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3 Direct Sensing

Most direct sensing tools are screening tools used to rapidly and efficiently detect the presence of contamination and characterize subsurface conditions. These tools provide high-resolution subsurface lithologic and groundwater data to aid in site assessment and improve the CSM, which allows a site or project to progress more rapidly toward cleanup or closure. Aside from profiling tools, where physical samples are collected (such as groundwater grab samples), many direct sensing tools are qualitative or semi-quantitative. Data generated with these tools can be used to select confirmatory soil boring and monitoring well locations to verify and enhance the direct sensing results.

Direct sensing tools are typically deployed using direct-push technology or are deployed in open boreholes. Given the potential for a high resolution of data, direct sensing investigations can be developed on a variety of scales based on the CSM and data objectives. Direct sensing tools can significantly improve a site CSM as well as help in the development of a more robust remedial design that addresses mass distribution, heterogeneity, and hydraulics by aiding in the understanding of the following:

- exposure pathways
- processes affecting fate and transport of contaminants
- contaminant mass distribution and flux by phase and media
- how remedial measures will affect the contaminant

The general adoption of direct sensing tools requires overcoming multiple barriers, such as misperceptions that the tools are not readily available or too expensive and beliefs that the resulting data are perplexing or subjective. The latter may result from a lack of knowledge of the basic principles underlying the function of direct sensing tools. Finally, the lack of guidance for the application of direct sensing tools and integrating them into a project to meet characterization and remedy objectives results in a hesitancy to use these tools.

3.1 How to Select and Apply Direct Sensing Tools Using this Document

Direct sensing tools evaluated in this section are based on subsurface advancement using direct-push technologies for the following data:

- downhole analytical [laser-induced fluorescence (LIF), optical image profiler (OIP), and membrane interface probe (MIP)]
- downhole physical [cone penetrometer testing (CPT) and electrical conductivity (EC)]
- hydraulic profiling [hydraulic profiling tool (HPT), Waterloo® advanced profiling system (APS) and HPT-groundwater profiler (HPT-GWP)]
- flexible liners [flexible underground technology (FLUTe™)]

In this guidance, each tool section includes a discussion of what the tool tells you, how it works, variations, benefits, appropriate use, limitations (both technical and nontechnical), data collection design, quality controls, data interpretation and presentation (including data extrapolations and misuse), which tools can be used together, costs, and references. The Direct Sensing Tool Summary Table allows you to select direct sensing tools to satisfy characterization requirements for a specific topic of interest. This table can help you identify the attributes and limitations of a selected tool. Direct Sensing Checklists (.xlsx version) are provided to support use of a selected tool and project management.

3.1.1 Tool Availability

The direct sensing tools described in this section are generally available in North America and many countries around the world. The systems associated with the tools are often portable and, with a trained operator, can be relatively easily transported if a local platform (for example, direct push rig) to “drive” the sensors is available.

3.1.2 Regulatory Considerations

Most direct sensing tools described in this section have proven histories of use and have been approved by regulators for use at particular sites across North America. Some regulators may not be familiar with the tools; however, this guidance provides information to assist those regulators in understanding the use and limitations of these tools. Nevertheless, practitioners should be prepared to provide regulators with information, case studies, and explanations of the tool's use in the field.

3.1.3 Public Acceptance

While the public may be unaware of direct sensing tools, acceptance and common use by practitioners and regulators who support and promote the technology generally leads to greater public acceptance. Direct sensing tools can significantly reduce the degree of uncertainty in the CSM by providing detailed three-dimensional data. The level of detail and the way the information is presented can increase the public's understanding of the CSM and potential receptor impact posed by the site. In turn, a clearer understanding of the site for all stakeholders can facilitate agreement of the best path toward closure.

3.1.4 Access

Most direct sensing tools use direct-push platforms to drive sensors and, therefore, need appropriate site clearance for this equipment. Probes can be advanced with smaller track-mounted direct-push-type drill rigs (versus large truck-mounted drilling rigs) that allow access to areas with low overhead clearance limitations (for example, inside buildings) and soft or unstable ground. Most direct sensing tools can be operated remotely from the platform, providing significant versatility.

When a direct-push platform is used, the application of direct sensing tools is limited to use in unconsolidated sediments or lightly consolidated or cemented rocks because cobbles and boulders can prevent the sensors from being driven into the subsurface. To investigate bedrock and other consolidated strata, boreholes can be drilled using other methods (for example, sonic, air-rotary casing hammer), but these investigations must be custom designed and are not routine.

3.1.5 Data Collection Design

To ensure that the data collected during the investigation using direct sensing tools is useful and cost-effective it is particularly important to define the purpose of the investigation (for example, identifying locations for soil borings/monitoring wells, assisting in the design of a remedial system, geotechnical investigation). Some pre-implementation data that may be useful for enhancing the CSM prior to beginning any direct sensing investigation include:

- point(s) of release or source area(s) information
- historic use of the property
- location of underground utilities or structures
- available soil and groundwater sampling data
- depth to groundwater and bedrock

These data should be used to develop proposed boring locations, and measurements of depth to groundwater and depth to bedrock can assist in estimating the total depth of the proposed borings.

Direct sensing tools can be used in conjunction with either static or dynamic sampling approaches. If using a fixed sampling approach or as the initial step in a dynamic sampling approach, boring locations are placed on a grid pattern so that resulting data aids in the understanding of the total subsurface. This approach is more useful in areas where little is known regarding contaminant distribution and hydrological conditions at a site. If the project budget is limited, sampling transects across key areas helps develop a site-wide understanding of the subsurface geology. Dynamic work strategies can use the flexibility provided by these tools to adapt the sampling plan (for example, modify or add sampling locations) in real-time to resolve uncertainties. The number of sampling locations needed for investigations using direct sensing tools varies from site to site and may be determined by defining the number of data points required to assess the geology, hydrogeology, and preferential migration pathways.

Similar to traditional drilling tools, direct sensing tools carry the risk of cross contamination depending on the depth of penetration. Cross contamination occurs when two or more transmissive zones that are separated by a lower permeability barrier are connected. If one of the transmissive zones contains NAPL or high contaminant concentrations, it is preferable to stop the penetration at the top of the lower permeability barrier so that the potential to open a pathway for contamination to migrate into a deeper, less contaminated or cleaner zone is limited.

While it is expected that direct sensing tools act as a seal when in direct contact with the subsurface, this is not the case during tool retrieval. If a monitoring device will not be installed, grouting the hole is the general best practice to prevent vertical migration of contaminants. Most states have rules or guidelines for sealing such boreholes under their water well drilling program.

3.1.6 Cost Considerations

A site characterization cost estimate should compare direct sensing technologies to traditional approaches to assess the most cost-effective method of filling the identified data need. Most direct sensing tools described herein provide real-time data evaluation, and, therefore, reduce the need for multiple mobilizations by allowing the investigation scope to be adjusted in the field as data are collected. The cost saved by avoiding multiple mobilizations should be considered, particularly when mobilizing equipment to remote areas or areas without established equipment and personnel.

As with all site investigation technologies, the primary considerations affecting cost are the number and depth of borings. Other common cost considerations of direct-push, direct sensing technologies are as follows:

- Mobilization – lump sum cost to mobilize the tool to the site, which varies depending on site location and proximity to tool suppliers and contractors
- Tool rental – day rate to operate the tool, including costs for drilling (daily rental rate)
- Logging/data generation– data management or data generation fee that is charged on a per day or per foot (ft) basis, including time to log the linear feet of drilling
- Duplicate borings for QA/QC
- Confirmation sampling (coring) and analysis for QA/QC
- Grout – per ft basis cost for use of material, if needed
- Oversight – labor cost for consultant to direct contractor on-site
- Weekend-in-place and/or per diem– an amount of money provided to a contractor to spend each day while working on lengthy investigations or investigations in remote locations
- Lost tooling or equipment –fee for tools or equipment lost down the borehole; the bid should clearly identify who is responsible for lost tools and the timing for replacement).
- Data post-processing and analysis – Additional costs may also be associated with post-processing and analysis of data, depending on project needs.

3.1.7 Supporting Tools

A variety of supporting tools may be used to strengthen and verify the results from the various technologies described in this section. Supporting tools are considered primary screening tools in some situations; therefore, the project scope should include the overall goals of the investigation and identify technical lines of evidence that need to be developed when methods and technologies are being selected. These supporting tools can be used to determine sample types, locations, and depths and analytical parameters so that specific compounds are identified, and actual mass concentrations are measured. Using these data in conjunction with other tools guides additional sampling efforts and monitoring well placement and screening. Like when using any tool, the user should be aware of tools' limitations in all applications.

3.1.7.1 Sampling

Advanced sampling tools provide physical samples of the media being investigated for field or laboratory analysis. These tools use methods that allow sample collection (groundwater, soil, or soil gas) over discrete depths (from a few ft to a few inches) and generally are employed at multiple depth intervals in a boring to provide a high-resolution vertical profile of analyte concentrations or physical properties across a formation. Samples are analyzed using appropriate field analytical or laboratory methods.

Advanced sampling tools include direct-push temporary well point systems and multi-level groundwater monitoring systems.

Direct-push temporary well point systems include Geoprobe Systems® Screen Point (SP) samplers (SP16, SP22, or SP60) and Sonic Screen Points. Multi-level groundwater monitoring systems include the Solinst Continuous Multichannel Tubing (CMT) system, Solinst Waterloo Multilevel Groundwater Monitoring System, Westbay® System, and Flexible Liner Underground Technologies (FLUTe™) system. Use of small diameter pre-packed well screens can also improve sample integrity compared to conventional well completions. Piezometric testing or monitoring can also be conducted with some of these systems. The Direct Sensing Tool Summary Table provides additional information on some of these tools.

Environmental soil sampling has traditionally included methods originally designed for geotechnical sampling, such as hollow-stem auger and sampling with drop hammer split-spoon samplers, which result in large data gaps and excessive waste soil. Better alternatives to these traditional methods include advanced site characterization technologies such as direct-push continuous dual-tube systems (for example, Geoprobe DT22 and DT325); hollow-stem auger continuous core systems; and, in more difficult drilling lithologies, sonic dual-tube continuous coring systems.

3.1.7.2 Analysis

Advanced analysis tools, rather than providing physical samples for subsequent analysis, are used to derive information from these samples or to directly assess flow characteristics or interconnectedness in bedrock. Logging bedrock cores and measuring fracture flow in open boreholes are examples of advanced analysis tools. The discrete-fracture network (DFN) method is an example of a complete system approach, developed by Dr. Beth Parker and her research team at the University of Guelph and summarized in (Parker 2007), to improve contamination characterization in fractured rock.

3.1.7.3 Field Analyses

Where direct sensing tools need actual soil, soil gas, or groundwater confirmation, direct sampling methods can be conducted, and samples can be analyzed in a conventional laboratory or by using mobile laboratories, various field instrumentals, or test kits. Where direct sensing tools cannot be used due to site geology, contaminant type, or other constraints and high-resolution soil, soil gas, or groundwater samples are collected instead, analysis using these methods can still allow real-time evaluations applying adaptive management strategies to the site characterization, similar to using direct sensing tools. A partial list of examples of supporting field analysis tools and methods is as follows:

- mobile laboratories (many analytical methods available)
- portable gas chromatograph (GC)
- portable gas chromatography /mass spectrometry (GC/MS)
- handheld organic vapor detectors such as photoionization detector (PID) and flame ionization detector (FID)
- air and landfill gas meters (for example, O_2, CO_2, CH_4)
- radiation meters
- vapor-sensing colorimetric tubes
- handheld metal detectors such as X-ray fluorescence (XRF)
- water quality meters (for example, pH, eH, conductivity, turbidity, temperature)
- water titration or colorimetric test kits
- soil and water test kits
- immunoassay and enzymatic assays

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