlor - “new solutions for complex pollutions” **http://www.citychlor.eu/**

1.3 Direct-push technology

Direct-Push Technology (DPT) refers to a group of techniques used for subsurface investigation by driving, pushing and/or vibrating small-diameter rods into the ground. By attaching tools to the end of the rods, they can be used for in-situ measurements or for the collection of samples from soil, groundwater or soil air. DPT holds a group of a versatile techniques that aid in cost-efficient and flexible soil investigation.

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An introduction to Direct-Push Technology is given in chapter 2. The chapter describes the possibilities and the advantages of DPT in general, but also lists the limitations and points of attention. Chapter 3 gives an overview of the techniques for sampling and in-situ measurements that can be applied by DPT. In chapter 4 a number of case-studies illustrate the use of DPT techniques in soil investigation and remediation. Chapter 5 describes in detail a number of selected techniques that are relevant for chlorinated solvent pollution.

2 Direct-Push Technology

Description and principles

Direct-Push Technology (DPT) is based on the use of probes that are driven into the ground by a static drive source (hydraulic push), a hammer drive source (pneumatic, drop or hydraulic), a vibration drive source or a combination of these. With DPT, depth profiles of physical or chemical parameters can be measured, samples can be taken and equipment for sampling or measurements can be installed. DPT can be used in non-consolidated underground for the investigation of soil, groundwater and/or soil air.

Advantages compared to other techniques

DPT probings are faster and more flexible than conventional drilling techniques. Due to the smaller diameter of DPT probes, the technique is less invasive. This reduces the time needed for sampling or measurements and increases the density of collected data. The number of sampling points can be higher than with conventional techniques within the same time and budget. As soil material is only pushed sidewards with the propulsion of the probe, there is no waste of soil material. This reduces costs as there is no need for removal of (polluted) material. The limited diameter of the probe will restrict the impact of the probings themselves on the underground. The equipment is also more easily cleaned than conventional drilling equipment, limiting the risks of cross-contamination.

Versatility and technical possibilities

A large number of probes is available for the measurement of physical and hydro-geological parameters and for the sampling of the underground under well defined conditions (e.g. in-situ sampling on specific depths). Several of these probes can be combined leading to an optimization of research. The high flexibility also allows fast and efficient installation of measurement and sampling equipment in the underground for continuous observations. Depending on the diameter of the probing equipment, also classic borehole measurements can be carried out with DPT (e.g. measurements of gamma radiation for the detection of clayey soil layers). Several techniques however require calibration by other techniques or by soil sampling and analysis.

Representativeness of results
Measurements and samplings are point measurements in space and time. Reproductive measurements at the same spot are not possible.

Taking into account small variabilities (cm to dm range), reproducible data can be collected with measuring and sampling probe. This means that repeated measurements will yield similar results in the same area, given that there is an unchanged distribution of parameters and pollutants. This implies that despite the spatially limited measured area round the probe (dm range), a high representativeness of results can be obtained.

Limitations

DPT can only be used in non-consolidated soils. The result of a probing and in particular the depth to be reached is little dependent on the grain size of the soil material but more on the “potential of displacement” of the surrounding soil matrix, i.e. how easily soil material can be pushed away around the probe. The technique can therefore be used with success in the wide spectrum of grain sizes from clay to coarse gravel and in exceptional cases also in strongly weathered rocks. For unconsolidated material – and in favourable conditions – depths of more than 50 m can be reached, with risks on breaking rods increasing with depth. Typical depths of application lie in the range of 15 to 35 m. The achievable depths generally decrease with increasing diameter of probe and rods. This is caused by the higher friction of the rods and the increased displacement of soil material as a result of the bigger cross-section and in particular the bigger surface of the rods. Dependent on the geologic conditions on a site, friction can be decreased and higher depths can be reached by applying pre-drillings (e.g. with an auger drill) or pre-probings. Typical probing diameter lies between 38 and 100 mm (1,5” and 4”). Therefore, different probes can not be randomly combined.

DPT measurements represent point measurements. The investigated volume is the area in immediate vicinity of the probe. For the understanding of the spatial distribution of parameters, several probings are required, e.g. along transects.

When the possibility for probings is doubtful on a site, it is recommended to perform a test in advance in order to assess the potential for DPT investigation. When DPT results are used to define the geological structure, it is recommended to perform the probings for geophysical and geo-hydrological parameters near well-described drillings in order to calibrate their use for description of soil profiles.

Closure of probing holes

In order to prevent vertical spreading of pollution and hydraulic short circuits, it is recommended to close and compact the created holes. This is obligatory when the borehole hydraulically connects previously unconnected hydro-geological units or when DNAPL are present as they can migrate downwards along the created vertical conduit. In these cases telescoped wells can be used to prevent downward migration of contaminants through a confining layer.

Therefore – as far as this is allowed by the used DP-technique – a mixture of cement and betonite is pressed under high pressure into the borehole form the bottom of the probe during the lifting the rods (“retraction grouting”). To guarantee a sound sealing, the quality of the betonite-cement-water mixture with regard to the viscosity and the portions of betonite and cement have to be tuned to the soil characteristics.

When using DP techniques for measuring geophysical and geochemical parameters (e.g. EC, MIP and LIF) the method as mentioned above cannot be used in most cases. Over-drilling with a new probing using hollow rods for the injection of a bentonite-cement suspension can be considered (“re-entry grouting”). However, a complete sealing of the original probing hole will not be guaranteed as the new probing may create a deviant hole.

“Surface pouring” is the most simple method of borehole decommissioning. However, it may in most situations not be as effective as the other methods. It involves pouring either dry bentonite, bentonite slurry or cement grout from the surface down the open borehole after the rods and probe are removed. Surface pouring may be effective if the borehole does not collapse after the rods are removed and if the borehole is relatively shallow (less than about 5 metres).

DP probings through sealing layers into deeper groundwater-bearing layers will not be carried out when the hydraulic isolation of the layer can not be guaranteed. As a rule the use of DPT will in those cases be limited to the upper layers. An extensive geological study of the underground of the site is therefore required preliminary to the DP-probings.

Use of Direct-Push Technology

DPT can be used for a wide range of research questions. Different techniques can be combined in a single probe. The use of DPT allows to react in a flexible way on results and to adapt the programme of the investigation to these. The principle of an adaptive progress is shown in figure 1. This method has the advantage that results are obtained in a more cost-efficient manner, with a higher quality and that to optimize the situation of sampling points.

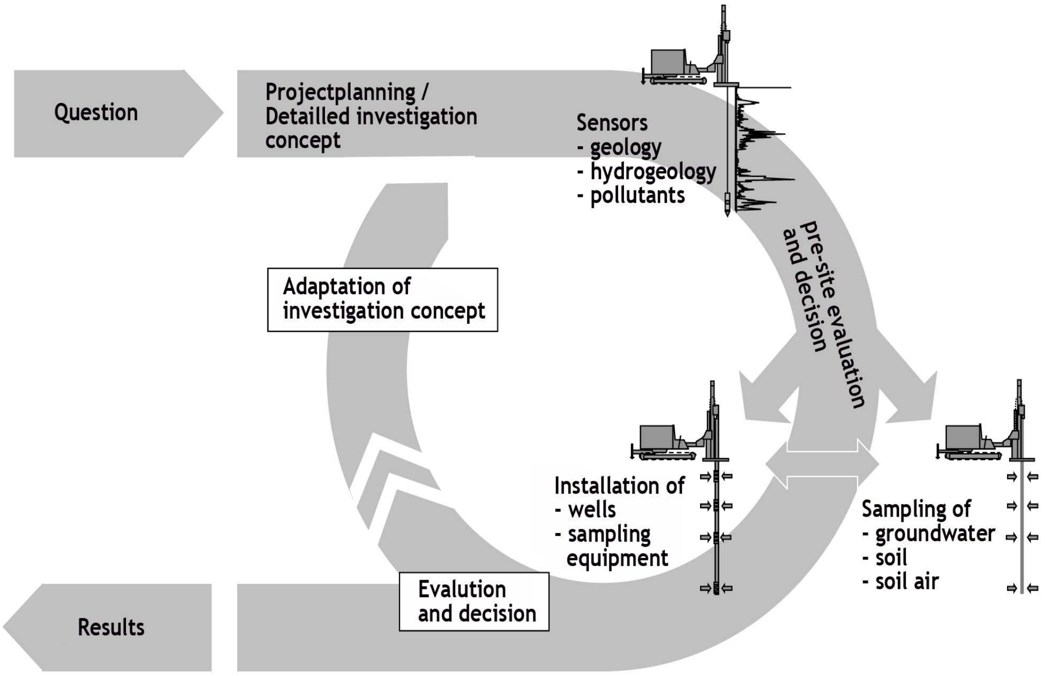


Figure 1. Adaptive progress using DPT (from: Leven et al. (2010))

General guidelines

A number of general guidelines for the use of DP can be formulated:

- a detailed work and probing plan have to be drawn up, listing the goals of the probings (order of the probings, parameters to be measured, depths, …);
- the location of underground pipes, cables and other obstacles has to be checked. In case of doubt, manual pre-drilling is necessary;
- the work is carried out by trained staff competent to evaluate results on-site. Knowledge of geology is required;
- during and immediately after the measurements a first check of quality and plausibility of the results is carried out;
- when probes require calibration, the results of this calibration remain available for later interpretation;
- the relevant parts of the equipment are cleaned between probings and after the work in order to prevent cross-contamination;
- the results are visualized as graphics and added as text. It is recommended to add the raw data to the report.

DPT technical characteristics

The table below summarizes a number of characteristics of DPT (from: Leven et al. (2010)).

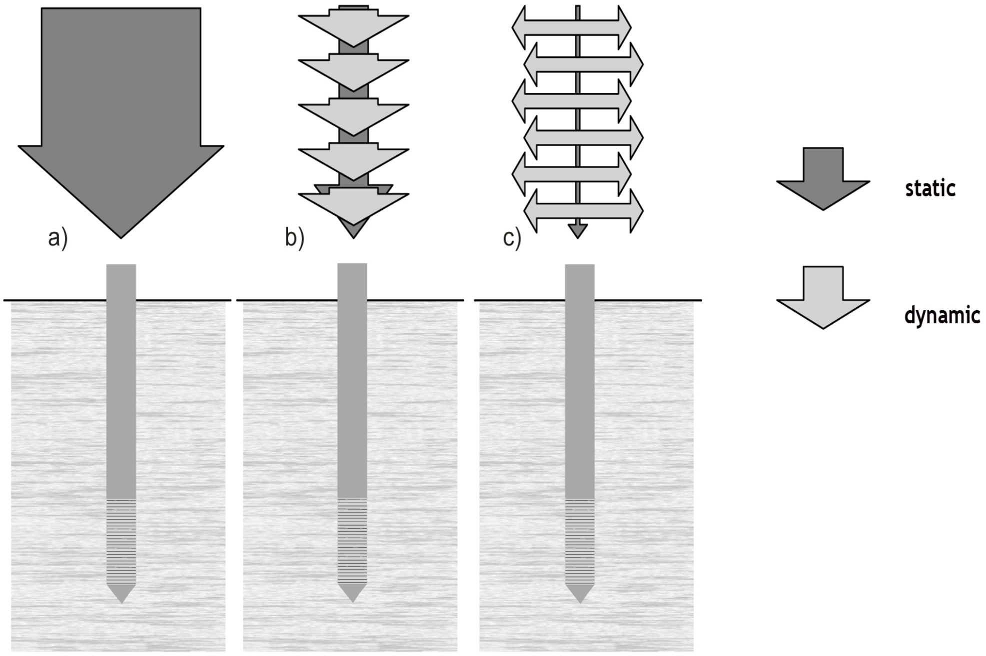
	Range	Remarks
Diameter	Outside diameter: typically 35 to 80 mm, up to 100 mm	Wall of rods: 8 tot 10 mm
Depth	Typically 15 to 35 m (dependent on the underground)	Up to 50 m
Time for a probing	Simple probings (e.g. measurements of EC): ca. 30 min Probings with groundwater sampling (e.g. sampling on 5 depths): ca. 3 h Installation of 1” measurement equipment: ca. 1 h (per probe)	
Size of equipment	From manual-driven to truck-mounted	

3 Description of techniques

3.1 Direct-push methods

3.1.1 Description

Direct-push based probings are in general carried out with a static or a dynamic driving force, or a combination of both. Static methods use the mass of a vehicle as well as anchoring in the soil for the deployment of a large reactive weight with hydraulic power. Dynamic methods use a hydraulic hammer for high or low frequency hammering or a high-speed engine for the production of high-frequency vibrations. Probes, rods and/or measuring and sampling equipment with relatively small diameter are pushed or hammered into the underground. An overview of the methods is given in figure 2.



a) Static method: the propulsion comes from hydraulic power as well as from the weight of the vehicle and anchoring in the soil;

b) Dynamic and static method in combination: the propulsion comes from a hydraulic hammer as well as from the weight of the vehicle and if necessary anchoring in the soil;

c) Dynamic and static method in combination: the propulsion comes from high-frequency vibrations as well as from the weight of the vehicle. No anchoring is required.

Figure 2. Schematic overview of propulsion methods (from: Leven et al. (2010))

3.1.2 General guidelines

The size and the chassis of the equipment (e.g. caterpillars) and characteristics of the site such as limited heights, narrow passages, soft underground, major slopes,... can limit the deployment of DP devices. In general, the heavier the carrier, the deeper it can push or hammer. On the other hand, heavier carriers are more difficult to deploy on undeveloped terrain.

Overview of systems for propulsion (from: Leven et al. (2010))

	Reaction weight (kg)	Typical depth (m)	Maximal depth (m)	Mobility
Hand hammer	14 – 40	2 - 5	12	Very good
Hydraulic hammer on mobile platform	2.200 – 7.700	6 - 35	75	Good
Anchored hydraulic press	90 – 18.000	6 - 35	60	Good
Truck with hydraulic press	14.500 – 54.000	6 - 35	100	Average

3.2 DPT for measurements of geophysical, geotechnical and hydrogeological parameters

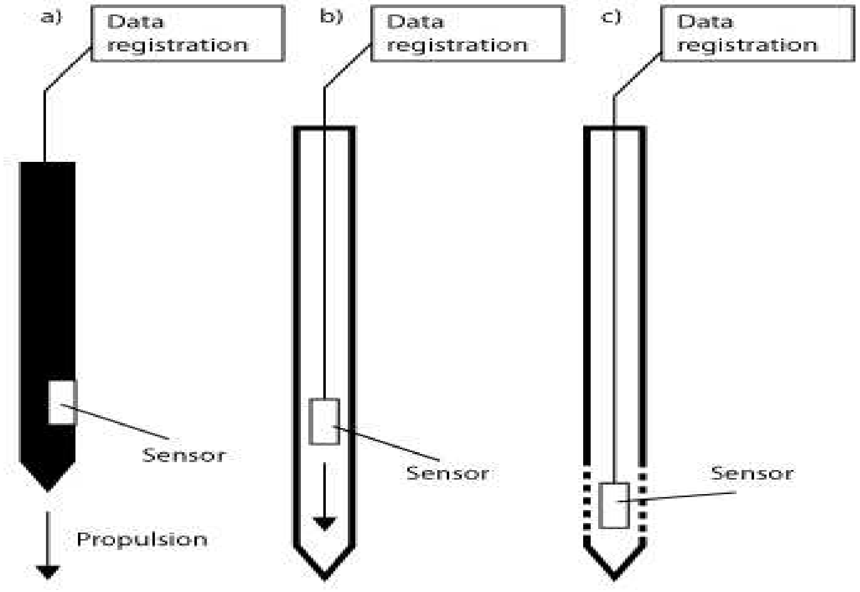
3.2.1 Description

With direct-push probes, geophysical, geotechnical and hydrogeological parameters parameters can be measured on a specific depth or along vertical profiles. Depending on the type of the probe, one or more parameters can be measured simultaneously during the probing. Within the techniques for measurements, these types can be distinguished:

a) continuous measurements during the probing;
b) continuous measurements in the hollow rods;
c) measurements on predefined depths.

The result is a continuous or discrete vertical profile.

An overview of different types of sensor systems is given in figure 3.



a) The sensor is installed directly on the probe or on the rods. Data are recorded during the probing or on specific depths;

b) Measurement are carried out when the desired depth is reached by lowering the sensors in the hollow rods;

c) On the desired depth a filter is opened and -if necessary- developed. A sensor is installed and measurements are carried out.

Figure 3. Schematic overview of DP probes for geophysical, geotechnical and hydrogeological measurements (from: Leven et al. (2010))

3.2.2 Variants (from: Leven et al. (2010))

Method	Measured parameters	Derived soil characteristics	Vertical coverage	Remarks
Cone Penetrometer Test (CPT)	Tip resistance, sleeve friction, pore water pressure	Variations in consistency and bulk density, sediment type	Continuous	Static propulsion with constant probing speed
EC-logging	Electrical conductivity	Clay mineral content, variations in sediment type	Continuous	Can be used as an indirect indicator of pollution (including NAPL)
Hammer-probing	Number of hammer-blows/10 cm	Variations in consistency and compaction	Quasi-continuous	
Soil Moisture Probe	Electrical conductivity,	Volumetric moisture	Continuous	Static propulsion

	relative permittivity	content, variations in sediment type		
Neutron-neutron/gamma - gamma-logging	Attenuation of artificial neutron or gamma radiation	Water content, density of sediments	Continuous	Measurements in hollow rods, results affected by the type of rods
Gamma-logging	Intensity of natural gamma radiation	Clay content	Continuous	Measurements in hollow rods, results affected by the type of rods
Seismic penetrometer	Compressible-wave velocties, shear-wave velocities	Type of sediments and elastic characteristics	Quasi-continuous	Production and registration of signals are spatially separated: resp. on the surface and in the probe
Injection-logging (DP-IL)	Injection rate and injection pressure of water	Variations in relative hydraulic conductivity	Quasi-continuous	
Hydraulic Profiling Tool (HPT)	Injection rate and injection pressure of water	Delineation of low-permeable layers	Continuous	
Temperature measurements	Temperature	Distribution of temperature	On specific depths	
DP-slugtest	Induced fluctuations of water pressure	Hydraulic permeability	On end depth	Quality of results dependent on reach of the filter: low permeability requires measurements over long time-period (> 1 h)
Dissipation test	Adaptation of pore pressure	Hydraulic permeability	On specific depths	Static propulsion

3.2.3 General guidelines

- Trained staff is necessary for the deployment of these techniques.
- Before and after use of the probes, control measurements have to be carried out.
- When probes require calibration, the results of this calibration have to remain available for later interpretation.
- When measurements are carried out inside hollow rods, the influence of the rods on the results has to be taken into account.
- When pre-drillings or pre-probings are carried out, this has to be taken into account in the interpretation of the results.
- In general, the probes have a bigger diameter than the rods in order to reduce the friction of the rods during the probing. When using these probes in heavy soils, the probing channel will have a bigger diameter than the rods. In this case, the risk of spreading of pollution has to be taken into account.
- During and immediately after the probings, a first check of quality and plausibility of the results is carried out on site.
- In the interpretation of results, possible deviations of the probings form the vertical axis have to be taken into account.
- the results are visualized as graphics and added as text. It is recommended to add the raw data to the

report.
- All relevant information on probings and sampling (type or probe, speed of probing, time, …) has to be registered

3.3 DPT for contaminant detection

3.3.1 Description

A number of direct-push probes allow for qualitative to semi-quantitative measurements of organic pollutants such as volatile, aromatic (BTEX) and polycyclic (PAH) hydrocarbons and inorganic pollutants, on specific depths or along a vertical axis. Depending on the type of the probe, single pollutants or groups of pollutants can be detected. Types of probes for contaminant detection that can be distinguished are:

- Membrane Interphase Probe (MIP-probe);
- Laser-Induced Fluorescence (LIF-probe), as B.ROST, UVOST and TARGOST;
- X-ray Fluorescence (XRF) and Laser-Induced Breakdown Spectroscopy (LIBS);
- NAPL visual detection (GeoVis, Videocone)
- NAPL detection by dye

The MIP-probe can be used for the detection of all organic compounds with boiling points up to 120-130℃ in the saturated and the unsaturated zone. The LIF-probe can be used for detection of light hydrocarbons and polycyclic aromatic hydrocarbons (PAH). The XRF- and the LIBS-probes can be used for the detection of heavy metals. A schematic overview of the MIP and LIF probes is given in figure 4.

NAPL can be detected visually by an in-situ camera attached to a probe. The image allows a visual evaluation of the stratigraphy and NAPL zones may be detected. The viewed area is however small (2 by 3 mm for GeoVis, resolution 20µm).

The detection of NAPL by dye uses liners equipped with a ribbon impregnated with a colouring agent that are brought in the soil by a probe. Colour reactions on the liner indicate the presence of NAPL.

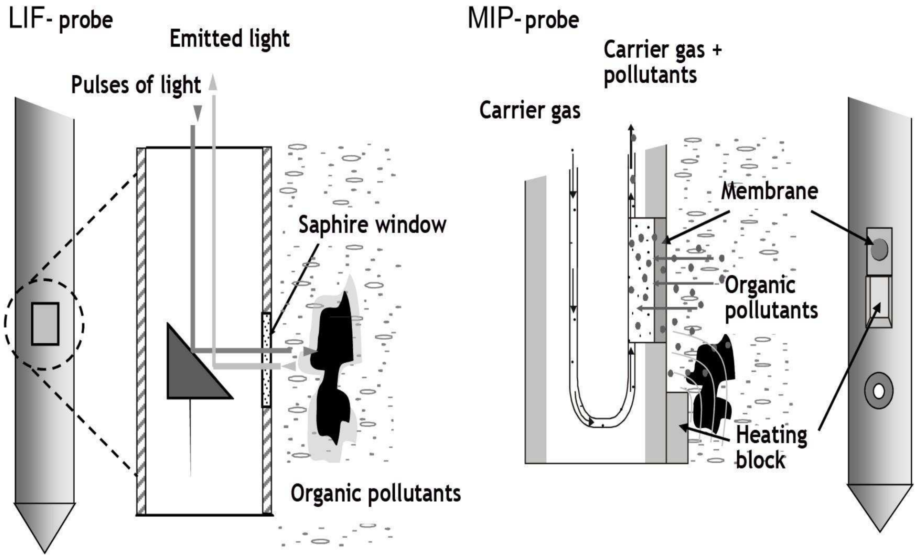


Figure 4. Schematic overview of LIF and MIP probes (from: Leven et al. (2010))

Probe	Pollutant	Vertical covering	Remarks
MIP	Light hydrocarbons, BTEX	Depth-specific to quasi-continuous	
LIF (ROST, UVOST, TARGOST)	BTEX, hydrocarbons, PAH	Continuous with depth-specific pollutant identification	Detection of PAH only with TARGOST and to lesser extent with ROST
XRF and LIBS	Metals	Continuous	
Visual detection	NAPL	Continuous	
Hydrophobic flexible membranes	DNAPL	Continuous	

3.3.2 General guidelines

- These probes can be used in combination with other probes such as the CPT-probe and EC-probe in order to determine lithology and pollution at the same time.
- The MIP probe can be used with different detectors (usually PID, FID, DELCD). Detection limits are dependent on the type of the detector.
- Detection of concentrations in the range of typical legal clean-up values is not possible for the conventional MIP. These probes can therefore only be used for the delineation of core zones or for the identification of depths for conventional sampling. New developments offer the connection of a gas chromatograph to the detectors, allowing for semi-quantitative detection (EnISSA MIP, see chapter 4.1).
- The quality of MIP-results is dependent on (amongst other things) the stability of the temperature of the heating block near the membrane. As part of the quality check, the temperature profile has to be

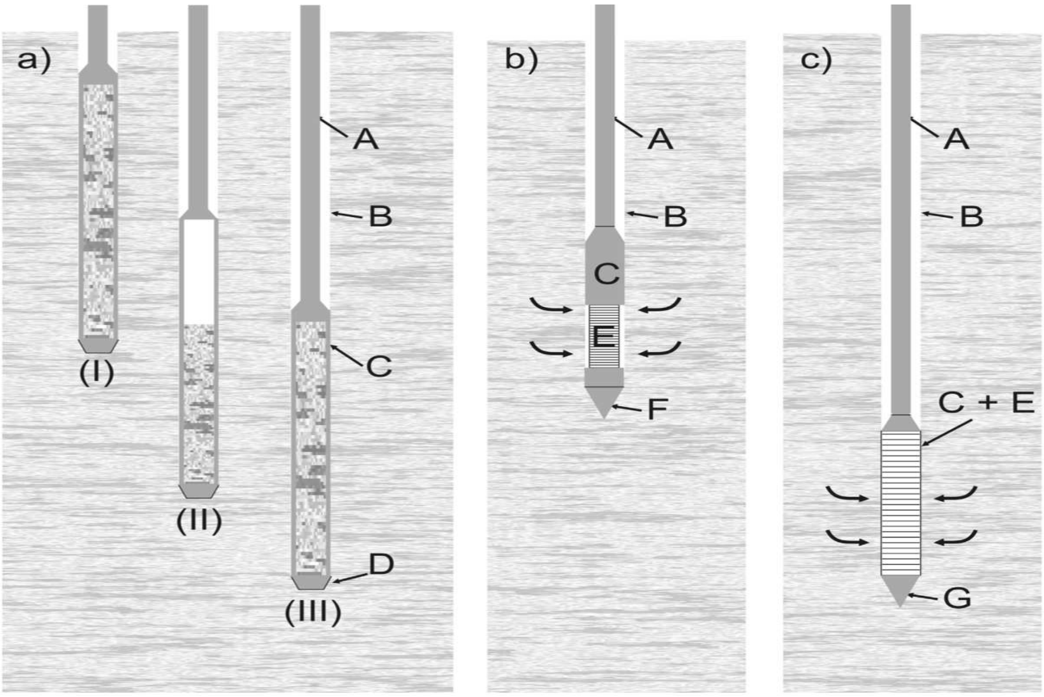
examined. Very high temperatures of the heating block can lead to unwanted and unknown changes of pollutants.

- In general, the probes have a bigger diameter than the rods in order to reduce the friction of the rods during the probing. When using these probes in heavy soils, the probing channel will have a bigger diameter than the rods. In this case, the risk of spreading of pollution has to be taken into account.

3.4 DPT sampling systems

3.4.1 Description

Direct-push systems can be used for sampling of the underground. Different systems are developed for specific applications. There are systems for sampling of soil, soil air and groundwater. Sampling systems for soil air and groundwater can also be used for short-term monitoring. For the sampling of soil, probes are available that are filled during the probing. For the sampling of soil air and groundwater, probes are brought to the desired depth, after which samples are taken in-situ or by pumping from the surface. A schematic overview of sampling systems is given in figure 5.



Legend: A – rods, B – probing channel, C – probe, D – cutting blade, E – filter, F – lost or withdrawable probing head, G – fixed probing head

a) Soil sampling systems: (I) and (III) probes on different depths, filled with soil material, (II) probe during sampling

b) system for soil air and groundwater sampling

c) system for groundwater sampling with exposed filter element

Figure 5. Schematic overview of DPT sampling systems (from: Leven et al. (2010))

3.4.2 Variants

a) Probes for sampling of soil material consists of a sampling tube with a cutting blade and a plastic or steel liner with core catcher. Depending on the probing depth and the characteristics of the underground, simple rods or a system with casing are used. With simple systems, the probing device is attached to the end of the rods. In systems with casing, the probe is brought to the desired depth in a protecting pipe, to prevent e.g. spreading of pollution when probing through contaminated layers. The probe is filled with soil material during the propulsion of the rods. The filled probe is subsequently lifted in order to retrieve the sample. Sampling is possible in the saturated and the unsaturated zone.

b) Probes for the sampling of groundwater are referred to as “temporary samplers” or “grab samplers”. They consist of an exposed or a sealed-screen filter that is advanced to the desired depth.

When probing with an exposed filter, this stays in direct contact with the surrounding soil formation, allowing for (quasi-)continuous groundwater sampling, i.e. on several depth intervals in a single probing.

Systems with a sealed-screen filter are equipped with a short filter in a waterproof probe. On the desired depth, the protective outer rod is retracted exposing the filter to groundwater. Sealed-screen samplers generally are limited to collecting one sample per advance of the sampler.

With both types, the groundwater generally flows through the filter into the rods or into a sampling chamber under ambient hydrostatic pressure. Groundwater may be collected from the sampler using bailers or pumps, or the sampler may be retracted to the surface to obtain the water sample. The filters have typical lengths between 5 and 110 cm and are perforated or covered with fine wire netting.

Sampling fine-grained formations may be difficult because of the long time it takes to fill the sampler with groundwater. Sample collection time in formations with low hydraulic conductivity may exceed several hours for some tools, compared to several minutes or tens of minutes in formations of high to moderate hydraulic conductivity. However, to avoid downtime, the samplers can be left to fill in the borehole while the installing rig moves off the hole to another location for sampling. To decrease sample collection time, samples can be collected from samplers with longer filter screens.

Multi-level samplers, most of which are exposed-screen samplers, are capable of collecting groundwater samples at multiple intervals as the sampling tool is advanced, without having to withdraw the tool for sample collection or decontamination. The screen remains open as the tool is advanced This allows samples to be collected either continuously or periodically as the tool is advanced to vertically profile groundwater chemistry and aqueous-phase contaminant distribution.

A drawback to multi-level sampling is the possible drag-down by the screen of contamination from zones above the desired sampling interval. The Waterloo Profiler minimizes the potential for cross- contamination by slowly pumping distilled or deionized organic-free water inside the drive rods to the sampling ports in the tool. The water keeps groundwater from entering the tool while it is advanced. After the first target interval is reached, the flow of the pump is reversed and the sampling tube is purged so that water representative of the aquifer is sampled.

These sampling tools are typically used during site characterization to identify plume boundaries or hot spots. They cannot be used for long-term monitoring or trend analysis since the boreholes need to be decommissioned after the sampling.

c) For the sampling of soil air, probes are used with screens on the sides or probes that are opened at the end by removal of a point at the desired depth. Sampling is done by pumping through a tube that is connected to the probe of directly through the rods. Basically, probes for groundwater sampling can also be used for the sampling of soil air.

3.4.3 General guidelines

- the use of probes with sealed filter element for groundwater sampling and the use or with casing for soil sampling, is recommended when risks exist of spreading of pollution by probing through highly contaminated layers;
- if no information is available on in particular the soil layering and texture, sampling will be “blind” which can lead to a misinterpretation of the results;
- spreading of pollution due to the use of insufficiently cleaned equipment has absolutely to be avoided;
- All relevant information on the probings and sampling (type or probe, speed of probing, time, depths, …) has to be registered;
- some probes for soil or groundwater sampling have a slightly bigger diameter than the rods in order to reduce the friction of the rods during the probing. When using these probes in heavy soils, the probing channel will have a bigger diameter than the rods. This means that in case of DNAPL pollution, risks for vertical spreading of pollution exist. In this case, the employment of this type of probe has to be evaluated in advance.

3.5 Installations for sampling of groundwater and soil air placed by DPT

3.5.1 Description

Direct-push installations for the saturated and the unsaturated zone can be divided in single and multiple well systems. Single wells can be installed with a continuous long (> 1 m) or several short filter elements. They can be sampled over the entire length or depth-specific with the use of mobile or half-stationary packers. Single wells with filter lengths < 1 m give an integral result over a relatively limited depth range. Multiple wells are permanent systems that can be sampled via the multiple channels with small-size pumps or with build-in lost pumps. Direct-push installation of wells allows for a spatially exact installation of filters and sealing layers between filters.

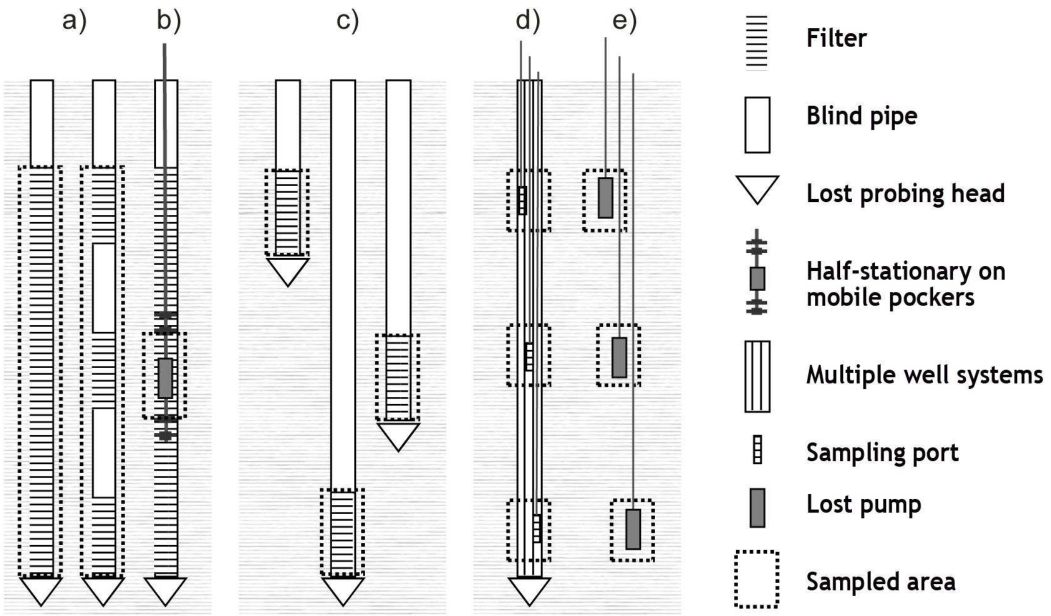
Wells can be installed with exposed or protected screen. With exposed-screen well installation methods, the well casing and screen are driven to the target depth using a single string of rods. Optimal conditions for well point installations are shallow sandy materials. Predominantly fine-grained materials such as silt or clay can plug the screen slots as the well point is advanced. Because well points are driven directly into the ground with little or no annular space, the materials are allowed to collapse around the screen, and the well point needs to be developed to prepare it for sampling.

When installing a protected-screen well, the well casing and screen are either advanced within or lowered into a protective outer drive rod that has already been driven to the target depth. Once the well casing and screen are in place, the drive rod is removed. Alternatively, the casing, screen, and a retractable shield may be driven simultaneously to the target depth. Once in place, the screen is exposed and the entire unit remains in the ground. If there is sufficient clearance between the inside of the drive rod and the outside of the well casing and screen, a filter pack and annular seal may be installed from the surface as the drive casing is removed from the hole.

When DPT wells are installed in non-cohesive, coarse-grained formations, the formation can be allowed to collapse around the screen after it is placed at the target depth since turbidity problems are unlikely. When turbidity is likely to pose a problem for groundwater sample quality, a number of methods for installing filter packs are available. The filter pack can be poured in place as the drive casing is removed. Depending on the relative size of the drive casing and well, however, it may be difficult to introduce filter pack or annular seal materials downhole unless the hole is in a cohesive formation that will remain open as the drive casing is removed. For the best control of filter pack placement and grain size, “sleeved” or “prepacked” well screens can be used.

An annular seal should be placed above the filter pack to prevent infiltration of surface runoff and to maintain the hydraulic integrity of confining or semi-confining layers, where present. Most protected-screen installations inject a high-solids (at least 20% solids) bentonite slurry or neat cement grout into place as the drive casing is removed from the hole. Similar to the pre-packed and sleeved screens mentioned above, modular bentonite sleeves that attach to the well screens and are advanced with the well during installation are also available. Some manufacturers provide a foam seal that expands immediately when the casing is withdrawn to form a temporary seal above the screen. A bentonite sleeve above the seal expands more slowly after the casing is withdrawn but forms a permanent seal once it hydrates. To ensure a complete seal of the annular space, the grout or slurry should be placed from the bottom up.

A schematic overview of installations for sampling is given in figure 6.



a) Single wells with long or several short filters

b) Single well depth-specific sampling with half-stationary or mobile packers

c) Single wells with short filter lengths

d) Multiple wells with parallel channels

e) Multiple wells with lost miniature pumps

Figure 6. Schematic overview of installations for soil air and groundwater sampling (from: Leven et al. (2010))

3.5.2 General guidelines

- In fine sands, loam or clay with low hydraulic permeability, the use of these techniques is limited, as the groundwater flow towards the filter can be below the pumping flow. The filter can silt up or the gauze can clog up.
- Due to high loam and clay content, the soil surrounding the filter can clog up and lower the hydraulic permeability when pumping. At the same time, the higher solidity of the soil can prevent the closing of the borehole after lifting the probe, leading to short circuits in the groundwater flow. This will impede depth-specific sampling. In this case, sealing systems such as betonite packers of swelling clay cartridges can be build in. Sampling can then only be carried out after sufficient waiting time.
- Installation of wells with exposed-screen is not recommended for installing well screens within or

beneath contaminated zones because drag-down of contaminants with the screen may cross-contaminate sampling zones and make acquisition of representative samples impossible.

- Due to short filter elements or short sampled segments, the sample volume is limited. With sampling flows of 100 to 1000 ml/min (“low flow sampling”), only the area immediately around the filter is sampled. The results are therefore only representative for this limited area. For the investigation of a bigger area, a dense sampling grid has to be used.
- A direct comparison with bigger wells and pumps with higher pumping rates, is in most cases not meaningful as the principles behind both techniques are different. Heterogeneities in the underground and distribution of pollution are handled in a different way.
- The choice of the type of the well is dependent on the goal of the investigation (e.g. bigger diameters allow for higher pumping rates of the use of packers for depth-specific sampling).

4 Case-studies

4.1 Use of EnISSA MIP

Site description and problem definition

The site of a former spinning and weaving mill in Kortrijk (Belgium) is polluted with chlorinated solvents and volatile hydrocarbons. Previous investigations showed a large-scale groundwater pollution with indications of the presence of DNAPL. The groundwater pollution with VOH, BTEX and mineral oil has spread in the loamy sandy underground to a depth of 20 m-gl where it is confined by a tertiary clay layer. In horizontal direction, the plume has spread over a distance of circa 130 m.

Previous MIP probings indicated the presence of DNAPL on depths between 3 and 6 m-gl. The highest concentrations in groundwater were measured in a well with filter just above the clay layer, but most MIP were not set through to this depth.

Hydrophobic Flexible Membranes (RNS, Ribbon NAPL Sampler) and EnISSA MIP were applied in the core zone to trace the presence of DNAPL. In addition, EnISSA MIP was used to check the contours of the groundwater pollution. The RNS and EnISSA MIP were carried out as a test project within the framework of CityChlor and were combined with 'classic' soil and groundwater sampling.

Fieldwork

5 EnISSA probings were carried out in (possible) core zones and 3 in the plume zone. RNS was applied on 4 locations. The locations for the EnISSA probings and the RNS sampling were defined on the basis of previous investigations.

Results and interpretation

EnISSA MIP was applied in the core zone in order to verify and to characterize the vertical distribution of the pollution. A comparison between the results of conventional MIP and EnISSA MIP is given in figure 7. Note that the conventional MIP were carried out in 2005 and that these technologies have also evolved since then.

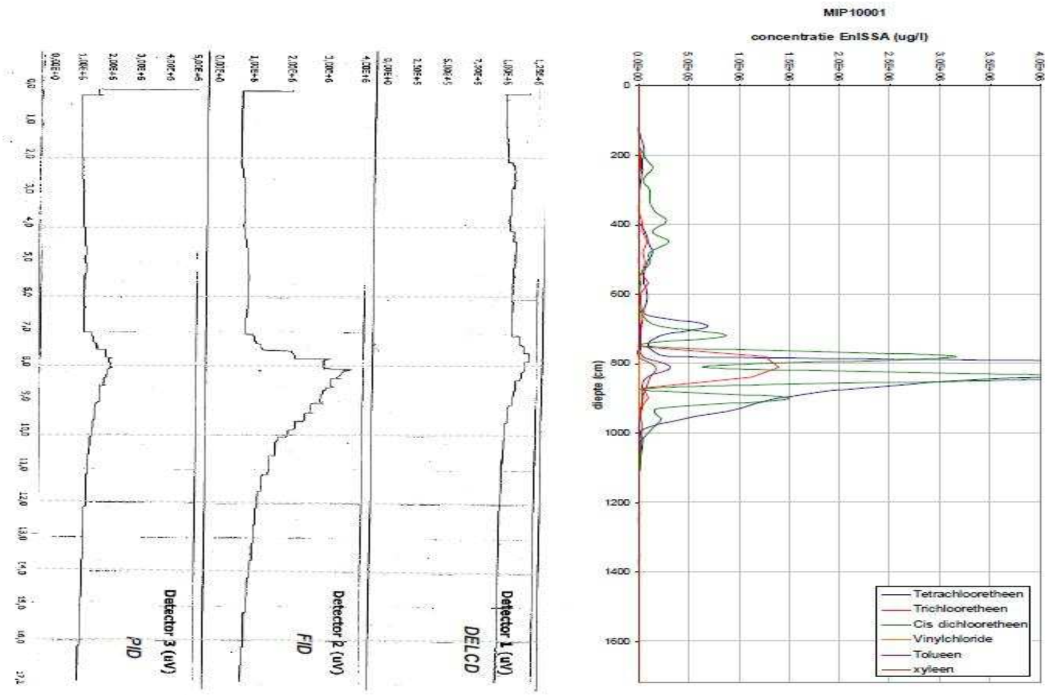


Figure 7. Results of conventional MIP vs EnISSA MIP

The polluted zones are decently mapped as well by the conventional MIP as the EnISSA MIP. EnISSA MIP has the advantage of component-specific measurements. The zone near 3 m-gl is mainly polluted by TRI and CIS while the zone near 6 and 8 m-gl is characterized by PER. The EnISSA MIP also shows a significant pollution with toluene that is not shown by the conventional MIP. The FID from the conventional MIP shows a strong tailing effect.

Additional EnISSA MIP were applied in the plume area. Comparison with classic sampling showed that although there is a rather good correlation, EnISSA MIP results can not be compared one to one with groundwater analysis due to differences inherent in the methods.

RNS was applied on 4 locations where DNAPL was suspected. None of the RNS showed indications of presence of DNAPL. Monitoring wells near the most suspected zone showed a small sinking layer as well as a small floating layer: a few mm of product were detected in the wells. Analysis of the products demonstrated the presence of - besides VOH - PAH and aromatic components. So although NAPL is present in the subsoil, there has apparently been no contact between the product and the membrane.

Further reading

Report 'CityChlor pilootonderzoek EnISSA MIP Spinnerijkaai Kortrijk', OVAM, 2012
Report 'CityChlor pilootonderzoek NAPL FLUTe sampler Spinnerijkaai Kortrijk', OVAM, 2012

4.2 Site screening with DPT techniques

Site description and problem definition

A site with a surface area of 2,7 ha in the harbour of Rotterdam was in use form 1964 to 2009 as a terminal for storage and transfer of chemicals. An aerial view of the site is given in figure 8. Previous investigations showed that the activities had caused a complex soil pollution as the soil is composed of an alternation of clayey and sandy layers. The site is mainly polluted with chlorinated compounds (VOH) and volatile aromatics (BTEXN).

Figure 8. Aerial view of the site

The development of the conceptual site model showed that there was insufficient insight in in the situation of the sources of the pollution, the spreading of pollution (NAPL) towards deeper layers and the presence of preferential channels in the soil. In order to understand these lacks of knowledge in a cost-effective way, a combination of soil air measurements, MIP and traditional techniques were used.

The search for source zones: screening of the soil-air

For a fast localisation of the shallow source zones, soil-air measurements were carried out. In a time-frame of 8 days, 150 direct-push probings were executed to a depth of 0,8 m-gl. Soil air was extracted through a probe and the content of volatile compounds was determined with a Photo Ionisation Detector (PID). The results were correlated to subsequent soil samples and laboratory analysis.

The interpretation showed that the pollution was mainly situated on the western part of the site. It became also clear that it was not a single continuous pollution but that 6 sources zones with different characteristics could be distinguished.

Spreading in the depth: screening with the MIP

Previous investigation showed that for at least one source zone, the pollution has spread to the deeper underground. The MIP was used to verify to what extent the deeper soil was affected. In order to gain insight in the relation between geology and the pollution was chosen for MIP-CPT probings. In 2 days 11 MIP-CPT probings were executed to a maximal depth of 35 m-gl. The results were used to refine the conceptual site model and to define the locations and depths of additional soil sampling.

The interpretation showed that in 2 of the 6 source zones the pollution had spread to the deeper underground. It became clear that the presence of soil pollution is correlated to the presence of clayey layers. From these layers pollution continues to leach to the groundwater.

4.3 Use of CPT, MIP and BAT for site characterization

A site of 6.700 m^3 near Paris has been in use by metal-using industry since 1926. PCE and TCE were used and are still being used on the site and caused a pollution of soil and groundwater with chlorinated solvents. The soil is composed of 50 cm to 1 m of embankments, then about 3 m of clay and finally fine sands up to 10 m-gl. The mean depth of the groundwater-table is 1,5 to 2 m-gl. Previous investigations showed 3 source zones of VOC pollution on the site.

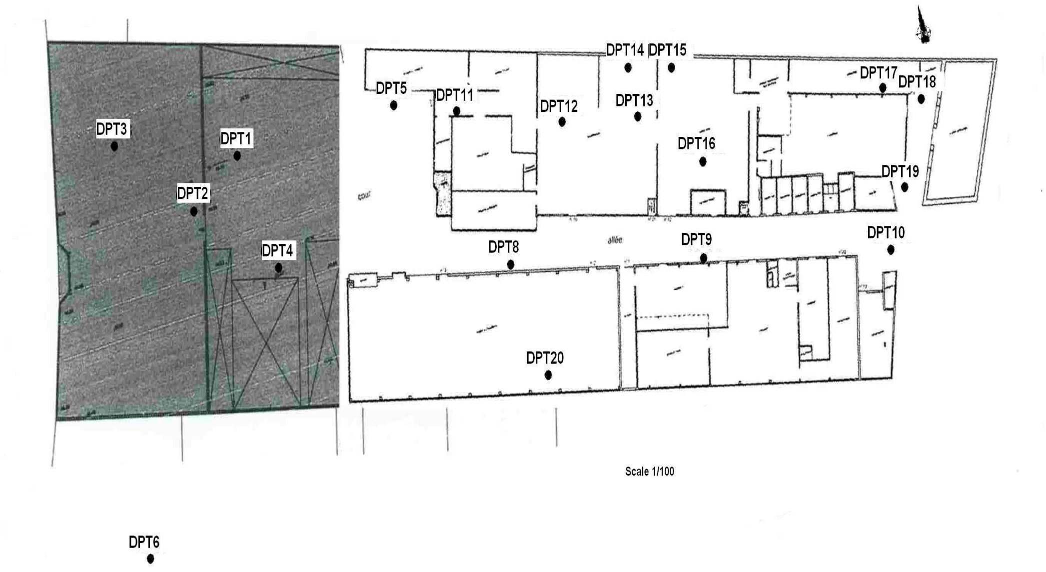


Figure 9. Overview of MIP-CPT locations

DPT techniques were used in order to decide where to install groundwater wells and soil air wells for a cost-efficient characterization of the site. In a first step MIP-CPT was used as a screening technique. 19 locations inside and outside the buildings near supposed pollutions sources and downstream of these were investigated. In the most polluted zones, 10 BAT samplings (see chapter 5.3) were carried out on different depths. An overview of the MIP-CPT locations is given in figure 9.

The DPT results confirmed the expected geology. MIP-results helped to indicate the locations for BAT sampling. Results of BAT sampling confirmed what was obtained with MIP.

Further reading

CityChlor report ‘Caractérisation des eaux souterraines, des sols, des gaz du sol et de l'air intérieur : site pilote Ile de France’.

5 Annexes

5.1 Membrane Interphase Probe (MIP)

5.1.1 Definition

Depth-specific in-situ detection in the saturated and the unsaturated zone of volatile organic pollutants

5.1.2 Description and principles

The MIP probe is equipped with a semi-permeable membrane that is heated up to 80 tot 125℃ so that vol atile organic compounds in soil and groundwater evaporate and permeate through the membrane. The gaseous compounds are brought by a carrier gas – usually nitrogen – through the hollow rods to aboveground online detectors. Typically, three detectors are used. The PID-detector (Photo Ionisation Detector) records the presence of compounds with an Ionisation Potential lower than the potential of the lamp (standard PID 10,2 eV) and is sensitive to aromatic hydrocarbons. The FID-detector has a low selectivity and is applied as a universal detector. The FID is sensitive to alkanes and other aliphatic and aromatic hydrocarbons. The DELCD (Dry Electrolytic Conductivity Detector) is sensitive to chlorinated and bromated hydrocarbons.

Figure 10. MIP probe

5.1.3 Objectives and performance

Parameters

Volatile organic compounds

Output

Semi-quantitative non-pollutant-specific depth profile

Detection limits

Detection limits are dependent on the type of detectors used, the soil type and the volatility of the compound: monoaromatic hydrocarbons 5 – 100 mg/l, chlorinated aliphatic hydrocarbons 1 – 50 mg/l, alkanes 250 – 400 mg/l, MTBE 25 mg/l.

5.1.4 Applicability

Medium

Saturated and the unsaturated zone (NAPL-phase, dissolved phase, soil air)

Capacity

Ca. 80 -150 m/day

Range

Maximal depth ca. 35 m

Additional steps

Results are available on site, but data processing and interpretation by trained staff is necessary.

5.1.5 Operation

Points of attention

Probing through highly polluted zones can lead to 'tailing' of the signals due to the memory-effect of the equipment. This can lead to a raised detection limit and will hamper the vertical delineation of highly polluted zones.

A response test has to be carried out in the beginning and in the end of the use of the MIP in order to define the trip time, i.e. the time it takes for the contaminant to go from the probe to the detectors. This time is needed for depth calculations.

The heating capacity of the heating element is crucial in order to maintain the temperature as constant as possible. A non-constant temperature will influence the detection limits.

Sample volume

N.a. as no samples are taken

Sample conservation

N.a. as no samples are taken

Costs

Ca. 25 to 55 €/m depending on the MIP-system used and depth of the probing

5.1.6 Evaluation

When to use

The technique is of value for the screening of potentially polluted sites, in particular for sites polluted with DNAPL. It allows to identify (highly) contaminated zones in the horizontally and the vertical plane and will therefore aid in working out a sampling strategy for the site.

Due to the relatively high detection limits, the technique can not be used for delineation up to background values or soil clean-up values, but it is suitable for the delineation of highly polluted zones.

Advantages

Rapid delineation of soil contamination
Aid to define the right locations to take soil and groundwater samples

Drawbacks and limiting factors

False negatives as well as false positives have been observed.

The results are semi-quantitative, as the signal is influenced by the lithology and the soil characteristics. The evaporation process releases pollutants in as well soil, groundwater as DNAPL phase. The results can therefore not unambiguously be correlated to concentrations measured with conventional techniques.

The response of the system is defined by the diffusion through the semi-permeable membrane. Therefore, the wear of the membrane has to be closely monitored in order to replace it when necessary.

Produced waste

None

Level of development

The technique is well developed and widely used since years.

Alternative and additional techniques

MIP is often combined with CPT or EC-logging in order to simultaneously obtain information on soil texture and layering.

5.1.7 New perspectives

The connection of a gas chromatograph (GC-MS) to a MIP probe allows semi-quantitative component-specific detection of pollutants (Enissa MIP, see chapter 4.1).

The use of a heated trunkline will prevent condensation of pollution in the line towards the detectors and will therefore limit the tailing effect.

5.2 Hydrophobic Flexible Membranes

5.2.1 Definition

Depth-specific in-situ detection of DNAPL

5.2.2 Description and principles

DNAPL can be detected by the use of colouring agents (dyes) that discolour in the presence of hydrophobic compounds. A liner fitted with a dye impregnated ribbon can therefore be used for in-situ detection of DNAPL zones. Originally sudan red was used as the dye, but is being replaced by non-toxic products of which the name is not revealed by the manufacturer. The liner is deployed through the rods of a direct-push rig. The liner is pushed directly into the rods with the hydrophobic ribbon facing out. Water is used to carry the liner down to the bottom of the cased hole where it is anchored by a sacrificial rod tip. As the rods are pulled up, more water is added to ensure that the liner and the reactive ribbon are kept against the surrounding soil. The water also should supply sufficient strength to keep the hole open. After a period of time (minutes to hours), the liner is removed inside out so that the reactive material does not touch the wall as it is brought to the surface. On the surface, the liner is turned inside out or cut open. Coloured spots indicate that the reactive ribbon has come into contact with DNAPL.

Figure 11. Colour-reaction indicating the presence of DNAPL

5.2.3 Objectives and performance

Parameters

The dye reacts with hydrophobic compounds and will therefore react with PER and TRI as DNAPL. For less common chlorinated solvents, the reaction may be less clear. Also LNAPL can be detected although the colour reaction is less obvious.

Output

Profile of depth discrete DNAPL distribution

Detection limits

Only DNAPL phase is detected. Dissolved phase are not detected.

5.2.4 Applicability

Medium

Saturated and unsaturated zone

Capacity

Use of a liner to 20 m takes 3 to 4 hours

Range

Maximal depth ca. 35 m

Additional steps

None

5.2.5 Operation

Points of attention

The reaction between the dye and the DNAPL occurs quickly (5-10 minutes), but longer exposure gives larger and clearer discolourings.

Sample volume

Stained areas can be preserved for laboratory analysis to identify the compound.

Sample conservation

Unknown

Costs
Liner ca. 45-55 €/m, not including installation

5.2.6 Evaluation

When to use
The technique gives information on the vertical distribution of DNAPL in the underground. It should be considered as an additional technique in situations where exact location of DNAPL zones is required (e.g. design and monitoring of in-situ remediation projects)

Advantages
In-situ verification of DNAPL through direct reaction.

Drawbacks and limiting factors
Some DNAPL chemicals may wick to the liner so that a much wider area is indicated than is actually there.

If there is a concern about spreading of DNAPL, the technique should not be used as it requires the borehole to remain open while the liner is placed and removed.

Because of disturbances caused by the DP rig (smearing of clay on the borehole walls), the technique may be subject to false negatives.

Produced waste
The water that is used to keep the liner in place does not come into contact with the groundwater and can therefore be discharged on site.

The used liners can be rolled into a small bundle for disposal. When not cut open, the liners can be re-used after replacement of the ribbon.

Level of development
Validated technique, false negatives may however occur (see chapter 4.1)

Alternative and additional techniques
The technique is an additional technique to unambiguously check the vertical distribution of DNAPL zones.

5.2.7 New perspectives

The liner can be fitted with discretely spaced hydrophobic sorbent packs, allowing for analysis and identification of DNAPL compounds

5.3 BAT sampler

5.3.1 Definition

Depth-specific in-situ sampling of groundwater or soil air

5.3.2 Description and principles

The BAT system is a direct-push probe that can be used for taking discrete groundwater samples at multiple depths in a single push. The BAT probe consists of a tip with a filter (length 10 cm) and a housing, the top of which is sealed with a disc containing a flexible septum. The tip is driven directly to the desired sampling depth or is installed in a pre-drilled hole. A tool containing a vacuum sample vial with a septum cap and a double ended hypodermic needle is lowered down the rod. When the tool encounters the sample housing, the needle penetrates the housing septum at the same time it penetrates the vial septum. Due to the action of both the groundwater pressure and the suction in the sample tube, groundwater and/or soil gas will be drawn into the sample tube. Upon lifting the he flexible septa in both the filter tip and the sample tube will automatically reseal. The liquid and/or gas sample is thereby kept hermetically sealed all the way from the point of sampling into the laboratory. The filter tip can be left in place for monitoring purposes.

Figure 12. BAT sampler

5.3.3 Objectives and performance

Parameters
Depending on laboratory analysis

Output
Depth-specific groundwater or soil air sample

5.3.4 Applicability

Medium
Groundwater and soil air

Capacity
The time needed for filling the vial is a function of the permeability of the soil. In medium to high permeable soils it is required only a couple of minutes for taking a full sample, whereas in low permeable soils, k < 10-10 m/s, it will take several hours. In case the vial has not been filled enough with groundwater, the vial can simply be reconnected to the filter tip.

Range
Maximal depth ca. 35 m

Additional steps
Laboratory analysis

Detection limits
Depending on laboratory analysis

5.3.5 Operation

Points of attention
The filter tip has a “dead” volume of 10 ml which ought to be purged before taking a fresh sample of the groundwater.

Sample volume
Standard vial content for 1” systems is 35 ml. Two sample vials can be cascaded together using an additional

double-ended hypodermic needle. Using a cascaded vial will also eliminate all headspace in the lower vial.

Sample conservation

As conventional groundwater samples

Costs

Ca. 25 €/m and 125 €/sample (not including analysis)

5.3.6 Evaluation

When to use

Depth specific groundwater of soil air samples.

Advantages

The BAT probe does not require pumping equipment, preventing losses of pollutants due to pumping and handling of the samples.

Coupled with the results of MIP measurements, it can be very efficient to take depth discrete samples of groundwater where a high contamination has been discovered.

Drawbacks and limiting factors

The system does not identify stratigraphy, so the sampling profile points need to be identified by a separate technique. Sampling is time consuming when working in a low permeable horizon.

Produced waste

The flexible septum in the filter tip and vials can be pierced hundreds of times without loss of its automatic, self-sealing function. The filter tip can therefore be re-used or left in place for long-term monitoring. The vials can be re-used after cleaning.

To avoid cross-contamination, filter tips can not be re-used between sampling points and have to be disposed off.

Level of development

Validated technique, applied by routine

Alternative and additional techniques

The BAT filter tip can be combined with probes for measurements (and logging) of pore pressure and groundwater levels and measurements of permeability.

The technique can be used for groundwater sampling at depths indicated by MIP probings.

6 List of abbreviations

BTEX(N)	Benzene, toluene, ethylbenzene, xylene, (nafthalene)
CPT	Cone penetrometer test
DCE	Dichloroethane
DELCD	Dry electrolytic conductivity detector
(D)NAPL	(Dense) non-aqueous phase liquid
DP(T)	Direct-Push (technology)
EC	Electrical conductivity
EnISSA	Enhanced in situ soil analysis
FID	Flame ionisation detector
GCMS	Gas chromatography Mass Spectrometry
LIBS	Laser-induced breakdown spectrometry
LIF	Laser-induced fluorescence
MIP	Membrane interface probe
MTBE	Methyl tertiary-butyl ether
PAH	Polyaromatic hydrocarbons
PCE	Perchloroethylene
PID	Photo ionisation detector
RNS	Ribbon NAPL sampler
TRI	Trichloroethylene
VC	Vinylchloride
VOH	Volaltile organic hydrocarbons
XRF	X-ray fluorescence

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