The British Columbia Field Sampling Manual

Part D

Solids

1 Introduction

Part D of the B.C. Field Sampling Manual (the ‘BCFSM’ or the ‘Manual’) provides guidance and instructions required to understand, plan and collect environmental samples of soil, sediment and composted Materials. Part D of the BCFSM is divided into three sub-parts; each of which covers a specific environmental matrix. Part D1 deals with Soil, Part D2 deals with Sediment and Part D3 deals with Composted Material. Part D of the BCFSM was initially published in 1996. The initial publication included a section on *Composted Materials Sampling*, and a section on *Lake and Stream Bottom Sediment Sampling* but did not include a section on *Soil*. Minor revisions of the two initially published sections took place in 2001 and again in 2013. In 2020 Part D1 *Soil Sampling and Investigations* was developed and published, *Lake and Stream Bottom Sediment Sampling* was substantially revised and renamed “Part D2 *Sediment Sampling”*, and Part D3 *Composted Materials Sampling* was republished without change.

1.1 Part D1 Soil

Part D1 provides foundational information and guidance on soil and soil vapour sampling and investigations. Soil and soil vapour investigations are typically carried out during an environmental site characterization process which may be conducted for agricultural purposes, to establish land suitability or to investigate potential contamination. Soil investigations can be carried out using a wide variety of tools and methods which are described in detail in this part of the BCFSM.

1.2 Part D2 Sediment

Part D2 of the British Columbia Field Sampling Manual (BCFSM) provides foundational information and guidance on sediment sampling and monitoring. The information presented in this part of the BCFSM provides essential components of sample plans and field work procedures. The information and guidance are based on a wide variety of sources including industry best practices, technology, Provincial and peer-reviewed literature.

Link to Part D2

1.3 Part D3 Composted Material

Part D3 was initially published to provide sampling requirements for composted material as specified under the terms of the Production and Use of Compost Regulation B.C. Reg.334/93. B.C. The original regulation (Reg.334/93) was superseded in 2002 by the Organic Matter Recycling Regulation B.C. Reg.18/2002. The Organic Matter Recycling Regulation did not include specific sampling requirements and as such Part D3 is published as an information source.

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Part D1

Soil

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1 Soil Fundamentals and Planning

1.1 Introduction

Part D1 of the BC Field Sampling Manual (BCFSM) provides foundational information and guidance on soil and soil vapour sampling methodologies and investigations. The information presented in this part of the BCFSM provides the essential components of sample plans, investigation plans and field work procedures. The information and guidance are based on a wide variety of sources including industry best practices, technology, Provincial and peer-reviewed literature. The primary objective of a soil sampling program or plan is to produce representative samples and deliver those samples to a qualified laboratory without contamination or deterioration. **The procedures outlined in this manual standardize sampling protocols and methods which may be required by permit, approval, regulation or bylaw. These procedures also serve as a guideline for regulatory staff, permittees, and consultants.** The BC Field Sampling Manual is a living document that will be updated periodically to reflect technological advancements and improvements to sampling methodologies.

This *part* of the BCFSM takes into account BC acts, regulations, protocols and technical guidance. The primary acts and regulations that apply to the information contained in this *part* of the BCFSM include:

The **Environmental Management Act (EMA)** regulates industrial and municipal waste discharge, pollution, hazardous waste and contaminated site remediation. The EMA provides the authority for introducing wastes into the environment, while protecting public health and the environment. The Act enables the use of permits, regulations and codes of practice to authorize discharges to the environment and enforcement options, such as administrative penalties, orders and fines to encourage compliance. The EMA is the enabling statute for both the Contaminated Sites Regulation and the Hazardous Waste Regulation.

The **Contaminated Sites Regulation (CSR)**[1] provides numerical and risk-based standards for soil, sediment, water and vapour which are used to determine a site's compliance with the regulation.

The **Hazardous Waste Regulation (HWR)**[2] addresses the proper handling and disposal of hazardous wastes, which could represent a risk to soil and groundwater.

Soil and soil vapour investigations are typically completed as part of an environmental site characterization process to establish soil characteristics and soil properties such as particle size, organic carbon content, mineral and nutrient content, permeability, and the presence, extent, and stability of soil and soil vapour contamination. The findings produced by a soil investigation can be used to assess agronomic capacity, to confirm or refute impacts that may have resulted from a contaminant spill, or the basis of a Preliminary or Detailed Site Investigation (PSI) or (DSI). For contaminant related investigations the findings are used to assess the environmental media at a specific site and neighbouring properties, so that risks to human health and the environment may be assessed.

Additional guidance regarding contaminant related investigations is provided in protocols, fact sheets, and technical and administrative guidance documents provided on the Provinces Contaminated Sites Guidance & Resources web page which can be found at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/guidance-resources.

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[1] *Contaminated Sites Regulation (CSR), B. C. Reg. 375/96, incl. amendments up to B. C. Reg. 196/2017, November 1, 2017.*

[2] *Hazardous Waste Regulation* (HWR), B. C. Reg. 63/88, incl. amendments up to B. C. Reg. 243/2016, November 1, 2017.

Note: The BCFSM does not address the collection of samples for the purpose of providing legal evidence. For information regarding legal sampling contact the Laboratory Standards and Quality Assurance unit of ENV.

1.1.1 Conceptual Site Models

A conceptual site model (CSM) provides a three-dimensional presentation of a site's historical, physical, chemical and biological conditions. Conceptual site models are used for effective planning and management of soil and soil vapour contaminant investigations. A preliminary CSM should be developed in the early stages of a contaminant investigation and refined as additional data is generated. The conceptual site model should encompass an understanding of hydrostratigraphy, the extent and nature of source contaminant zones including NAPL, groundwater flow, downgradient dissolved phase contamination, and contaminant migration pathways from source zones to receptors. Soil samples are typically used to define source zones of contamination. Numerous contaminants, including petroleum hydrocarbons and VOCs, will sorb onto soil and can represent long-term sources of soil vapour and groundwater contamination. For this reason, source zones should be well delineated and accurately represented in the CSM for remediation purposes.

The migration of soil vapour, LNAPL and DNAPL at a site can cause an increase of soil and groundwater contamination and as such the properties governing this migration, including the site's possible migration pathways must be understood. Contaminated groundwater has the potential to contaminate soil. Key processes that affect or influence the occurrence, fate and presence of contaminants include ion exchange, precipitation, dissolution, sorption/desorption, oxidation/reduction reactions, volatilization, diffusion and biodegradation. In addition, groundwater processes such as advection, dispersion, and retardation may also affect soil contamination. A solid and informed understanding of the conceptual site model will allow a contaminant investigation to effectively progress and achieve its objectives.

1.2 Identification of Soil Sampling Objectives

Sampling objectives are an essential component of soil sampling plans and soil monitoring programs. Sampling objectives must be established prior to developing a soil sampling plan or soil monitoring program to ensure that a project's objectives can be met. Soil sampling is typically completed to assess soil quality for a given land use such as agriculture or residential. Soil quality assessments may be required for a development permit, to investigate the presence and extent of soil contamination, to identify landfill impacts or to assess the capacity of an agricultural field to produce a specific crop. The number of samples required as well as the sampling method/s and equipment required to complete the sampling depend on the sampling programs objectives. Data quality objectives must also be established and included in the soil sampling plan.

Sampling objectives for contaminated soil investigations typically include contaminant delineation and identification of contaminant migration mechanisms. Preliminary investigations may begin with a surficial soil sampling program to generate the data required to develop more extensive investigation plans which may involve soil vapour and groundwater sampling. Soil samples are required to confirm compliant soil boundaries at the conclusion of remediation projects, to classify soil stockpiles that were excavated as part of a remedial excavation, or to classify soils for relocation purposes. Soil sampling is also a requirement for permitted facilities, such as soil treatment facilities and industrial landfills. For some investigations, soil samples may be collected for particle size analysis to aid in stratigraphy determinations, for estimates of permeability or for laboratory analysis of permeability using a permeameter (see Part E2, of this manual).

Soil vapour sampling objectives typically include the characterization and delineation of soil vapour to investigate human health risks for various site uses. Soil vapour surveys may also be completed to investigate soil vapour migration that may be causing contamination in other media such as groundwater.

An additional objective of a soil vapour investigation may include collecting and analyzing soil vapour samples as a screening tool for the identification of locations where additional soil or groundwater investigations may be required.

1.3 Sample Planning and Design

A primary objective of soil sampling is the characterization and assessment of a given volume of soil. Analytical testing can determine a soil's cation exchange capacity (CEC), nutrient values, permeability and particle size, appropriateness for a given land use, impacts from specific land use activities and compliance with regulatory standards and guidelines. Sample planning and design requirements depend on a project's scope and objectives. In order to fulfill a project's scope and achieve its objectives the requirements for soil sampling and analysis must be fully understood and documented. A basic rule in the design of sample plans is that samples must be representative of their parent material and the method and number of samples tested must be adequate to represent the area being assessed. The information presented in this section provides high level considerations and guidance applicable to most soil sampling programs.

Screening level investigations may be conducted to obtain initial hydrostratigraphic or contaminant data for a site. Screening level investigations may include geophysics, shallow soil sampling or soil vapour surveys and direct-push methods such as CPT, laser-induced fluorescence (LIF), or membrane interface probes (MIP). Direct push discrete groundwater samples may also be obtained to provide screening level contaminant information. This preliminary information can be used to update the CSM, identify optimum locations for boreholes, test pits and groundwater monitoring wells, and to mitigate the potential risk of cross-contamination. Direct push methods can also produce detailed subsurface information, inform remediation decisions and track the progress of remediation measures. Details of direct-push methods are presented in Section 3.

Soil investigations on sites with potential contamination are carried out in stages which must be considered in the design of sample plans. During preliminary investigations soil samples are collected from locations to confirm or refute the presence of contaminants. Samples may be collected from test pits, boreholes and surficial locations to generate a suite of analytical data competent to conclude a finding of presence or non-presence. If contamination is confirmed a Detailed Site Investigation (DSI) is planned and conducted. The primary objectives of a DSI are to sufficiently characterize and delineate the lateral and vertical extent of soil contamination and to identify mechanisms of contaminant migration. To achieve these objectives the sampling plan, informed by data generated during Stage 2 PSI activities, is more targeted and strategic. Sampling near property boundaries may also be required to assess potential contaminant migration from off-site sources.

Guidelines for the investigation and characterization of fill or soil at sites that may be contaminated are specified in the *Contaminated Sites Technical Guidance*[3] document TG1 - Site Characterization and Confirmation Testing. This guidance document includes recommendations for *in situ* soil collection and sampling, sample spacing guidelines and step-out sampling for different classes of soil quality. In addition, this document provides guidance for the confirmation of remediation, and *ex situ* sampling of stockpiles.

As part of a soil sampling investigation, it may be necessary to establish baseline (background) concentrations of substances in soil. Baseline concentrations may be required to determine if a site is contaminated, has been adequately remediated or is suitable for relocation. Data produced from these investigations can be used to identify naturally occurring substance concentrations that may be at or above standards prescribed in the Contaminated Sites Regulation. Protocol 4[4] for Contaminated Sites provides information and guidance to establish background concentrations in soil.

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[3] www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/technical-guidance

[4] www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/technical-guidance

1.3.1 Soil Sample Types

TG 1 specifies that ENV's preferred approach for site classification is to use *in situ* characterization of soil materials. An *in situ* discrete sample is described as follows:

- Collected from similar *in situ* fill or soil at one location;
- Confined to collection within a contiguous volume of 1 m^3;
- Within the upper 1 m from the existing or identifiable historical site surface: collected over a maximum depth range of 0.5 m;
- At depths greater than 1 m: sample collected over a maximum depth range of 1 m;
- Not collected from two distinct fill or soil zones;
- Not collected from two sides of an air-water interface (e.g., unsaturated/saturated soil zone interface); and,
- Not composed of a mixture of material that is contaminated with material that is not contaminated, as determined through field observations such as appearance, odour, gas meters, etc., even if the physical characteristics are similar.

Soil samples can be collected as bulk samples, representative samples, undisturbed samples and composite samples. It is important to determine which type of sample/s are required to achieve the objectives of the sample plan. Under TG 1, the preference would be to collect discrete representative or undisturbed soil samples for *in situ* characterization. Each of these main sample types are described below (Nielsen, 2006).

1.3.1.1 Bulk Samples

Bulk soil samples are usually collected as grab samples scraped from a borehole, test pit or backhoe bucket, as cuttings from a borehole, or collected by hand directly from an auger (e.g., solid stem or hand auger). Bulk samples can be collected by hand using a trowel or shovel as part of a surficial soil investigation. Bulk sampling during drilling is quick and inexpensive, provides an opportunity to observe and report soil stratigraphy, to locate the water table and identify visual and olfactory evidence of contamination. Bulk samples collected during drilling are typically obtained from mixed and disturbed soils resulting in a loss of VOCs if present, and sample accuracy. In fact, of the four basic types of soil samples, bulk samples are considered to provide the least accurate representation. The representativeness of the sample may be improved by scraping off a layer of the surface material to expose fresher and potentially less-mixed soil.

This type of sampling is usually limited to within 7 m of ground surface.

1.3.1.2 Representative Samples

Representative samples are discrete samples typically collected in a drive or push tube with a sharp cutting edge at its lower end. The cutting edge is forced in the ground by static thrust or dynamic impact, or is rotated in the ground (Sara, 2003) from a specified depth within a borehole. Representative samples are samples in which all constituents are present, but the sample may not be completely undisturbed. From this collected sample, a subsample is often collected, depending on the sample requirements for laboratory analysis (e.g., VOC analysis).

These samples are typically collected using a split spoon, Shelby tube or direct push samplers, as well as Sonic drilling methods, although the heat and vibration generated by Sonic drilling may affect sample quality.

1.3.1.3 Undisturbed Samples

Undisturbed samples are discrete high-quality samples that are collected from a specified depth under controlled conditions that limit any physical or chemical disturbance to the sample. Specifically, all constituents in the sample should not have been altered or changed during the sampling process. These samples are typically collected for laboratory analysis of permeability (Nielsen, 2006), although they are also very suitable for analysis of volatile parameters.

1.3.1.4 Composite Samples

Composite samples are a blend or mix of numerous discrete samples collected from the same location or from different locations. Discrete samples from the same formation may be collected from several locations and mixed together and submitted as a composite sample. Discrete samples can be collected from stockpiles and combined to provide composite samples for characterization, as described in TG 1. Composite sampling may also be used to characterize small piles or barrels of soils generated from drilling or small excavations.

1.3.2 Sampling Design Strategies

The strategy of a sampling program depends in large part on the level of investigation the program is being designed for. Screening level investigations will generally be designed with a broad scope and encompass a wide variety of objectives including the determination of a sites soil type/s and stratigraphy. Detailed Site Investigations will focus on specific locations and analytes. Regardless of the level of investigation the formulation of a strategy should consider the overall objectives of the program, the location and frequency of soil samples required, sample collection methods and the excavation and or drilling method to be deployed.

During Preliminary Site Investigations, soil samples are typically collected from areas of potential contamination to confirm or refute the presence of potential contaminants. During these investigations soil samples can be collected at wide lateral spacing’s that range from 20 m to 50 m (TG 1). Within a borehole, 0.6 m long split spoon samples are typically collected at intervals of 1.5 m.

During Detailed Site Investigations areas that are confirmed to contain contamination are investigated further. In this case lateral spacing is reduced to a range of 5 m to 7 m, with grid spacing’s of 10 m to 20 m for larger suspect areas (TG 1). Within a borehole, it may be desirable to collect continuous soil samples to accurately delineate the vertical extent of contamination. Additionally, a DSI may require statistical analysis, including estimates of contaminant distributions, contaminant concentration means, upper confidence limits of the means and 90th percentiles.

The conceptual site model should be considered in the planning of a sampling design strategy. A solid understanding of site history, hydrostratigraphy, preferential pathways and the physical and chemical behaviour and migration properties of suspected or known contaminants, is of considerable importance in identifying locations where samples should be collected. For example, if gasoline, an LNAPL, is suspected to have been released into soil primarily composed of sand and gravel, with clay lenses, it will typically migrate through the vadose zone, possibly pooling and laterally migrating along low permeability or perched units. The LNAP may eventually reach the capillary fringe and water table, where it will pool and spread laterally. Residual LNAPL and associated petroleum hydrocarbon soil contamination will be present along the migration pathway. Vapours generated from the residual contamination may also migrate, resulting in additional soil contamination. At a minimum, soil samples should target areas where LNAPL is expected to pool, which would include perched or clay lenses within the unsaturated zone, as well as the water table. As an alternative approach, and assuming suitable soil conditions, a direct push LIF survey may be more appropriate to quickly delineate petroleum hydrocarbon soil impacts and select locations where soil samples may be needed. For DNAPL investigations, soil samples should be collected immediately above fine-grained units, where DNAPL is expected to pool, both above and below the water table. PCBs generally remain in surficial soil so initial sampling should be focussed near ground surface.

In all sampling scenarios, soil samples should be screened using a gas meter appropriate for the organic PCOCs under investigation to identify which of the collected soil samples to submit for analysis. In most cases metals concentrations cannot be estimated by visual observation or meters and as such a competent number of samples are typically analyzed.

1.4 Soil Classification

Soil classification systems vary nationally and are used by a wide range of sectors within Canada. Although the *Canadian System of Soil Classification* is designed to cover Canadian soils it is closely aligned with the U.S. system. In fact, the first system used in Canada was developed by the U.S. Bureau of Soils[5]. Soil classification and soil parameters such as permeability, cation exchange capacity, and particle size are vital to civil engineering, forestry, agronomy and issues of public health and environmental protection. Soil properties are used to assess the stability and suitability of an area for development, the capacity of a field to produce crops; to calculate infiltration rates and holding capacities of soils during heavy rain events and to predict the preferential pathways and fates of contaminates in soil.

Accurate and consistent soil classifications facilitate competent land use decisions and treatment options including remedial strategies. For long-term projects, soil classification records will be considered and included in many decisions over the course of the project. Accurate classifications will facilitate the proficient deployment of expensive and potentially impactful soil amendments such as fertilizers and remediation products. Consistent classification allows multiple parties to draw competent and consistent conclusions regarding the status and or progress of soil quality. During contaminated site assessments and remediation plans, soil classifications form the basis for many important decisions, including the choice of samples to be submitted for analysis and the design of remedial action plans. Soil stratigraphy is an integral part of a CSM due to its influence on contaminant distribution and migration; information that is also used in the development of remediation strategies.

During Preliminary and Detailed Site Investigations (PSI and DSI) it is important to classify and record soil stratigraphy to the full depth of the investigation. The descriptors used should be accurate and consistent to enable lithology correlation between borehole logs. This is especially important for projects with numerous phases of investigation or wide area projects that require multiple field staff to classify a sites soil. Careful observations should be recorded in field notes regarding not only the physical description of the soil sample, but of the drilling action, changes in drill cuttings, etc. Photographs depicting field observations provide valuable information regarding site characteristics and changes, soil characteristics and sampling activities and should be maintained along with field notes. It is equally important to remember that information provided in borehole logs (including the classification of soils) may also be used by other parties, for work directly or indirectly related to the project’s goals.

Soil samples required for laboratory analysis should be collected prior to soil classification. A sample should be representative of the stratum from which it was obtained. The sample depth interval should be accurately recorded. Careful notes of observations made during sample collection such as the presence of cobbles/boulders, difficulty in drilling, blow counts during split spoon sampling, sample recovery and anything else which may provide information regarding *in situ* characteristics of the soil should be recorded.

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[5] The Canadian System of Soil Classification 3rd edition, Agriculture and Agri – Food Canada

Soil classification field records should include the following descriptive information, as applicable:

- **Composition/gradation**, can provide information as to the geologic origin, *in situ* permeability characteristics, and engineering characteristics for construction and/or remedial systems;
- **Angularity** provides information as to the geologic origin of the soil;
- **Colour** can provide useful information as to the geologic origin of the soil, seasonal fluctuations of the groundwater table, presence of organic soils, and/or presence of residual contamination. Grey soils in areas where hydrocarbon contamination is known or suspected may be the result of iron mobilization due to biodegradation. Accurate descriptions of colour can be obtained through the use of standard colour references such as Munsell Soil Colour Charts. The presence and colour of mottling should be noted;
- **Consistency** of fine-grained soils (i.e., very soft to hard) and **density** of coarse-grained soils (i.e., very loose to very dense), provides a measure of toughness or hardness of soils. Toughness and hardness is based on the effort necessary to dig into the soil or remold it thorough handling. These properties can provide useful information for later use in construction, or to assess *in situ* permeability characteristics of the soil;
- **Plasticity** is an important characteristic for fine-grained soils. Water added to the soil can aid in testing. Soils can be described as non-plastic, or of low, medium or high plasticity;
- **Structure**, or fabric, can provide information as to the geologic origin of the soil, *in situ* permeability characteristics of the soil, and contaminant pathways [e.g., fractures, anisotropy]. Reasonably undisturbed samples are best for identifying structure. Examples of structure classification include stratified, laminated, fissured, slickensided, blocky, lensed or massive;
- **Moisture** content can provide useful information to assist in classifying the soil type [fine-grained, coarse-grained] and determining the approximate depth to groundwater. Soils are classified as dry, damp, moist and wet (or saturated). To determine whether the soil is saturated, place a sample of the soil on a paper towel and see if it wets the paper towel – if the towel becomes wet, the soil is likely saturated;
- **Inclusions**, such as rootlets, grass, weeds, shell fragments, wood, or construction debris can provide information as to the location of former ground surfaces, depositional patterns, or whether soil is native or fill; and,
- **Visual evidence** of contamination and or **odour** can provide useful information with respect to the origin/type of residual contamination, and the identification of organic soils. Odours should be investigated without unnecessary exposure to harmful vapours. Examples of odours that can be described include gasoline-like, oil-like, mothball-like, pungent, solvent-like, weathered, rotten egg, faint, strong, sweet, and organic (i.e., peat).

Soil classification carried out in the field is based on information obtained by visual observations, olfactory characteristics and physical tests which are detailed in the Standard Operating Procedure SOP D1-1. The field soil classification method provided in SOP D1-1 is based on ASTM standards D2487-17 (Unified Soil Classification System) and D2488-17 (Visual-Manual Procedures), with modifications to accommodate environmental investigations.

To aid in soil classification, chip trays may be used, which consist of between 10 to 40 sealable compartments for storing soil or rock chip samples. A small volume of soil or rock material can be contained in each compartment. The chip tray allows for the soil or chip samples to be reviewed at a later date, so that the soil descriptions may be reviewed and revised if needed. In addition, as additional boreholes are advanced, chip trays from previous boreholes can be reviewed to ensure consistency in classification.

Figure 1.1: Example of a chip tray used to store soil or rock chip samples.

For fine-grained soils, test procedures for dry strength, dilatancy and toughness can aid in classification. These test procedures are described in more detail in SOP D1-1. Mineral soil which contains enough organic particles to influence soil properties is considered organic fine-grained soil. Organic soils are often dark brown to black, and often change colour when exposed to air. Organic soils will normally not have high toughness or plasticity, and the thread for the toughness test will be spongy.

2 Investigation Techniques

The investigation techniques outlined in Section 2 include information that is necessary in determining the most suitable technique for investigation projects based on project objectives and a site's potential or known contaminants. The following subsections provide brief outlines of each technique including how they work and where they might be used.

2.1 Passive Soil Gas Monitoring

Passive soil gas monitoring is used to passively collect gas samples for analytical testing of volatile organic compounds (VOCs) or semi-volatile organic compounds (SVOCs). Passive soil gas monitoring deploys sorbent samplers placed into the subsurface in a grid pattern or transect across a site. It is an effective method of assessing a contaminant source in the vadose zone, delineating contamination across a site, and refining the conceptual site model. Passive samplers can be placed directly in the soil or below a concrete slab or asphalt. The samplers are inserted into a hole drilled approximately 2.5 cm in diameter and 15 cm to 1 m deep. Following a predetermined exposure period, the samplers are retrieved and analysed at the laboratory. Passive soil gas monitoring is minimally invasive, easy to implement, and inexpensive. Disadvantages of passive soil gas monitoring include potential starvation effects during sampling or an insufficient amount of sorbent (the exposure time to sorbent ratio is dependent on the porosity of the soil and the molecular weight of the compounds being tested). Additionally, the data cannot be used alone to make conclusions on site soil gas concentrations (ASTM 7758, 2017).

2.2 Soil Vapour Screening

Soil vapour screening is a semi-quantitative method of estimating vapour concentrations in soil using a hand-held instrument. Instruments used to produce the vapour readings include combustible gas meters (CGM), photo-ionization detectors (PID), and flame ionization detectors (FID). For contaminated site investigations, compounds that can be analyzed for screening purposes include volatile petroleum hydrocarbons (VPH), VOCs, and SVOCs. Vapour readings produced by hand-held instruments do not provide the vapour concentration of a specific compound, but rather a value that is correlated to the response of a sensor calibrated to a specific gas. As a result, the reading is semi-quantitative and can only be used to assess a relative contaminant level.

The operating principle, applicability, advantages and disadvantages of the three types of hand-held instruments are provided in Table 2.1.

Table 2.1: Soil Vapour Screening Tools[a]

Instrument Type	Application	Calibration Gas[b]	Operating Principle	Advantages	Disadvantages
Combustible Gas Meter	Used to measure combustible vapours so that fire and explosion hazards may be evaluated; can be operated in methane elimination mode when methane measurements not desired	Hexane	Measures the presence of compounds by measuring the heat produced by combustion at a catalytic detector	› Some instruments can detect multiple gases including oxygen, hydrogen sulphide, and carbon monoxide.	› Accuracy may be low because different compounds produce different amounts of heat when burned; and, › Requires atmospheric oxygen levels to operate.
Photo-ionization Detector	Can detect a variety of organic compounds, especially chlorinated	Isobutylene	Responds to compounds that have ionization potentials	› Oxygen not required to operate; and,	› Sensitive to humidity and dust and must use

(PID)	solvents; can also detect some inorganics (ammonia and hydrogen sulphide)		equal to or lower than those produced by the lamp	› Better for screening halogenated compounds.	a filter to minimize effects; and, › May have higher readings under low oxygen conditions although oxygen is not required to operate.
Flame Ionization Detector (FID)[2]	To detect organic compounds such as chlorinated VOCs and hydrocarbons	Zero-gas or span gas	Detection of ions formed during combustion of organic compounds in hydrogen flame	› Inexpensive; › Low maintenance; › Better suited use for hydrocarbon mixtures than PIDs; and, › Not affected by humidity.	› Cannot detect inorganic substances; › Oxidizes compounds; and, › Requires hydrogen fuel supply.

a. Information from Robbins et al. (1989), EPA (1990) and CCME (2008). b. Calibration Gas types are recommended gas types.

Soil samples are typically obtained during drilling operations, from soil stockpiles, remedial excavation walls and floors, or surface grab samples using shovels or trowels. Samples may also be obtained directly from the buckets of excavators or backhoes or bucket augers. Information produced from field screening can be used to identify locations requiring additional investigation, and to select which soil samples should be submitted for analytical testing. Soil vapour screening can also be used to provide preliminary clean soil boundaries although analytical testing is required to confirm those boundaries. Soil vapour screening can be used to quickly scan excavations and soil stockpiles to identify sample collection locations by taking direct readings of soil vapour using the meter or detector. Screening can also be completed by inserting the meter or detector into a sealable plastic bag or jar that has been partially filled with a sample of soil that has been allowed to equilibrate for a period of approximately 15 minutes. The 15 minute period allows any volatile constituents to liberate from the soil and cumulate in the free space of the bag where the vapour measurement is taken.

It is important to note that the difference between vapour concentrations measured using meters or detectors and the concentration provided through analytical testing may vary considerably. The readings provided by meters and detectors can be influenced by field procedures, the type and relative concentrations of the volatile constituents being measured, instrument response, soil particle size, moisture content, sample volume/headspace ratio, temperature, and equilibration time. Instruments must be calibrated regularly and before use. SOP D1-2 provides additional details regarding proper field screening and calibration requirements.

For metals screening soil samples can be analyzed using a handheld X-ray fluorescent (XRF) meter to detect specific elements. XRF meters use an x-ray beam to displace electrons which release energy that is characteristic of a specific element. The energy released is recorded by a detector in the XRF which can categorize the energies by element. Due to the cost of an XRF meter, it is not routinely used in environmental investigations for screening purposes.

2.3 Direct Push Technology

Direct push technology includes a wide range of tools mounted on steel rods that are driven into the subsurface using hydraulic, percussive, or vibratory/sonic methods to investigate soil, soil vapour, and groundwater properties. Direct push technology offers a number of advantages over traditional drilling methods, including rapid, high density data collection, specialized tools for physical property or contaminant characterization, minimal waste generation (i.e., soil cuttings), and a reduced amount of materials needed for well installation. Penetration depths are dependent on soil type, compactness and consistency and the type of equipment used (i.e., hammer energy and carrying vehicle weight). The maximum depths achievable via direct push methods depend on the weight of the carrying vehicle and the density and consistency of the soil. Depths of 20 to 50 metres can be achieved in soils composed of clay, silt and sand. The penetration depth in soil with gravel or cobbles or in dense, highly compacted soil will be limited, and may result in equipment damage.

Direct push technologies include the following methods:

- Direct collection of soil, soil vapour, or groundwater samples (i.e., point-in-time sampling);
- Installation of soil vapour or groundwater monitoring wells or other monitoring equipment (such as vibrating wire piezometers), and;
- High resolution *in situ* measurement of subsurface properties and contaminants such as:
    - Soil stratigraphy by Cone Penetrometer Testing (CPT);
    - Geotechnical engineering parameters by Standard Penetration Testing (STP);
    - Presence of contamination via soil conductivity for electrically conductive plumes;
    - Laser-Induced Fluorescence [LIF] profiling to delineate petroleum hydrocarbons, and chlorinated solvents; and,
    - Membrane interface probes [MIP] for VOC investigations.

These methods allow a high number of sample locations to be analyzed over a relatively short period of time. The results can be used to provide a 3D snapshot of site conditions, including source zones and contaminant plumes. This detailed characterization can be used to inform subsequent investigation activities such as the installation of soil vapour and groundwater monitoring wells, and aid in the development of remediation strategies. As with other drilling methods, care must be taken to prevent cross contamination through the migration of contaminants along the depth of a borehole where layers of low permeability may be encountered. In addition, utility locates should be completed prior to any direct push program to ensure that utilities are not encountered or damaged. Direct push methods used for soil sample collection are described in Section 3.1.5.

2.3.1 CPT Profiling

Cone penetrometer test (CPT) profiling is used to determine a continuous profile of subsurface stratigraphy and geotechnical properties of soil without the need to collect soil samples (ASTM 3441, 2016). The method involves advancing an electronic cone into the ground using a direct-push drilling rig. The cone measures the tip resistance, sleeve friction and groundwater pressure. The data produced provides a profile of the subsoil that can be used to infer soil stratigraphy. Estimates of permeability can be achieved using a pore pressure dissipation test.

CPT profiling can be completed on rigs that range from small portable rigs to large truck-mounted rigs. The method is suitable for softer sediments such as clay, silt, and fine to medium sand deposits and less well adapted to gravel deposits or stiff/hard cohesive deposits (Bowles, 1996). The depth of penetration is dependent on the soil type and the type of equipment used; typically, penetration depths of 20 to 50 m can be achieved. Since the cone displaces soil, no soil cuttings are produced. The open hole is typically backfilled with bentonite grout after the test is completed.

2.3.2 Electrical Conductivity Profiling

Direct push electrical conductivity (EC) profiling is a direct push method that provides a continuous log of soil conductivity with depth. The electrical conductivity is dependent on the moisture content of the soil and the conducting properties of pore fluids and sediments within the soil. EC profiling can be used to provide information on soil type, since fine grained soils typically have higher electrical conductivity than coarser grained sands and gravels (Schulmeister, et al., 2003). EC profiling is also useful in characterizing saline plumes (e.g., from salt storage, brine generation during oil drilling, or seawater intrusion).

EC profiling can be used in conjunction with surface geophysical electromagnetic (EM) methods used to map soil conductivity or electrical resistance tomography (ERT). The EC profile can provide a high resolution correlation between the geophysical data and soil electrical conductivity which can confirm saline plume extents and can help to guide monitoring well placement.

2.3.3 HPT Profiling

The hydraulic profiling tool (HPT) is a high resolution direct push method which can provide a detailed log of relative formation permeability, hydrostatic pressure, and electrical conductivity. The HPT incorporates a screen discharge port to pump water through the probe and into the soil formation at a controlled rate, and a pressure transducer to measure the injection pressure, which correlates with formation permeability. Higher resistance to flow suggests the presence of dense soil conditions, silt and/or clay, and less resistance to flow suggests that more permeable material is present (e.g., unconsolidated sand or gravel).

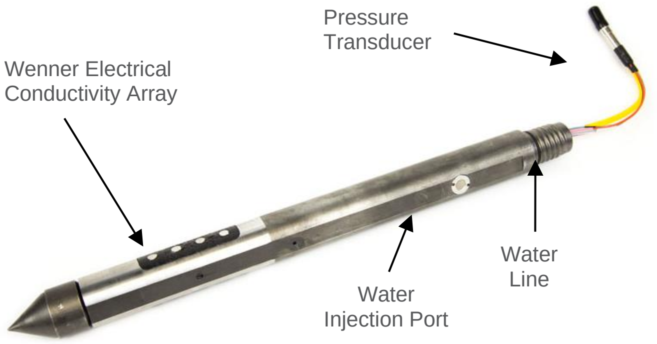

Figure 2.1: Components of an HPT probe.

(Courtesy Geoprobe® https://geoprobe.com/hpt-hydraulic-profiling-tool)

When water is not discharged into the soil formation the pressure transducer can measure hydrostatic pressure which can be used to estimate the location of the water table through the use of a dissipation test. The dissipation test results, in conjunction with hydrostatic pressure and flow logs can be used to measure very high resolution permeability (i.e., on the scale of several centimetres; McCall, 2011). It is recommended that at least one dissipation test be conducted to compare and correlate HPT data.

A Wenner or dipole array is incorporated into the HPT to measure bulk formation EC. This can provide some lithological information and is also useful in characterizing saline plumes, as described in Section 2.3.2. However, when the EC data is used in conjunction with the HPT pressure log, it is possible to distinguish between coarser-grained units (i.e., silty sands, sands and gravels) impacted with salt, which demonstrate a relatively high EC and low HPT pressure, and fine-grained units (i.e., silt and clay) which have high EC and high HPT pressure (McCall, 2011).

HPT logs are useful for identifying permeable zones for groundwater sampling, for selecting screen depths for monitoring wells, injection locations for remediation programs, and effectively characterizing saline plumes. The HPT log can be used to identify preferential migration pathways and aquitards, to more accurately develop a CSM and provide data for groundwater models. The HPT can be combined with other sensors such as LIF and MIP, and groundwater sampling tools (McCall, 2011, McCall et al., 2016).

Soil sampling is required to confirm HPT results because fine-grained soil with abundant fractures can have permeabilities similar to sand, and cemented or compacted sand and gravel (e.g., till) can have permeabilities similar to silty clay. In addition, some clay minerals do not have high EC, and the presence of elevated dissolved ions can cause elevated EC readings in saturated sands and gravels. High-pressure injection in shallow fine grained or cemented materials may result in formation fracturing if lithostatic pressure is exceeded, or result in water flowing up the drive rods, which usually occurs when the probe stops advancing (McCall, et al., 2017). As with all direct push methods, the use of the HPT is limited by the soil type and the type of direct push equipment used, and care must be taken to prevent cross contamination across layers of low permeability through the migration of contaminants along the borehole.

2.3.4 LIF Profiling

Laser induced fluorescence (LIF) profiling is a high-resolution *in situ* direct push investigation method that is used in the delineation of non-aqueous phase liquids (NAPL). LIF profiling identifies the relative presence of petroleum hydrocarbon contamination in soils and pore fluids immediately after each test, which allows for the adjustment of subsequent profiling locations during the investigation program (ASTM D6187, 2010). LIF profiling can be used to detect petroleum products containing polycyclic aromatic hydrocarbons (PAHs). It is particularly effective in the detection of LNAPLs and can be used to qualitatively identify the LNAPL type.

LIF can be used in the undisturbed vadose zone, capillary fringe, and saturated subsurface and can detect different types of petroleum such as gasoline, diesel fuel, and oil. LIF sensitivity to petroleum hydrocarbons on soil is inversely proportional to the surface area of the soil; therefore, clay has a greater available surface area, but will have a lower fluorescence response. LIF profiling enhanced technologies such as UVOST®, TarGOST®, and DyeLIF are capable of detecting a variety of DNAPLs. UVOST can be used to detect petroleum, oils and lubricants, TarGOST is used in the detection of DNAPLs such as coal tars, creosotes, and heavy crude, and DyeLIF is used to detect chlorinated solvents.

LIF profilers deploy a nitrogen laser that emits pulsed ultraviolet light which causes PAHs, aromatic hydrocarbons and some minerals and non-petroleum organic matter to fluoresce. The fluorescence is measured by a full spectrum sensor as the probe is advanced. Discrimination between petroleum hydrocarbons and other fluorescing matter can be achieved by using spectral features associated with the data, although soil samples should be submitted for analytical testing to provide confirmation. This method is not a replacement for traditional investigation methods (i.e., drilling and well installation), but it can be used to reduce the number of drilling locations, soil samples, and well installations for site characterization. It is commonly used in conjunction with other direct push methods, including CPT. Correlation of LIF logs can provide both a 2-D and 3-D representation of petroleum hydrocarbon contaminant plumes in the subsurface.

2.3.5 MIP Profiling

The membrane interface probe (MIP) is a high resolution direct push screening tool that can estimate the distribution and relative magnitude of VOCs (including BTEX and chlorinated solvents), as well as dense non-aqueous phase liquids (DNAPL) in the subsurface. The MIP uses heat to diffuse VOCs from the formation through a permeable membrane which partition into a stream of carrier gas (typically nitrogen or helium) through a trunk line to one or more detectors on the surface which measures total VOC concentrations (Figure 2.2). Detection limits of up to 0.1 parts per million (ppm) can be achieved. Detection limits depend on soil type, temperature, and the detector used. A list of detectors and the range of their detection limits is provided in Table 2.2. The MIP is typically advanced in increments of 30 cm, with a 1 minute residence time to take readings at each increment. The MIP probe includes a dipole EC array to aid with formation lithology evaluation (McCall, et al., 2014).

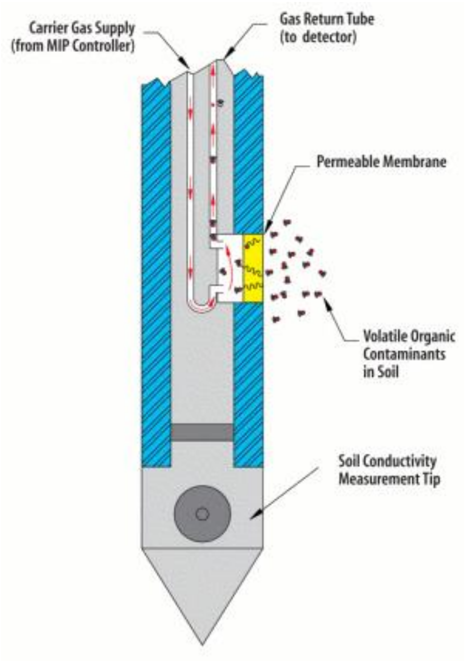

Figure 2.2: The components and operation of a membrane interface probe (Courtesy Geoprobe®).

The MIP can detect VOCs in coarse and fine-grained saturated and unsaturated soil. Membrane interface probes can identify the precise depth at which contamination is located, allowing the collection of targeted and representative soil or groundwater samples. An MIP can provide a real-time VOC assessment of the subsurface, which can be used to optimize the selection of additional sample locations and identify locations for well installations facilitating a dynamic work plan. Correlation of MIP logs can be used to provide both a 2-D and 3-D representation of VOC plumes in the subsurface. In conjunction with other direct push data (e.g., EC, CPT, HPT) it is possible to evaluate VOC migration pathways. MIP profiles can also be used to guide the injection of remediation materials and monitor the progress of remedial treatments (ASTM D7352, 2012).

Table 2.2: Common Detection Limits of MIP Detectors[1]

Detector	Contaminants	Detection Range (ppm)	Gases
Photo-Ionization Detector (PID)	Hydrocarbons and chlorinated VOCs with ionization potential <eV of bulb	0.20 - 2.0	Carrier
Flame Ionization Detector (FID)	Hydrocarbons and chlorinated VOCs, Methane, Butane	10 - 20x	Carrier, Hydrogen, Air
Electron Capture Detector (ECD)	Chlorinated VOCs	0.20 - 2.0	Carrier
DELCD (Dry Electrolytic Conductivity Detector)	Chlorinated VOCs	0.20 - 2.0	Carrier, Air
Halogen Specific Detector (XSD)	Chlorinated VOCs	0.10 - 2.0	Carrier, Air

[1] Source: https://clu-in. org/characterization/technologies/mip. cfm and Geoprobe® (https://geoprobe. com/mip-specifications)

2.4 Test Pitting

Test pitting is an intrusive investigative technique used to characterise shallow or intermediate soil stratigraphy, investigate potential contaminants of concern (PCOCs), identify possible migration pathways, and assess for buried wastes. Test pitting can be a cost effective investigative approach and is generally used on closed or unpaved sites. Test pits are usually excavated using rubber tire backhoes for maximum excavation depths of 3 to 4 m, or track-mounted excavators for maximum excavation depths of 5 to 6 m. Test pits can also be excavated by hand to a maximum practical depth of approximately 1 m. Table 2.3 summarizes the advantages and disadvantages of the three methods of test pit excavation.

For typical investigations soil is collected in the backhoe bucket from a location in the pit specified by the sampler. The samples are then collected from the bucket using a methodology appropriate for the PCOCs being analyzed. Sampling is usually conducted in 0.5 m depth increments, although this can vary depending on site-specific requirements and soil conditions. Samplers may have difficulty sampling loose material or soil below the water table. Test pit soil is typically returned to the test pit after samples have been collected; however, if contamination is suspected or identified during sampling, the excavated soil may be stockpiled onto plastic sheeting and covered or placed in labelled barrels on-site until analytical results are obtained so that disposal options may be evaluated.

Detailed procedures for test pit soil investigations are provided in SOP D1-3. Additional details regarding soil characterization in BC are described in ENV Technical Guidance (TG) 1 - Site Characterization and Confirmation Testing (ENV, 2009).

Table 2.3: Methods and Equipment Used for Test Pit Excavations

Equipment	Application	Advantages	Disadvantages
Rubber Tire Backhoe or Extend-a-Hoe	Non-operating sites	› Cost effective; › Provides good visualization of subsurface; and, › Large sample volume.	› Disruptive (large holes); › Shallow reach (up to 4 m); and, › Difficult to collect discrete samples in unstable soil conditions (e.g., below water table).
Track Excavator	Typically used at non-operating sites where an excavator is required for other tasks (e.g., tank removal)	› Cost effective; › Provides good visualization of subsurface; › Large sample volume; and, › Deeper sampling than rubber tire backhoe.	› More disruptive than a rubber tire backhoe; › Shallow reach (up to 6 m); and, › Difficult to collect discrete samples in unstable soil conditions (e.g., below water table).
Hand Digging	Sites where mobilizing equipment may be difficult	› Inexpensive; and, › May not require utility locates.	› Very limited reach; › Time consuming and labour intensive; and, › Cannot be conducted in hard soils.

2.5 Surficial Soil Sampling

Surficial soil sampling is used to assess possible impacts of surface spills or leaks, industrial operations or airborne fallout impacts on the quality of shallow or surficial soil. Soil may be sampled in a grid formation, at random sampling locations, or at targeted sampling locations (referred to as hot spots or probable hot spots) depending on the site's objectives. If targeting hot spots, a site characterization identifying PCOCs and transport mechanisms is required, and sampling is generally carried out using 25 to 50 m spacing. A detailed investigation focuses on suspect areas with 5 to 7 m step-outs from suspect locations or 10 to 20 m step-outs from larger suspect areas. Sampling in low lying areas where water may pond is not recommended. Detailed procedures for surficial soil sampling are provided in SOP D1- 4.

Surficial soil samples should be collected from a circular area over a maximum depth of 0.5 m within the upper 1 m from the existing site surface or identifiable historical site surface (ENV, 2009). Different ranges are recommended for grassed areas and gardens (refer to SOP D1-4). Soil samples must be collected in accordance with the appropriate methodology for the PCOCs to be analyzed. Common equipment used for surficial soil sampling and the advantages and disadvantages of the equipment are listed in Table 2.4: Common Equipment Used for Surficial Soil Sampling below.

Table 2.4: Common Equipment Used for Surficial Soil Sampling

Device	Use	Advantages	Disadvantages
Trier	Soft to firm soil	› Easy to use and clean; and, › Inexpensive.	› Difficult to use in stony soil, dry sandy soil, or hard clay.
Trowel	Soft to firm soil	› Easy to use and clean; and, › Inexpensive.	› Difficult to use in hard clay; and, › Difficult to obtain sample that is representative of a specified depth.
Tulip Bulb Planter	Soft to firm surface soil, 0 cm to 15 cm deep	› Easy to use and clean; › Inexpensive; › Uniform diameter and volume; and, › Relatively undisturbed sample suitable for volatiles analysis.	› Suitable for only one depth; and, › Difficult to use in hard soil or in dry, loose soil.
Soil Probe or Corer	Soft to firm surface soil, 0 cm to 15 cm deep	› Easy to use; and, › Core is often relatively undisturbed and suitable for volatiles analysis.	› Limited depth capabilities; › Difficult to use in hard, stony, or dry sandy soil; and, › Difficult to clean off cohesive soil.
Hand (Dutch) Auger, **Auger Buckets**	Surface soil to intermediate depth	› Will sample to greater depths than above equipment; and, › Can be used in stiffer soil.	› Depth limited by soil conditions (stones and collapsing side walls); › Soil mixing occurs during sampling; › Not suitable for volatiles; › Difficult to obtain sample from one depth; and, › Difficult to clean.

Device	Use	Advantages	Disadvantages
Hand-held Subsoil Probes (Soil Core with Slide Hammer)	Surface soil to intermediate depth	› Will sample to greater depths than most other equipment; › Can be used in stiffer soil; maintains an undisturbed core; and, › Suitable for volatiles analysis.	› Depth limited by soil conditions (stones and collapsing side walls).
Hand Operated Power Auger	Soil, 15 cm to 5 m	› Good depth range; and, › useful in wide range of soil types.	› Soil mixing occurs during sampling; › Not suitable for volatiles; › Requires two or more operators; › Gasoline engine poses risk of contamination; › Difficult to obtain sample from one depth; and, › Difficult to clean.

2.6 Drilling

Borehole drilling is conducted to investigate soil stratigraphy, soil quality, soil vapour, bedrock, and groundwater. Information provided by drilling is used to identify contamination, and possible migration pathways. Various drilling methods are used to collect soil, bedrock, and groundwater samples, to assess geotechnical properties, and install soil vapour wells and groundwater monitoring and groundwater production wells. Drilling methods have been developed to penetrate and collect samples from all geological materials to depths of hundreds of meters or more. Borehole drilling is an essential tool in contaminated site investigations.

Drill rigs are provided by and are the responsibility of appointed sub-contractors. Drill rigs can be mounted on several types of carriers, including trucks and all-terrain vehicles. Truck-mounted drill rigs are useful when working on hard, relatively level, and/or paved surfaces. All-terrain drill rigs such as track-mounted or large-tire rigs are better suited to off-road sites. In difficult to access areas, hand augers or small portable rigs may be used. Prior to drilling BC-One must be notified of the intended drilling and a utility locates contractor must complete an on-site utilities location survey to identify water, sewer, gas, electrical, underground and overhead utility lines prior to drilling. Documents provided by BC-One-Call, local or provincial utility companies and available site-specific drawings must be consulted to identify possible underground and overhead utility hazards. It is good practice to photograph each drilling location prior to any site disturbance to ensure that the site is returned, as close as possible, to pre-drilling conditions upon completion of work. Photographic documentation will help prevent disputes over pre-drilling conditions. In addition, appropriate precautionary measures should be taken to minimize damage to ground surfaces that may be caused by the drill rig.

During the planning stage of an investigation it is important to gather available site information such as accessibility, soil type and depth to groundwater. Site information can be retrieved from a review of topographic maps, aerial photography, geological maps and reports, geophysical investigations, water resource investigations, investigations of proximal sites and borehole logs accessible on the BC Water Resources Atlas. This information is critical to selecting the appropriate drilling method to meet the objectives of the site's investigation program. Planning should also include sampling objectives, monitoring well completion requirements and drilling equipment decontamination requirements (ASTM D6286-12, 2012). If geophysical logs or borehole imaging are to be completed, drilling methods that leave an open borehole may be needed.

Inclined drilling may be used to drill under otherwise inaccessible areas, or to investigate vertical discontinuities (e.g. fractures in clay or bedrock). Inclined drilling is susceptible to borehole deviation due to the weight of the drill string, which tends to bias the borehole to a vertical orientation. In addition, the presence of boulders or alternating soft and hard dipping geological units can cause the drill bit to deviate around the hard units (Sara, 2003). Depending on the drill rig selected, boreholes may be angled at 20° degrees or more from vertical. With care, monitoring wells can be installed within angled boreholes, although groundwater elevations need to be corrected to account for the angle.

To determine the best locations for boreholes and or monitoring wells, historical documentation and data regarding the site should be reviewed for completeness and reliability. Additionally, a conceptual site model should be developed, and a data gap assessment should be completed. Using this information, borehole or monitoring well locations can be selected to fill in the identified data gaps assuming an understanding of site hydrogeology.

Before drilling at contaminated sites, it is important to plan and take measures to mitigate the potential for cross contamination across layers of low permeability. When drilling through contaminant zones of low permeability, conductor casings can be used and grouted into place at the top of each impermeable unit.

With the exception of direct push methods, most drilling methodologies will produce soil cuttings. Soil cuttings suspected of being contaminated should be isolated and stored as a contaminated product until analytical data is available to confirm its status. Soil cuttings can be piled on tarps and covered or placed in drums or soil bags. The analytical results of soil samples collected during drilling or results of samples collected from the cuttings can be used to classify the soil for disposal purposes.

The height and space requirements of each proposed drilling location needs to be reviewed for safety planning and to ensure an appropriate drilling rig is contracted. In-door drilling will typically require a limited access rig. The depth capability of these rigs is limited and must be considered to ensure that target depths are achievable. The presence of overhead utilities or other overhead structures or vegetation may limit the selection of drilling rigs. A further consideration is municipal noise ordinances, since some drilling methods, such as air rotary, may not comply with municipal regulations for noise.

Details of specific drilling techniques and their associated advantages and disadvantages are outlined in Section 3.

3 Drilling Investigations

The information presented in Section 3 provides a general overview of different auger and rotary drilling methods and associated sampling methods. The advantages and disadvantages of each method and the type of subsurface material that is most suitable for each method are also provided. Auger drilling methods include hand augers and hollow and solid stem augers. Rotary methods include direct rotary drills, reverse circulation rotary drills, and dual wall reverse circulation rotary drills. Additional methods include ODEX percussion and air-operated down-the-hole hammer drills, vibrasonic or sonic drills, direct push drills and cable tool drills. Sampling methods presented in this section include slide hammer samplers, split spoon, Shelby tube, and direct push samplers.

Table 3.1: Summary of Drilling Methods[1]

Method	Use	Type of Material	Typical Depth (m)	Typical Borehole Diameter (m)	Advantages	Disadvantages
Hand Auger	Soil sampling and well installation at shallow depths	Soil	< 5	0.05 – 0.15	› Does not use drilling fluids or lubricants; › Equipment is highly mobile and can access many areas inaccessible to a drill rig; and; › Least expensive	› Borehole collapse may occur; › Slow and labor intensive; › Limited to shallow depths; › Limited borehole diameter; and, › Limited soil types.
Solid Stem Auger	Soil sampling and monitoring well installation	Soil, weathered rock	< 45	0.05 – 0.25	› Drilling is moderately fast; › No drilling fluids or lubricants required; and, › Equipment is relatively mobile.	› May be difficult to install monitoring well due to sloughing of borehole wall; › Borehole may collapse under saturated conditions in some soil types; › Difficult drilling in saturated or very coarse soil; › Soil samples may be smeared with soil from borehole wall; and, › Soil samples may be disturbed.
Hollow Stem Auger	Soil sampling and monitoring well installation	Soil, weathered rock	< 120	0.127 – 0. 55	› Drilling is moderately fast; › Lubricants not required; › Continuous sampling possible during drilling; › Favoured method for soil sampling and well installation; and, › Equipment can be relatively mobile.	› Fluid may be required for pressure equalization of heaving sands or silts below water table; and, › Difficult drilling in tills or other dense soils, or coarse materials (i.e., gravels or cobbles).
Direct Rotary Drilling – Air	Soil sampling and monitoring well installation	Soil, rock	> 460	0.05 – 0.9	› Drilling and well installation readily accomplished in partially lithified rock and hard rock; and › Relatively fast; drilling depth unlimited.	› May inject water, foam, or other fluid; › Water-bearing zone may be hard to detect; › Compressor discharge air may contain hydrocarbons;

						› May pose health risk in contaminated soil and rock; and, › Lubrication used during drilling.
Direct Rotary Drilling – Fluid	Soil sampling and monitoring well installation	Soil, rock	> 300	0.05 – 0.9	› Drilling depth is unlimited for geoenvironmental drilling and can be in soil or rock; › Logging from drill cuttings is moderately reliable; and, › Drilling is fast.	› Drilling fluid can alter borehole fluid chemistry; › Lubricants can contaminate samples; › Drilling fluid may be lost to the formation; and, › Difficult to detect water bearing zone
Reverse Circulation Drilling – Air or Fluid	Soil sampling, but not recommended for well installation	Soil and most hard rock	< 600 (fluid) > 300 (air)	0.3 – 0.9	› Relatively fast and for large-diameter holes	› Drilling through loose cobbles and boulders may be difficult; › Requires high volume of water; › Lubricants, drilling fluids with additives as well as air can affect borehole chemistry; and, › Large and heavy equipment.
Dual Wall Reverse Circulation Drilling – Air or Fluid	Soil sampling and monitoring well installation	Soil, rock	Unlimited for practical purposes > 400	Up to 0.25	› Prevents borehole collapse; › Can drill with air or fluid, drilling fluid loss is minimal; › Reduces uncertainty of sample depth; and, › Borehole remains stable for sampling or well installation.	› Equipment is expensive and may not be readily available; › Can smear borehole when extracting casing; and, › Case can damage well screen.
ODEX – Percussion Down-the-Hole Hammer	Soil or rock sampling	Soil, rock, boulders	< 600	0.1 – 0.4	› Rapid method of drilling in cobble or boulder formations; and, › Can collect soil samples with split spoon.	› Samples are disturbed if not using split spoon; and, › Air compressor needed.
Air-operated – Down-the-Hole Hammer	Soil or rock sampling	Rock, boulders	< 600	0.1 – 0.4	› Rapid hole advancement; and, › Drilling in difficult formations is possible.	› Not effective in silty and clayey soil; › Fracturing of the formation is possible; and, › Heavy clay soil may require drilling with fluids.
Sonic	Soil sampling and monitoring well installation	Soil, rock, boulders	< 150	0.1 – 0.3	› Obtain large-diameter cores without rotation or drilling fluids; › Continuous record of stratigraphy can be obtained; › Can drill through boulders, wood, concrete; and, › Fast drilling and minimal drift.	› Expensive; › Extraction can cause smearing of borehole wall with silt or clay; › Maximum borehole diameter 0.3 m: › Water often needed to keep core barrel cool and to advance outer casing to fluidize soil; and, › Soil samples can be heated.
Direct Push	Monitoring well installations,	Soil	6 – 30	0.038 – 0.15	› Drilling fluids and lubricants not required;	› Limited to clay, silt, sand, and gravel;

	water sampling, soil sampling, and continuous core to log lithology, CPT, HPT, LIF, MIP, EC				› Highly mobile equipment; › Fast drilling; no drill cuttings; › Well screens emplaced without exposure to overlying soil; › Can use multiple tool types for measuring soil properties and presence of contamination; and, › Can be very portable.	› Depths limited by lithology; and; › Backfilling and sealing can be difficult due to small diameter.
Cable Tool	Soil sampling and water well and monitoring well (less ideal) installation	Soil, rock	< 1,500	0.1 to 0.6	› Small drill rig useful for limited access areas; › Practical for drilling through cobbles, boulders, and fractured rock; › Good for detecting water bearing zones; and, › Primarily used for drinking water well installations.	› Very slow drilling rate; › Possible cross contamination with bailer sampling method; › Heaving of unconsolidated sediment may be a problem; and, › Cannot obtain groundwater samples during drilling as groundwater is mixed.

[1] Data retrieved from ASTM D6286 (2012)

3.1 Drilling Methods

A key consideration in the selection of a drilling method is the ability of that method to accommodate sampling. Samples need to be representative of *in situ* conditions. Samples submitted for laboratory analysis must be suitable for testing of both physical and chemical properties and for this reason the sample cannot be physically altered by the drilling method or adversely affected by drilling fluid. Some methods of drilling such as air/mud rotary and ODEX, use fluid or air to transport cuttings to the subsurface. Methods such as solid and hollow stem augers, direct push and vibrasonic do not require air or fluid. A summary of common drilling methods used for environmental investigations, including maximum drilling depths and borehole diameters, is presented in Table 3.1.

3.1.1 Auger Drilling Methods

3.1.1.1 Hand Augers

Hand augers are ideal for collecting soil samples from various depths of up to 5 m. Hand auguring is practical in both disturbed and undisturbed soil. Although this method is best suited to soils above the water table it is possible to advance augers below the water table in cohesive soils and with the use of a conductor casing (typically PVC) which limits soil heaving and keeps the borehole open. Hand auger samples are collected by turning a hand auger barrel attached to an extension rod into the ground until the barrel is filled with soil. The auger is withdrawn from the borehole, and the soil is removed for examination or sampling. The process can be repeated, using additional extension rods as needed, until the required depth has been achieved (ASTM D6286, 2016). The choice of auger bit style depends on application and soil conditions. Soil samples can be collected directly from the augers, or a relatively undisturbed soil ample can be collected using a core barrel attached to a slide hammer. In addition, monitoring wells can be installed, provided that the borehole remains open. Table 3.2 provides a summary of bit styles and their associated uses.

Table 3.2: Summary of Hand Auger Methods

Method	Advantages	Disadvantages
Helical Style Bit 	› Very good for augering in dense (undisturbed) soil, including soil with coarse gravel.	› In general, not very well suited for collecting soil samples.
Dutch Style Bit 	› Very good for collecting samples from soil piles (disturbed soil) and for augering in rooty or boggy soil conditions.	› Not very well suited for augering and collecting samples in loose material (sand, gravel) or for augering in dense (undisturbed) soil with gravel.
Bucket Style Bit 	› Very good for collecting samples from soil piles (disturbed soil) and for augering and collecting samples in loose material (includes sand and fine to medium gravel) and clays (use open sided bucket auger).	› Not very well suited for soils containing coarse gravel.

3.1.1.2 Solid Stem Augers

A solid stem auger flight comprises a plugged or solid steel cylinder around which is welded a steel strip in the form of a helix. When connected, the flights form a continuous helix. The lead auger is equipped with a cutter head which typically is slightly larger in diameter than the auger column. Various cutting head configurations are available, and suitability depends on expected subsurface characteristics. The entire drilling assembly is connected to a drill head on the drill rig, and boreholes are advanced by a combination of rotation and downward pressure. Additional auger sections are added as required to form a continuous auger string. Auger fights are typically 1.5 m (5 ft.) long. Solid stem auger sections are available in a range of diameters and are specified by the nominal diameter of the drill head. The most common auger diameter used is 0.15 m (6 inches) in diameter (US Department of the Interior, 1998; ASTM D6286-12, 2012).

Solid stem augers are suitable for relatively soft or loose, unconsolidated soil deposits or soft weathered bedrock. The maximum workable drilling depth of a solid stem auger is dependent on soil firmness, presence of gravel or cobbles, depth to bedrock, depth to the water table, torque capability of the drill rig, and the driller’s technique, but commonly a depth of 20 to 30 m in favourable conditions can be achieved. Deeper holes may be drilled under ideal conditions. Borehole advancement is usually completed in 1.5 to 3.0 m (5 to 10 ft) increments depending on *in-situ* soil conditions. Between increments, the entire auger string is withdrawn to ground surface for sample collection and soil classification. These samples are considered disturbed as the soil coils around the auger as it corkscrews into the subsurface. In addition, the augured material may mix with soil present in the borehole walls as cuttings are brought to surface, resulting in a non-representative soil sample; this effect becomes more significant at greater borehole depths.

Soil samples may be collected using down-hole techniques provided the borehole does not collapse when the augers are removed. If the soil is dense or has abundant cobbles or boulders, drilling can be difficult and sample recovery will be limited. If the soil is predominantly saturated loose sand, drilling is typically easy, but sample recovery will be limited as only a limited volume of sand will remain on the auger as it is brought to the surface.

Detailed procedures for borehole advancement using solid stem augers are presented in SOP D1-5.

3.1.1.3 Hollow Stem Augers

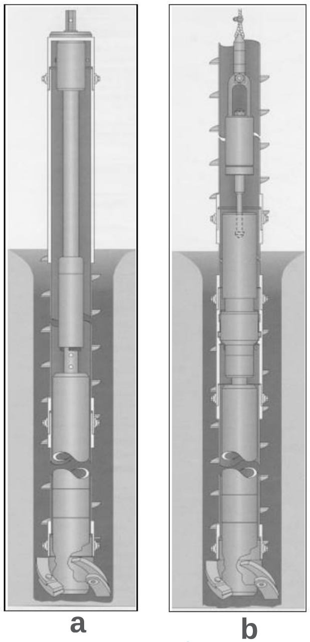

Figure 3.1: Hollow Stem Augers a) Rod and, b) Wire line (US Bureau of Reclamation,1998).

Hollow stem augers consist of a continuous-flight auger with a helix wound around and welded to a hollow inner tube, which is used for the collection of soil samples and monitoring well installations. The drill head of a hollow-stem auger generally consists of an outer head with abrasion-resistant cutters or teeth, and either an inner pilot assembly with a removable center bit or an inner sampling barrel for continuous sampling. The pilot bit assembly or sampler can be removed and replaced using drill or hex rods while leaving the augers in place, which provides a cased hole to insert items such as soil or groundwater samplers, instrumentation, and monitoring wells. When the auger head is rotated, it cuts through the base of the borehole, directing cuttings to the auger flights which convey the cuttings to ground surface. Additional hollow auger sections, which are usually 1.5 m long, are attached to the top of the auger assembly to continue drilling (Nielsen, 2006; ASTM D5784/D5784M, 2013).

Hollow stem augers are used with high torque top-driven rotary drill rigs and are suitable for most soil types. Refusal may be encountered during drilling in very dense soils or soils with cobbles and boulders, or if bedrock is encountered. The maximum drilling depth of the hollow stem auger method is dependent on soil firmness, presence of gravel or cobbles, and the rotational torque capability of the drill rig, but is commonly about 30 m in good conditions and much less in some soil types. Borehole penetrations of up to 120 m may be achieved with the combination of ideal drilling conditions and a deep water table. Continuous sampling can be achieved using split spoons which provide undisturbed or nearly undisturbed samples without cross-contamination from shallower soils. Hollow stem auger drilling is a good technique for monitoring well installations in caving or collapsing ground conditions (i.e., loose/saturated granular deposits or soft, fine-grained soils).

Hollow stem augers can also be used as temporary casings, allowing rotary drilling or coring to advance the borehole beyond the maximum extent achievable by the auger.

Below the water table groundwater pressure can cause sand to heave and enter the hollow stem which can have a limiting effect on drilling. In certain circumstances water can be used to equalize this pressure and flex plugs (plastic baskets) can be used to allow the passage of samplers.

To sample soil with a hollow stem auger, two methods are used:

- A continuous sampling device (typically within an acrylic liner) can be used within the lead auger section; the sampling device fills with material as the auger is advanced, or
- The entire drill assembly is advanced to the top of the desired sample depth, at which point the pilot assembly is removed and a sampling device is attached to drill rods (or wire line) which is inserted through the hollow stem of the auger column. A sample is collected by pushing or driving the sampler into the undisturbed formation in front of the auger head using the drill rig's hydraulics, or a drop hammer. The sampling device typically used is the split spoon sampler (split-barrel drive samplers).

Other types of samplers that can be used include Shelby tubes, piston samplers, direct push samplers, ring-lined barrel sampler, or modified versions of the above (ASTM D6286, 2012). Select sampling devices are discussed in Section 3.2.

The inside diameter (I.D.) of hollow stem augers range from 0.057 m (2.25 inch) to 0.32 m (12.25 inch). The most common size used for monitoring well installation is the 0.11 m (4.25 inch) to accommodate the installation of 0.05 m (2 inch) diameter wells. Augers with inside diameters of 0.15 m (6. 25 inch) I.D. are used to install 0.05 m (2 inch) and 0.1 m (4 inch) diameter wells.

Detailed procedures for borehole advancement using hollow stem augers are presented in SOP D1-6.

3.1.2 Rotary Drilling Methods

Rotary drilling methods represent one of the most useful tools for subsurface investigations, in both unconsolidated materials and bedrock. The rotary drilling method uses a drill rod with an attached bit that is continuously rotated against the base of the borehole to break up the underlying formation which is conveyed to ground surface as cuttings using a circulation fluid (typically air or a water-based fluid). Down force pressure can be used during bit rotation to more efficiently advance the borehole. Rotary drilling rigs use core barrels, diamond bits or hardened metal bits, and a hydraulic or screw feed. A wide variety of samplers and bits can be used with rotary drilling.

The drilling rig is usually mounted on a rubber tired truck, track, or skid, and can vary from a lightweight and highly mobile all-terrain carrier to heavy stationary rigs. Rotary drills can produce borehole diameters that range from 0.025 m (1 inch) to 0.9 m (36 inches); boreholes can be advanced to depths of hundreds or thousands of metres. The most common rotary drilling methods are described in the following sections.

3.1.2.1 Direct Rotary Drilling

Direct rotary drilling uses rotation and axial pressure on the drill bit and string while simultaneously introducing compressed air or a water-based drilling fluid through the drill string and bit. The drilling fluid or air is recirculated in the borehole and cuttings from the drilling process are brought to ground surface through an annulus formed between the drill string and borehole wall. Drilling fluid brings the cuttings to the surface, prevents the borehole wall from collapse and prevents groundwater from entering the borehole. Air rotary drilling, in contrast, does not prevent collapse of the borehole wall and is therefore better adapted to partially lithified soil. Cuttings brought to the surface with the drilling fluid settle out in a pit and cuttings from the air-rotary drill method are either disposed of adjacent to the borehole or carried to various soil sampling devices. Direct rotary drilling is appropriate for soil and rock and can be used to sample soil and install monitoring wells. Soil samples collected using this method are highly disturbed and as such are not suitable for contaminant characterization. Another disadvantage of direct rotary drilling is the potential for contaminants to be introduced into the borehole or aquifer from lubricants or additives used in the drilling process. Additionally, it may be difficult to detect water-bearing zones, and the air stream can strip VOCs from the borehole wall, which may affect groundwater quality and could pose a health risk at ground surface. Both air and fluid rotary drilling are fast processes that are not limited by depth (ASTM D6286, 2012).

3.1.2.2 Reverse Circulation Rotary Drilling

Reverse circulation rotary drilling uses a water-based drilling fluid that is circulated through the annulus formed between the drill string and the borehole wall. Cuttings are discharged at ground surface with the drill fluid via the drill string and settle in a pit or series of pits. The process is the opposite of direct rotary drilling where the drilling fluid descends through the drill string and cuttings and the drill fluid returns via the annulus. Reverse circulation rotary drilling is not widely used for installing groundwater monitoring wells because the drill fluid often contains additives that can penetrate the aquifer and change the fluid chemistry or contaminate groundwater (ASTM 6286, 2012). Reverse circulation rotary drilling uses large quantities of water and is not suitable for drilling through cobbles and boulders. The equipment is large and heavy and may result in site access difficulties. Advantages of reverse circulation rotary drilling are speed and its effectiveness in most soils and hard rock.

3.1.2.3 Dual Wall Reverse Circulation Drilling

The dual wall reverse circulation drilling method uses a double walled tubular drill rod. Pressurized air is circulated downhole through the annulus between the inner and outer rod wall. Air ejected near the bit provides cooling and moves the cuttings up though a central opening in the bit into the central tube from which it is ejected to ground surface.

The major advantage of the rotary dual wall reverse circulation drilling method over other rotary drilling methods is its ability to prevent borehole wall collapse during drilling or when the temporary casing is removed. Drilling can be completed in loose soil where a loss of circulation would typically occur. This method is useful for aquifer yield testing, facilitates easy installation of monitoring wells and accurate determination of sample depths (ASTM D6286, 2012). In addition, samples are not contaminated by drill fluid.

This method is limited by high cost and potential difficulty in accessing equipment. Additionally, the well screen can be damaged when the casing is extracted.

3.1.3 Percussion Drilling Methods

Percussion drilling methods use a hammering force to advance the borehole. Rotation may be added, but it is used primarily to maintain a straight, round borehole. There are three main types of percussion drilling methods: the cable tool method, the air percussion method and the air operated casing hammer method.

3.1.3.1 Cable Tool Drilling

One of the oldest drilling techniques is cable tool drilling, which uses a weighted bit attached to a cable which is repeatedly dropped and lifted to loosen soil and rock from the base of the borehole (ASTM 6286, 2012). The bit is removed periodically from the borehole to remove water and cuttings using a bailer. Disturbed soil can be sampled from the bailer, or a split tube sampler can be used to obtain soil samples. A casing equipped with a drive shoe can be advanced during drilling by using the weight of the bit to hammer the casing into the borehole. A casing is typically driven into the hole to prevent cross contamination of aquifers and to facilitate the installation of a monitoring well upon completion of the borehole.

Cable tool drilling is possible in most soil and rock to depths exceeding 1500 m. The water-bearing zones and water yield are more easily identified using the cable tool drilling method. Large volumes of drilling fluid are not needed, and groundwater can be sampled as drilling progresses. A small rig is used for cable tool drilling making it a good choice for areas where access is limited however borehole advancement is very slow, with drilling rates of three to five metres a day being typical. Borehole diameters are typically 0.15 m (6 inches) or greater due to the large bit size. Cable drilling is rarely used for environmental investigations however this method is still commonly used to drill drinking water wells.

3.1.3.2 Air-Operated Down-the-Hole Hammer (Air Percussion)

Air-operated down-the-hole (DTH) hammers use compressed air to power a downhole casing hammer into the subsurface and to provide air circulation through the hammer and up through the casing (ASTM 6286, 2012). A drive shoe is used to cut the material before the casing is advanced.

Figure 3.2: Air-operated down-the-hole hammer bit.

The DTH hammer is a rapid and very effective technique for drilling though cobbles or boulders and hard rock. Silty and clayey soils are not suitable for DTH hammers. Samples can be collected from drill cuttings using a cyclone sampling device that brings cuttings up to ground surface. In some cases foam may be used in addition to air to drill. If foam is used, samples are more difficult to collect. Samples may also become contaminated if hammer lubricants are used during the drilling process. Additionally, traces of air compressor lubricant can often be detected in samples and steps should be taken to prevent cross contamination. An alternative sampling method is to incrementally sample at the base of the hole.

3.1.3.3 ODEX – Percussion Down-the-Hole Hammer

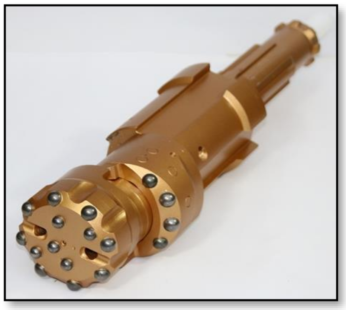

Figure 3.3: ODEX drill bit.

ODEX is an adaptation of the air-operated down-the-hole casing hammer that uses a two-part percussion bit. The assembly consists of a concentric pilot bit, and a swing-out eccentric bit that is used to enlarge the borehole diameter. The swing-out is controlled by forward or reverse rotation of the drill string and casings are pulled down by the drill string as the borehole advances. Cuttings are blown up through the annulus to a sample collector on the surface (Nielsen, 2006). ODEX percussion down-the-hole drilling is a rapid and effective method for drilling through cobble and boulder formations and is commonly used in environmental investigations in B.C.

3.1.3.4 Air-Operated Casing Hammer

The air-operated, drill-though casing hammer operates similarly to a pile driving hammer, with the exception that it is hollow which accommodates the insertion of a drill rod string. As the name suggests a casing is driven into the subsurface while drilling is occurring. The drill head of the drilling assembly creates a pilot hole, removes the cuttings and allows for a casing drive shoe to be lowered. This configuration enables drilling and coring of saturated soils which may otherwise collapse and eliminates the issue of lost fluid circulation (i.e., fluid lost through the formation). If pressurized air is used as the drilling fluid, water-bearing units can be identified, and aquifer yields can be estimated. The casing can seal off contaminated layers and minimize drill fluid contact with an adjacent formation. This method also allows soil core samples and groundwater samples to be collected from current drill depths rather than from other depths in the borehole (ASTM D6286, 2012; US Bureau of Reclamation, 1998).

A Becker hammer is a specific type of reverse circulation percussion drill that uses a double-acting diesel percussion hammer to drive a double-wall drive pipe fitted with a drive bit. Compressed air is forced down the annulus of the drive pipe to lift the penetrated formation material through the center of the double wall pipe where it is discharged to a cyclone. The center of the drive pipe remains clear for sample collection or well installations.

3.1.4 Vibrasonic or Sonic

Vibrasonic or sonic drilling is a rapid drilling method capable of providing continuous core samples in most geologic settings. The vibrasonic drill rig is similar to a conventional rig, although the drill head has an oscillator which applies a high frequency vibration as well as a mechanism to apply rotary motion to both a sampler barrel and an outer casing. The operator controls the vibration frequency to obtain a balance between a high drilling rate and optimal core recovery. In unconsolidated material, the drill bit vibrations cause the surrounding soil to act as a fluid, allowing borehole advancement. In bedrock, the vibratory movement causes the rock to fracture, which creates rock dust and small rock fragments as the sampler barrel is advanced.

With sonic drilling, the vibration and downward forces advance a sample barrel into the formation, to a depth that is typically equal to the length of the casing (3 m), at which point the outer casing is vibrated over the sampler to the same depth. The sample barrel can then be removed from the borehole, and the recovered core is vibrated or slid out and into a flexible plastic sleeve that provides a continuous core for logging and sample collection. The sample barrel is then inserted into the outer casing for further advancement (ASTM 6286, 2012, Nielsen, 2006).

Drilling fluids are not needed to advance the sampling barrel, however a drilling fluid (usually water) is sometimes used to prevent soil from entering the annular space between the sample barrel and outer casing, and to prevent the two components from locking up. In very dense formations, water or drilling mud can also be added to control heat. In bedrock, compressed air or fluid is needed to remove drill cuttings as they cannot be forced into the formation. When drilling in paved or otherwise developed areas, a hydrovac truck may be needed to recover the slurry discharging at ground surface when water is used.

Advantages of the sonic method are minimal drill cuttings, unless drilling fluid is used, and an outer casing that seals the borehole which can limit cross-contamination and make monitoring well installation relatively easy. If water is added, the amount should be recorded and removed during well development. Well completion materials such as sand and or bentonite pellets can be vibrated into place to allow for a faster and higher quality well completion while mitigating the probability of bridging. Penetration is possible in dense soils with cobbles and boulders. In addition, the recovery of a continuous core allows for a very thorough classification of soil type.

Disadvantages of soil sampling using sonic drilling include negative bias which may occur when sampling for volatile organics in dense deposits due to heating and vibration of the core sample. Poor core recovery may be experienced in organic deposits (e.g., peat or wood waste), or at the interface of dense to loose or soft deposits.

Detailed procedures for advancing boreholes with sonic drill rigs are presented in D1-7.

3.1.5 Direct Push

Direct push technology, also known as direct drive, drive point, or push technologies, refers to a family of tools used for subsurface investigations by driving, pushing, or vibrating narrow tooling into the ground. The investigation method can be used to quickly acquire continuous vertical logs, and to collect discrete depth soil gas, soil, and groundwater samples. Very little excess soil cuttings are produced with this investigation technique. In addition to improved soil logging capabilities, the method can be used to install conventional monitoring wells, wells with pre-packed screens, or small diameter temporary monitoring wells for groundwater or soil vapor sampling.

Direct push rigs include a sampling or logging tool connected to a drive rod or casing, which extends to the equipment used to drive the tool at ground surface. Samples are collected directly from the recovered core. Equipment used to drive direct push tools range from simple slide hammers or pneumatic hammers for limited access areas, bobcats, pickup trucks, or conventional rigs to 36,000 kg and CPT trucks fitted with hydraulics. Some units include percussion hammers or vibratory heads which can reduce the static weight required for successful penetration and sampling. Rigs can include both rotary and direct push drilling equipment (ASTM 6286, 2012, Nielsen, 2006).

Direct push methods are not recommended in soil with cobbles or boulders. Additionally, penetration can be limited in dense and stiff soils. Poor core recovery may be experienced in loose organic deposits (e.g., peat or wood waste), or at the interface of dense to loose or soft deposits. The maximum direct push drilling depth in ideal settings is 30 m.

Direct push boreholes should be sealed after tool withdrawal, since it may provide a conduit for vertical contaminant migration. Grout, bentonite chips or bentonite pellets may be poured in the borehole after the direct push rods have been withdrawn, either directly or through the use of a tremie pipe. Re-entry grouting may be used via a probe rod and expendable tip to pump grout into the borehole, or retraction grouting, which uses the direct push rods as a tremie pipe to pump grout into the borehole as the rods are withdrawn. It is also possible to grout during advancement using expendable friction reducers (Sara, 2003).

A detailed description of direct push drilling procedures is provided in SOP D1-8.

3.2 Core Sampling Devices

Optimal methods for soil sampling in environmental investigations are methods that provide continuous or near-continuous sampling and those that provide minimal disturbance of the sample matrix and methods that do not volatilize target parameters. The advantages and disadvantages of select core sampling methods are provided in Table 3.3.

Details regarding select sample methods are described in subsequent sections. Note that advantages and disadvantages of soil sampling using sonic methods are described in Section 3.1.4.

Table 3.3: Summary of Core Sampling Devices

Sampler Type	Description	Advantages	Disadvantages
Slide Hammers with Core Sampler	The core sampler with slide hammer is manually placed in an open borehole and the slide hammer is dropped from height onto the core sampler to drive it into the soil.	› Can be easily transported and used in locations with limited access.	› Force is dependent on the weight of the slide hammer and the height from which it is dropped; › Used for shallow boreholes; › Core sampler may be difficult to retrieve; › Difficult to use in stiff or coarse soils; and, › Plastic baskets and catchers can be used to retain loose sands or gravels.
Split Spoon	Hollow stem auger drilled to a set depth and split spoon (thick-walled tube) is driven into the soil (typically 0.45 m long and 38 mm in diameter)	› Commonly used; and, › Soil sample is only moderately disturbed.	› Sample recovery may be poor for unconsolidated sand and gravel; and, › Plastic baskets and catchers can be used to retain loose sands or gravels.
Shelby Tube	Thin-walled tube with a tapered cutting head that is pushed into the soil	› May be used to collect samples for chemical analysis, but primary use is geotechnical; and, › Undisturbed sample	› Only applicable for soft soils.
Direct Push Samplers	Single rod or dual tube samplers	› Continuous soil core possible; and, › Dual tube sampler preserves sample integrity.	› Depth limitations; and, › Not possible to sample very dense or coarse soil.

3.2.1 Slide Hammers with Core Sampler

Slide hammers with core samplers use the force of the dropping hammer to push the core sampler into the subsurface. Slide hammers are manual rod drivers typically used in shallow boreholes without drill rigs (Nielsen, 2006). To use a slide hammer, a retaining cylinder is inserted into the core sampler and capped. The core sampler is then attached to the slide hammer and inserted into a predrilled hole. The slide hammer portion of the apparatus slides up the rods, drops from height, and applies pressure as it contacts the core sampler pushing it into the soil. The slide hammer may be dropped several times before the core sampler has been filled with soil. After the sample is collected, the slide hammer can be removed from the hole and the core sampler can be detached from the hammer. The sample, encased in the cylinder, can be removed from the core sampler and capped or transferred into sample jars for laboratory analysis. After a sample is obtained, the core sampler must be cleaned with a pressure washer or wire brush, laboratory grade detergent (e.g., Alconox®), and inspected for damage before it is reused to collect another sample.

Loose sand and gravel may not be retained in the core sampler, however this can be alleviated through the use of a disposable plastic basket sand catcher, which allows loose material to enter and hold the core sample.

3.2.2 Split Spoon

Split-barrel or thick-wall split spoon samplers are typically used in conjunction with hollow stem drilling investigations and occasionally with other drilling techniques that provide an open bore into which the split spoon can be inserted. In addition to hollow stem drilling, split spoon samplers can be used with ODEX, Becker Hammer, air/mud rotary, and solid stem augers if the borehole remains open. Split spoon samplers provide discrete, relatively undisturbed (intact) soil samples for characterization and chemical analysis and provide a means to measure the relative density or firmness of the soil deposit with deployment of the Standard Penetration Test (SPT). This method of sampling is generally not suitable for gravel deposits, deposits with a significant amount of cobbles or boulders, very dense deposits, or fibrous peat deposits. Larger diameter (non-standard) split spoons may provide adequate sample recovery in gravel or fibrous peat deposits. Split spoons are also ineffective for recovery of loose sand and samples below the water table, although a disposable plastic basket (sand catcher) can be used to help to retain the sample. The split spoon may be used either unlined or lined (ASTM D1586-11, 2011; ASTM D5872/D5872M-13).

The outer diameter (OD) of a split spoon sampler is typically 50 mm or 75 mm and 0.45 m or 0.6 m long. The split spoon is driven into the subsurface by a drive hammer and/or lift system that is attached to a drill rig. The drive hammer typically weighs 63.5 kg and is either a manually operated rope and cathead system or a hydraulically operated safety hammer.

3.2.3 Shelby Tubes

Shelby tube samplers are open-tube, thin-walled samplers used to collect intact cores of silty and clayey sand or silt and clay above the water table (ASTM D6169, 2013). Shelby tube samplers are primarily used for *in situ* physical and hydraulic properties such as density, permeability, compressibility, and strength, but Shelby tubes may also be used to collect samples for chemical analysis (ASTM D1587, 2015). Shelby tube sampling can produce relatively undisturbed high quality core samples for analysis of both physical soil properties analysis and chemical analysis. A disadvantage of this sampling method is that it is ineffective in cohesionless sand or gravelly soil and that it may not be able to penetrate dense soil.

Shelby tube samplers are deployed with rotary drills or hollow stem augers and are typically made of steel, stainless steel, galvanized steel, or brass; however, stainless steel is used for collecting samples for chemical analyses (US EPA, 2014). It is recommended that the open borehole diameter and casing or hollow stem auger I.D. not exceed 3.5 times the outside diameter of the thin-walled tube. Tubes should be at least 75 mm longer than the design push length in order to accommodate possible sloughing.

Shelby tubes are attached to a drill rod and lowered (not dropped) into the borehole where it is pushed, without rotation, into the sample material by hydraulic force. It should take less than 15 seconds to push a 1 m sample tube. It is important that the tube be pushed smoothly into the soil to minimize sample disturbance. The sample is extracted from the tube once it has been brought to the surface. The top of the sample collected may account for slough in the borehole if it is uncased and should be examined prior to sampling. To avoid sidewall contamination and slough at the top of the sample, a casing should be used, and the sampler should be coincident with the drill depth.

3.2.4 Direct Push Samplers

Direct push sampling is used extensively for environmental investigations. Direct push sampling is preferred over rotary drilling sampling methods (e.g., solid stem augers) because they are less disruptive to the soil column and do not generate excessive cuttings. Direct push samplers, also referred to as direct drive, drive point, or push samplers, are small-diameter hollow steel samplers that are driven into the ground from the surface or through pre-drilled boreholes. Direct push samplers can provide continuous or discrete interval samples (ASTM D6282, 2014). The sampler may be advanced by static push, impact, percussion, vibratory/sonic methods, or a combination of these methods. The method used will depend on the drill rig used for borehole drilling. Different hammer styles that may be used to push the sampler into the subsurface include drop style, hydraulically activated, air activated, and mechanical lift devices. Samples can be collected for soil classification, lithologic or hydrostratigraphic logging, and chemical analyses.

Direct push soil sampling is limited by the ability of the sampling tool to penetrate the soil and unconsolidated material which is dependent on the compactness and consistency of the soil and the hammer energy and carrying vehicle weight. Attempting to penetrate difficult soil with inadequate hammer energy or drill rig weight can damage the equipment, including the sampling tool. It is also important to consider the ability of the rig to extract the sampler after it has been driven into the subsurface. If the drill rig does not have enough force to extract the tool from the borehole, then the sample and sampler may be lost.

Direct push rod systems include single rod, which requires that the tool string be removed from the borehole each time a sample is collected, to dual-tube systems, allowing for sampling through a hollow outer drill rod. Dual tube systems prevent sloughing or collapse of borehole walls and downhole contaminant migration, which can be an issue with single rod systems. Dual tube systems allow for continuous coring and when sampling is not required, the inner drive point can be locked in and soil will not be collected. When using dual-tube systems below the water table in loose sands, hydraulic pressure and suction created by the removal of the sampler can cause sands to enter the bore of the outer drilling rod, which can prevent further sampling. Although water can be used to equalize the pressure, it has the potential to dilute or alter groundwater chemistry. Another disadvantage of dual tube sampling is that more friction is generated, which may require more powerful equipment. Sealed single rod samplers do not have this limitation (Nielsen, 2006).

Most often the direct push method is used to provide a continuous soil core, which can be described and logged, field screened for indicators of contamination, and sampled for detailed laboratory analysis. For these programs the Geoprobe® DT45 (dual tube 4. 5”) tooling and sampling system is commonly used. The DT45 outer casing is 114 mm (4. 5”) OD with either a fixed 127 mm (5”) sampling cutting shoe or a 127 mm (5”) expendable cutting shoe holder. Samples are typically collected using a 1.5 m (5 ft) long, 76 mm OD sample sheath with a hydrocarbon resistant PVC liner. The sheath and liner are placed against the cutting shoe within the outer casing and held in place with either 1.25” or 2.25” probe rods. The sample sheath is fitted with a core catcher if necessary. Advancement is achieved through a combination of percussion and downward pressure generally in 1.5 m intervals. Once the full length of the core has been achieved the sample can be brought to the surface.

If a monitoring well is going to be installed, an expendable cutting shoe holder and shoe will be required in order to install a monitoring well within the outer casing. The expendable cutting shoe will be pushed out of the holder after soil sampling has been concluded and before the monitoring well is installed. The shoe is composed of stainless steel and will permanently sit below the monitoring well. Boreholes can also be advanced by plugging the expendable cutting shoe with a point drive tip. The tip displaces soil as the outer casing and sample sheath are advanced until a target depth is reached at which point the drive tip can be pushed from the expendable cutting shoe holder. The point drive tip is composed of stainless steel and will permanently sit below the monitoring well. This technique is useful for caving ground conditions, or to advance the borehole to the top of a zone of interest but does not allow for samples to be collected as the borehole is advanced.

4 Sampling Methods

4.1 Establishing Background/Baseline

As part of a soil sampling investigation, it may be necessary to establish background conditions in soil, which can be completed following the procedure provided in CSR Protocol 4 - Establishing Background Concentrations in Soil. This may be necessary if concentrations of selected metals or other parameters exceed applicable standards, but the exceedances are not related to APECs, historic land use activities or other known site conditions. Complete sampling information and technical guidance specific to establishing background/baseline conditions is provided within the Contaminated Sites Regulation and Technical Guidance documents and as such is not provided in detail within the B.C. Field Sampling Manual. The following information is provided as an overview of available guidance materials.

The following sections of the CSR apply with respect to background soil conditions:

- Under Section 11(3) of the CSR, a site with soil that contains a substance at concentrations above the applicable numerical soil standard but below the local background concentration for that substance, would not be considered to be contaminated;
- Under Section 17(2) (b) of the CSR, soil that has been remediated for a substance to concentrations above the applicable numerical soil standard for the site but below the local background concentration for that substance would be considered satisfactorily remediated; and,
- Under Section 45 (3) (b) of the CSR, soil to be removed from a site that contains a substance at concentrations above an applicable numerical soil standard for the receiving site, but below the local background concentration for that substance at the receiving site, can be considered acceptable for deposit at the receiving site.

In addition to the CSR the following documents provide further guidance;

- Table 1 of Protocol 4 presents regional estimates of background soil concentrations, based on the 95th percentile of near surface soil samples collected from ENV background sites within each region.
- Technical Guidance 17 (Background Soil Quality Database) provides individual data points for each sample location, which may be used to estimate background, although due to limited data, the median value has to be used to estimate the background concentration.
- TG 16 provides a detailed soil sampling guide for local background reference sites. TG16 also provides some statistical guidance in identifying anomalous results so they may either be resampled or re-analyzed.
- TG 12 - Statistics for Contaminated Sites provides additional guidance.

4.2 Soil Conditions/Considerations

When collecting discrete soil samples, care must be taken to ensure that the sample is representative of the formation from which it was obtained and should not be mixed with soil from other formations. Soil contamination may occur along discrete units, particularly if the main transport pathway for the contaminants was the infiltration of precipitation or NAPL. It is common for the contamination to be located in coarser soil, following the migration pathway however, contamination may also be present in silts and clays of lower permeability, due to fractures, diffusion and rootholes, or even improperly sealed boreholes or poorly screened or improperly decommissioned wells.

Many contaminated sites contain a layer of fill, which may be contaminated due to land use activities or the land use activities of the site where it originated. Fill is usually placed to level a site and add foundation stability, or it may be used to raise and reclaim land that was previously underwater. It can be used to fill in streams or other topographic depressions. The thickness of fill can vary widely at a site, from a thin veneer to several metres or more. Fill material is usually easily identified as it may be loose or soft, is generally not stratified and contains anthropogenic materials such as aggregates, building rubble, bricks, blast-furnace slag or clinker, mine waste rock, furnace ash, organic matter, hogfuel or other wood debris. However, in some cases it may be difficult to determine the contact between fill and native soil, since the fill used may have been obtained from a local source and may have been placed in lifts, which may give it a stratified appearance. Careful judgment is needed to identify fill, both during the Stage 1 PSI process and during the Stage 2 and DSI stages of an investigation. A review of old air photos or topographic maps may help identify buried streams or depressions. Geophysical techniques such as ground-penetrating radar (GPR) can also be used to identify the depth of fill materials. It is important to distinguish fill from native materials during characterization and for remediation purposes. Contaminants leached from fill may also impact underlying soil and groundwater.

It may not be possible to collect soil samples from some materials, such as gravels or cobbles, or construction debris. Analytical methods should be consulted for specific particle size sample/sampling requirements. Where soil samples cannot be collected it is important to photograph and record indications of contaminant presence. Where soil exists above and beneath a coarse layer of material that is not suitable for analytical testing, those soils should be sampled so that the results can be used to infer the presence of soil contamination in the coarse layer. Follow-up groundwater samples collected from wells screened within a coarse layer of material can also be used to infer the presence of soil contamination. Soil leachate testing may also provide indications of contamination. Leachate testing provisions are outlined in Protocol 27 and the Hazardous Waste Regulation.

When soil samples are recovered in split spoons or via sonic cores, full recovery may not be achieved; due either to lost sands, or possibly a blocked spoon opening. Conversely, cores recovered during sonic drilling may be longer than expected due to material expansion. In all instances, review the recovered core closely to determine where the discrepancies may have occurred, and adjust the sample depth appropriately to be as accurate as possible. If no recovery is obtained, this should also be recorded.

4.3 Groundwater Considerations

Soil contamination near ground surface can represent a risk to human health and the myriad of living organisms that spend some or all of their lives underground. Contamination which occurs at greater depths represents less of a risk unless the contaminant is volatile, however contamination at greater depths pose a greater risk to groundwater. Depending on soil conditions, depth to groundwater and contaminant characteristics, contamination can migrate to and impact the underlying groundwater. Contaminants in groundwater have the potential to migrate to receptors such as surface water bodies or drinking water wells. Thus, it is of great importance to thoroughly investigate soil contamination pathways and linkages to environmental receptors.

Contaminant releases generally occur at or near ground surface and often pose a risk of infiltration and migration. Migration can occur laterally or vertically within the subsurface or follow manmade conduits such as storm drainage structures and other underground utilities. Contaminants that infiltrate surface soils may also enter the water table or pool on top of the water table. Contaminants may move through transport pathways as plumes traveling below ground surface and upward as soil vapour. These mechanisms can result in soil contamination extending to the water table and beyond depending on the contaminant's characteristics and the sites hydrostratigraphy. As such, the properties governing migration and possible migration pathways should be understood and be included in the CSM. Key processes that affect or influence the occurrence, transport and fate of contaminants include ion exchange, precipitation, dissolution, volatilization, diffusion, sorption/desorption, oxidation/reduction reactions and biodegradation. In addition, groundwater processes such as advection, dispersion, and retardation may also affect soil contamination.

The fate and transport characteristics of Light non-aqueous phase liquids (LNAPL) and dense non-aqueous phase liquids (DNAPL) differ significantly and must be considered in any contaminant investigation. LNAPLs such as fuels and oils will migrate downward under the force of gravity and may continue to migrate until it reaches the capillary fringe of the water table (EPA/540/S-95/500). If perched aquifers are present LNAPLs can pool and spread laterally over units where groundwater is at 100% saturation. If it reaches the edge of these units, the LNAPL can migrate deeper.

Due to seasonal variations, the elevation of the water table can vary by many metres, causing LNAPL to smear across this zone. Residual LNAPL and associated petroleum hydrocarbon soil contamination will be present along the migration pathway. At a minimum, soil samples should target areas where LNAPL is expected to pool, which would include perched or clay lenses within the unsaturated zone, as well as the smear zone of the water table. In general, soil samples may not be necessary from depths exceeding two metres below the minimum water table elevation, as LNAPL migration is limited in the saturated zone. However, if fractures and or fissures are present in unconsolidated soil (clay, silt, or till) or bedrock, LNAPL does have the potential to migrate well below the water table, and in these cases, deeper soil sampling is warranted. These conditions should be evaluated and confirmed on a site-specific basis.

DNAPLs include products such as solvents, coal tars and pesticides. DNAPLs migrate vertically under the forces of gravity and capillarity and laterally due to geologic controls (e.g. bedding planes). DNAPLs or a portion thereof can be retained in soil as isolated residual globules (EPA/540/4-91-002). Vertical and lateral DNAPL pathways can be very discrete, since small changes in permeability can influence DNAPL migration. Consequently, it can be extremely difficult to locate DNAPLs released in soils providing the potential for discrete pathways. Chlorinated solvents are usually clear and colorless and as such do not provide visual indicators of their presence. Areas to target for soil sampling in DNAPL investigations are zones immediately above fine-grained units, both above and below the water table.

Due to the difficulty in assessing DNAPL soil contamination, and the risk of drilling through the source zone, which may result in cross-contamination, downgradient groundwater investigations can be completed to infer the presence of upgradient soil contamination. This type of investigation can be completed to infer the presence of DNAPL contamination. With a thorough understanding of groundwater flow and contaminant migration, the depth and extent of contaminated soil or bedrock in the source zone may be inferred via the collection and analysis of discrete groundwater samples and a thorough understanding of stratigraphy and groundwater flow.

4.4 Field Preparation

Preparation for each sampling trip is critical since oversights usually go unnoticed until the field crew reach their first station. The most effective way to prepare for a sampling trip is with a checklist that is designed to meet the requirements of each project.

Other than considering site-specific instructions, the checklist should identify the following needs:

- Site map;
- Well Headspace Screening Equipment (e.g., calibrated photo-ionization detector or an organic vapour/combustible gas meter);
- Non-contaminating, chemical-resistant gloves (e.g., nitrile, or equivalent);

- Clean sample coolers, sample containers, preservatives, and chain-of-custody forms provided by the contracted laboratory;
- Double-bagged wet ice for sample cooling;
- Re-sealable bags for ice and sample storage and packing materials (bubble wrap or foam);
- Type and number of (labeled) bottles and containers, including extras;
- VOC-free markers;
- Trip blanks provided by laboratory;
- Deionized water provided by the laboratory, for preparation of field or equipment blanks;
- Field sampling tools (drive samplers, hand augers, trowels, etc.);
- Distilled water (for decontamination);
- Decontamination kit (buckets, water, phosphate-free cleaner, deionized water);
- Field notes and borehole logs or soil sampling forms;
- If drilling, an electric water level meter to confirm the depth to water in a borehole;
- Container or garbage bag for waste;
- Personal gear and personal protective equipment (PPE) (e.g., steel toe boots, hardhat, safety glasses), including specific equipment that may be required for the site;
- First aid kit and other safety equipment (life jackets, survival suits); and,
- Camera or video equipment as required.

It is good practice to store key pieces of equipment in a container such as a box or plastic tote and to maintain the container for field trips. In addition to soil sampling equipment, all other equipment used for soil sampling must be selected and treated with care to mitigate the potential of contamination from previous investigations affecting current and impending investigations. For some contaminants, new sampling equipment may be necessary. Sampling equipment that comes into contact with soil samples (e.g., split spoons, trowels) must be thoroughly decontaminated before use and before storage.

4.5 Field Notes/Observations

Legible and detailed field notes represent the foundation of good sampling practice. Specific information about seemingly unimportant facts such as the time of day and weather conditions is often important when interpreting data. A field note template or checklist secured to the inside cover of field log books will prompt field staff to observe and identify specific details regarding project sites, weather conditions, staff and contractors and equipment. Field measurements should be recorded in the field including those retained by instrument logging functions.

A **field log book** (3-ring binder with water proof paper) for each project is strongly recommended and may be mandatory for specific projects. All field measurements should be entered (by date) directly into this field log book. Along with the field book, sampling forms or borehole logs may also be used to record sample information and observations.

The following list emphasizes those observations that should be recorded:

- Date and time of arrival;

- Site/project name and location;
- Names of all personnel on the sampling crew;
- Ambient weather conditions;
- Contractor names;
- Equipment used (i.e. type of drill rig, soil sampling equipment);
- Soil sample location or borehole location (preferably located with GPS or surveying, although distances to fixed local features may be used);
- Sample collection depths and sample IDs;
- Any other relevant drilling information (blow counts, depth to water, etc);
- Recovery estimate (i.e. % recovery in soil core);
- Soil Characterization (see Section 1.4), including soil sample ID;
- Gross characteristics of vertical profile (distinct layers, depth of layer changes);
- Any instances that may affect quality of soil samples collected (i.e. spilled hydraulic oil from drill rig, broken equipment, dusty conditions, nearby construction, etc.);
- Decontamination methods used (i.e. steam cleaner, three bucket rinse); and,
- Time when site was left.

4.6 Stockpile Sampling

Stockpile sampling, also referred to as *ex situ* sampling is typically carried out to further characterize the quality of soil that was first sampled and characterized *in situ*. Stockpile characterization is used in support of various contaminated site management decisions. During remedial excavations, soils that have been previously characterized *in situ* are often excavated and stored in temporary stockpiles for subsequent management. Soil stockpile sampling in these instances is completed to support decisions regarding the fate of excavated soils. Analytical results of stockpile samples can be used to confirm that the soil meets applicable criteria for re-use at a given site, or to provide characterization for remedial strategies or offsite disposal at a permitted facility. Stockpile sampling may also be carried out for general characterization purposes during Stage 2 PSIs and during the management of soils undergoing *ex situ* treatment (i.e., bioremediation). Similar principles apply for each of the stockpile characterization purposes to ensure thorough and appropriate characterization occurs.

Detailed procedures for soil stockpile sampling are provided in SOP D1- 4.

4.6.1 Stockpile Sampling Methods and Design

Stockpile characterization is typically determined from the analytical results of composite or proportional samples. Characterization requirements vary depending on the level of the contaminants in the soil. The level or suspected level of contamination in the soils of a stockpile are based on *in situ* test results which is used to categorize the soil material as either ‘suspect hazardous waste’, ‘suspect waste’ or ‘suspect industrial quality material’ or other ‘suspect quality material’ classes. The category of the soil is in turn used to determine the maximum allowable volume of waste in a single stockpile, the maximum number and volumes of cells in a stockpile, and the sampling method. Technical Guidance 1 (TG1) on Contaminated Sites provides all of the necessary details to produce soil samples that are representative of the soil contained in a stockpile. Applicable soil sampling and handling procedures are described in Section 4.7 of this Part of the BCFSM.

The design of sampling methods, including locations and frequency of sample collection, must take into account information that is known about the soil stockpiles in question. Informed by analytical data obtained from *in situ* sampling or other previously collected data, investigators should be able to better estimate the suspected soil quality classes[6] and better understand the variability of contaminant concentrations within a given stockpile. Field screening technologies relevant to the subject contaminants, along with field observations, can provide useful information on the variability of contaminant concentrations that should inform a sampling design.

The procedures provided in TG1 are designed to facilitate a thorough characterization of soil stockpiles and a measure of the variability of contaminant concentrations within a given stockpile. Instructions on the interpretation of soil analytical results from stockpile composite sampling are provided in the technical guidance document, along with guidance on appropriate Quality Assurance/Quality Control measures.

If the contaminant concentration distribution suggests data represent a single population, TG 2 - Statistical Criteria for Characterizing a Volume of Contaminated Material provides useful information for determining soil quality class. Specifically, the conditions and criteria for the use of statistics in classifying materials are provided.

Composite sampling which involves the mixing of soil sample aliquots is not considered appropriate for volatile contaminants of concern due to the potential for contaminant loss through volatilization. Collection of discrete samples is considered an acceptable best management approach when volatile contaminants require characterization. Additional sampling frequency and field screening results should be completed in support of sampling design and to inform decisions regarding sample selection for laboratory analysis.

Soil stockpiles may contain highly heterogeneous materials, contaminants and contaminant levels. To reduce heterogeneity stockpiles should be constructed of soils from defined or known locations that have previously been characterized. Large area sites should be characterized by grids that can be used to maximize the uniformity of each stockpile. Soil from remedial excavations should be placed in distinguishable cells. Observations, field screening and analytical data collected during excavation and/or following remedial treatment provide important information regarding contaminant distribution and variability within *ex situ* soils. This information should be included in stockpile management and sampling design. Stratification of contaminant concentrations can occur in stockpiles during their excavation and stockpiling from inadvertent mixing, dilution, and mechanical sorting. Additionally, losses from volatilization and/or bioremediation will in most cases occur and should be considered. In order for sampling designs to capture these potential sources of variability, sampling from various depths is necessary. This could require appropriate tools such as hand augers or support from an excavator.

4.7 Soil Sample Collection and Handling

Once the soil sample is retrieved, the soil sample can be placed into laboratory-supplied containers with required preservatives if needed. Samples to be analyzed for parameters that are most sensitive to handling should be collected first. The typical sampling order by parameter group is as follows:

- Volatile Organics;
- Semi-Volatile Organics;
- Non-Volatile Organics;

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[6] As defined in the BC Contaminated Sites Regulation according to land use.

- Total Metals;
- Nutrients;
- Other General Chemistry Parameters, and,
- Particle size.

Volatile organics should be collected and placed in coolers as soon as the sample is collected. Other samples can be collected after the soil classification details have been logged. Soil should always be handled with decontaminated tools while wearing disposable non-contaminating, chemical-resistant gloves (e.g., nitrile, or equivalent).

The selection of samples to be analyzed will depend on field observations, field screening results, lithology, the work plan and objectives of the sampling plan. Regardless, all of the soil samples collected should be placed in laboratory-supplied containers and submitted to the laboratory including samples that are not scheduled for analysis. Samples that are not slated for analysis can be placed on-hold until analytical data or supporting information becomes available to determine the value of having those samples analyzed. The results from the first set of analyzed samples may determine the need for subsequent testing of samples placed on hold (e.g. to confirm delineation), assuming the samples are not past their hold time. Alternately the additional samples can be stored locally in a refrigerator, but it generally is better to submit them to the lab, as the lab may be able to dispose of the unused samples more easily.

4.7.1 Borehole Advancement and Completion

Once the borehole has reached the target depth and all samples have been collected, the borehole may be used to install a groundwater monitoring well (see Part E2, Section 3.4), a soil vapour well, or other devices. If no further uses are planned for the borehole it should be sealed to permanently prevent the movement of soil vapour or fluids through both the vadose zone and saturated zones. Such movement can affect groundwater flow and result in vertical contaminant migration. A perfectly sealed borehole should have no adverse effect on the environment or the natural hydro geologic setting. Common materials used for sealing a well casing or a drilled out well include Portland cement, usually with 2% to 6% bentonite, bentonite grout, or bentonite chips, granules or pellets. In general, grout is preferred as it will provide the most effective seal, particularly in the vadose zone where soil vapour migration may occur. Although alternating layers of sand (6 m) and bentonite (1 m) can be used in BC[7], ensuring that low-permeability units are also sealed, it is highly recommended that the entire borehole be sealed to prevent any chance of future vertical contaminant migration due to uncertainties in future development, contamination or remediation activities. The following considerations should be addressed regarding borehole sealing:

- Hydrostratigraphy should be reviewed to evaluate the risk that a borehole may provide a vertical conduit for groundwater and contaminant migration. Factors that should be considered include the depth to water, the presence of low permeability units intersected by the borehole, and if the borehole extends to bedrock and if the bedrock is fractured;
- The geochemical environment should also be reviewed. If a borehole intersects highly acidic or alkaline groundwater, seals using bentonite and Portland cement may not remain stable. The borehole seal must be permanent. The borehole log should be reviewed as well as historical analytical groundwater data to aid in the selection of well sealant materials, and;
- The future land use should be considered. If the site will remain as an active industrial or commercial site and the risk of a future spill is present, then a more robust decommissioning

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[7] *Groundwater Protection Regulation (GPR)*, B.C. Reg. 39/216, includes amendments up to B.C. Reg. 152/2016, June 10, 2016.

program may be recommended, as opposed to a rural site with no activity or a site where future construction or excavation may destroy the entire well length (e.g., foundation construction for a large building).

A common method of sealing boreholes is to fill it with bentonite, bentonite grout, or cement. Coated bentonite pellets may be used across the saturated portion of the borehole, if present. When using chips, they should be added slowly to prevent bridging. Native material from the area may be spread over the sealed borehole. In areas with asphalt, cement or asphalt cold patch (or hot asphalt) is typically used for surface completion.

4.7.2 Soil Screening

Screening tools such as Photo Ionization Detectors (PIDs) and Gas Meters can be used to measure volatile compounds in soil. Screening is typically carried out on sub-samples placed into sealable bags. Once collected the soil bags are left undisturbed for a period of time during which volatile compounds, if present, will accumulate in the head space of the bags. The screening tool is placed into the head space to measure the volatile compound/s which in turn provides a measure of volatile organic analytes that may be present in the Soil.

Soil samples should be screened in the field, particularly to select which of the collected samples will be analysed for organic analytes and potentially which will be held by the lab and or discarded. Screening tools can also be used to measure vapours along the length of a recovered soil core, or along excavation walls and or floors to identify areas where organic contamination may be present. An XRF tool is available to screen soils for metals.

Details regarding the proper deployment of screening tools are described in the procedures presented in Section 2.2.

4.7.3 Volatile Organic Compounds

Volatile organic compounds (VOCs) are defined as organic compounds with relatively high Henry's Law constants which partition rapidly from water to air and/or compounds with a relatively high vapour pressure which partition rapidly from the liquid phase to air. VOCs include low molecular weight aromatics, light aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylenes (BTEX), volatile petroleum hydrocarbons (VPH), trihalomethanes, keytones, acetates, nitriles, acrylates, ethers (e.g., 1,4-dioxane), and halogenated hydrocarbons (e.g., chlorinated solvents).

Studies have established that traditional soil sampling methods which include placing samples in glass jars filled with no voids or headspace, and with a septum sealed screw cap have resulted in significant VOC losses (Ball, et al., 1997; Hewitt, 1999; Minnich, 1993, Minnich, et al., 1997; Siegrist and Jenssen, 1990; Siegrist 1991; U.S. EPA 2002).

These losses are primarily due to the following:

- Sampling activities that result in a disturbance of soil structure or aeration of soil samples;
- Volatilization and diffusion through the sample container during storage/shipping, and
- Biodegradation during storage/shipping.

These processes can produce sample results that are biased low or sample results that have detectable biodegradation products not present in the initial sample.

Potential VOC loses can stem from sample compression and loss of pore space, air entering the sample matrix, and mechanical heat. To reduce VOC loses, bulk soil samples should be obtained using coring techniques that preserve soil integrity and cohesion. Recommended techniques for the collection of soil samples include split spoon samples, core barrel liners, and single tube and dual tube direct push soil sampling devices. Soil samples collected directly from solid stem augers or vibrasonic cores are less ideal as these methods may cause soil disturbance and or soil heating. If drilling is not used, soil integrity should be maintained where possible. For soil collection from excavations or stockpiles, several centimetres of soil surface should be scraped clear to expose fresh soil prior to collecting the soil subsample for analysis. In all cases, the VOC samples should be collected as fast as possible, and exposure to air should be minimized.

The BC Environmental Laboratory Manual requires that soil samples collected for VOC analysis, specifically BTEX, styrene, MTBE and chlorinated solvents, must be field preserved with methanol or collected using hermetically sealed sampling devices to minimize losses. Methanol field preservation, using laboratory-prepared vials containing methanol, is typically preferred as it provides an extended hold time of up to 40 days. Although hermetically-sealed samplers need to be submitted to the lab and extracted within 48 hours (this can be extended to 7 days if the sample is frozen), there is no need for methanol preservation. Procedures for both methods are included in SOP D1-9. It is important to note that in addition to a sample collected for VOC analysis, an additional jarred sample is required to determine the moisture content.

4.7.4 Other Organics and Inorganics

Samples collected for semi-volatile or non-volatile organic and inorganic parameters are more stable than VOCs and as such can be placed directly into clean, laboratory-supplied soil jars. The soil should be placed directly from the device used to collect the sample (e.g. split spoon, vibrasonic, solid stem auger) or from a test pit or excavation wall/floor into the jar. If at all possible, the soil should be sampled by pushing the open jar directly into the soil. If the soil is too hard to sample in this manner, then a suitable sample tool such as a trowel may be used. Regardless of the device and or method used soils disturbance should be minimized. Jars should be filled as completely as possible and gravel-size soil particulates should be avoided if possible/practical. If the material being sampled is hard, or very dense (e.g., till) it may not be possible to fill the sample container to achieve zero head space.

After soil is placed in the jar, a clean paper towel should be used to clean off excess soil. The threads of the jar should be cleaned by using gloved fingertips, and then the jar should be securely closed, labelled, wrapped in a protective product such as bubble-wrap and placed into a cooler.

Additional details regarding the collection of soil samples for general organics and inorganics are presented in SOP D1-10.

4.7.5 Particle Size Analysis

Selecting samples for particle size analysis will depend on the objectives of the investigation. Particle size analysis can be used to confirm soil descriptions, or to aid in monitoring well construction (i.e. the selection of appropriate filter packs and screen slot sizes). Particle size analysis can also be used to estimate permeability (see Part E2, Section 3.8.1). For federal sites, particle size analysis may be needed in order to select the appropriate federal quality guidelines.

Care should be taken when collecting samples for particle size analysis to ensure that the analysis is carried out on soil from the formation of interest. Soil samples for particle size analysis are typically placed in a sealable plastic bag or other container and submitted to the lab (refrigeration is not necessary). Typically, a few handfuls of soil will satisfy the volume requirements for this test. Samples that are contaminated, especially with LNAPL or DNAPL, should be avoided. Since the lab may have different options for particle size analysis, with varying degrees of detail, the objectives of the project should be considered prior to selecting the type of particle size analysis and volume of material necessary.

4.7.6 Decontamination of Field Equipment

Field sampling equipment that may come into contact with soil samples must be decontaminated prior to sample collection and after each sample is collected. This includes multiple sampling locations within a single site or program area. In addition, any ancillary equipment that may come into contact with a portion of the sample material to be analyzed must also be decontaminated to avoid contaminant spreading. Examples of field equipment that possess the potential for cross-contamination include any equipment that enters a borehole or well, including augers, drill pipe, split spoons or other sampling devices, trowels or spatulas, and nitrile gloves. The level of effort expended for decontamination of field equipment will depend on the type of contaminants encountered, the equipment materials used, and the level of QA/QC required for a particular investigation (ASTM D5088-15a, 2015).

The minimum recommended procedure for cleaning field equipment for soil sampling is as follows:

- Initial wash with potable water and laboratory-grade detergent using a brush made of inert material to remove particles or surface film; and,
- Secondary rise with potable water.

It is recommended that a final rinse with deionized water also be completed, particularly at sites with a high risk of cross-contamination.

The decontamination process can be completed using a three-bucket rinse, with the first bucket containing water with detergent, the second bucket containing potable water, and the third bucket containing deionized water. As soon as the deionized water becomes dirty, the water should be cleaned out (or alternatively this bucket becomes the secondary rinse).

For drilling equipment such as augers, the preferred method is to use a pressure washer or a steam cleaner so that visible soils, sludge, grease or tar that could contaminate the samples or the site are removed and contained. A decontamination pad should be designed and prepared to capture all of the rinse water generated during the decontamination process. The pad should consist of an impermeable material placed on the ground to capture decontamination fluids (typically polyethylene or high-density polyethylene [HDPE] sheeting (ASTM D5088-15a, 2015). The decontamination water can be captured using a pump and placed in a drum or other storage container for later disposal by a licensed waste hauler. Alternatively, a vacuum truck could be used to recover the rinse water.

Note that all drilling and sampling equipment should be fully decontaminated prior to arriving at a site.

4.7.7 Sample Handling

Potential errors in analytical results can be introduced during a number of sample control and handling activities. These may include but are not limited to; contamination, cross-contamination, improper sample preservation, mislabelling samples, improper storage and shipping, or erroneous instructions to the laboratory. The following subsections provide best practices and general procedures that will help prevent these types of errors from affecting the quality of the analytical data produced.

4.7.7.1 Preventing Sample Contamination

Samples can become contaminated while being collected, preserved, packaged and while in transit. Contamination can occur when exposed soil samples come in contact with contaminated sampling equipment, contaminated gloves or hands, contaminated sample containers, or other contaminated media. Samples can also become contaminated when sample container lids are placed on contaminated surfaces and by contaminants that may be present in ambient air. While in transit improperly sealed sample container lids can result in contamination from cross contamination, or from liquids or airborne particulates present in the shipping container. Ultimately, one or more of these potential sources of contamination can render a sample invalid.

Detectable levels of contamination in samples can result from the introduction of very small amounts of a contaminant. To minimize the risk of cross-contamination, the following procedures should be followed:

- Only use laboratory-supplied sampling containers;
- When sampling containers are received from the laboratory ensure the caps/lids of each container are firmly closed/sealed.
- Do not remove the caps/lids of the sample containers until you are ready to transfer soil into them;
- Avoid contacting the sample material as well as the inside of the sample container and lid with potentially contaminated surfaces including skin (insect repellant, sunscreen), ground surface, instrumentation, etc.;
- Replace the caps/lids as soon as the sample has been collected and processed;
- Use dedicated sampling equipment whenever possible;
- Decontaminate all field equipment between sample collections and sampling locations;
- Collect samples from the least contaminated areas first and then progress to more heavily contaminated areas;
- Collect appropriate quality assurance/quality control samples (e.g., equipment blanks, field blanks, trip blanks – see Section 5);
- Avoid using markers or pens which contain contaminants of concern (e.g., many felt tip markers contain toluene and/or xylenes);
- Avoid fuelling equipment immediately before or during sampling;
- Avoid sampling downwind of contaminant sources (e.g., fuel pumps, vehicle exhaust);
- Keep heavily contaminated samples separate from low to non-contaminated samples (e.g., store and ship in separate coolers);
- Wear clean PPE (e.g., new sampling gloves before collection of each sample);
- Field equipment that has the potential to come in contact with soil or soil samples must be decontaminated between uses at different sampling locations and between samples during soil sampling programs. Disposable equipment (e.g. nitrile gloves) should be changed between samples. Decontamination procedures are described in Section 4.7.6.;
- Ensure that each sample container is adequately insulated to withstand the physical impacts that will occur during transit.

4.7.7.2 Sample Preservation

The purpose of sample preservation is to stabilize the sample matrix from the time it is collected until the laboratory conducts their analysis. Preservation helps minimize chemical, physical and biological changes in the sample media. Preservatives can reduce the potential for microbial activity, volatilization, precipitation, or other physical or chemical processes that may otherwise result in a change of chemical constituents and concentrations. In addition, the physical integrity of the sample container needs to be maintained. Specific preservation requirements are determined on a parameter specific basis and, therefore, should be established with the laboratory performing the analysis prior to ordering bottles and collecting samples. In general, soil sample preservation procedures consist of either physical preservation or chemical preservation (ASTM D6517-00, 2012).

Physical preservation methods include using appropriate sample containers for each parameter being analyzed and using appropriate packaging and shipping containers (typically coolers are used) to transport the samples to the lab. Competent sample containers, packing materials, shipping containers and cooling will prevent breakage and cross-contamination, and by controlling the temperature of the samples during transport, provide a measure of chemical stability. The laboratory will supply clean-certified sample containers along with caps and liners that are chosen for the particular analytical parameter to be tested. Sample containers supplied by the laboratory are made of materials that are non-reactive with the sample matrix and the contaminants the sample may contain. When filling containers, exposure to the atmosphere should be kept to a minimum; samples should be filled to minimize headspace and kept full until analysis.

Chemical preservation methods involve the addition of a reagent to the sample at the time of sample collection. Reagents stabilize the chemical constituents or inhibit microbial activity. Several preservation reagents are used for environmental samples. The specific reagent required for a given test is dependent on the sample media and the parameter being analyzed however laboratories will provide this information along with the required reagent/s.

Sample hold times must be strictly adhered to. A *hold time* is defined as the time that elapses between sample collection to when the sample is prepared by the laboratory for analysis or is analyzed by the laboratory. Sampling plans should consider shipping times to prevent the exceedance of hold times and to ensure that the samples are maintained at proper preservation temperatures. Courier collections or drop-offs on Friday's may result in samples sitting in a warehouse over the weekend which may in turn result in a hold time exceedance and or sample temperatures exceeding their limits. Prior to shipment, samples can be stored in a clean refrigerator to avoid weekend delivery as long as hold times will not be exceeded.

ENV maintains a 'table' of required sample containers, storage temperatures, preservation requirements and holding times on their website at:

https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf.

The table is maintained as part of the BC Environmental Laboratory Manual. Note 3 of the 'table' states that samples collected for all tests where refrigeration at ≤ 6°C is required at the laboratory, should be packed with ice to maintain a temperature of ≤10°C during transport to the laboratory. However, microbiological samples should be stored at <8°C during transport to the laboratory.

4.7.7.3 Sample Labelling

Sample containers must be clearly and legibly labelled. Where practical, sample containers should be labeled during field preparations in a controlled setting such as an office space, before heading out to the field. Ensure the caps/lids of the containers are closed tightly prior to labelling. Include all known information on the label during this preparatory phase; additional information can be added to the labels in the field as information becomes available. Information should be recorded on the sample container label with a permanent waterproof marker. Only markers which are free of toluene (e.g., Staedtler® Lumocolor permanent marker), should be used on sample containers containing samples being analyzed for benzene, toluene, ethylbenzene, xylenes (BTEX), volatile organic compounds (VOC) or purgeable hydrocarbons, as other types of markers may contaminate these samples. Sample labels should include the following information: Sample ID, date and time, analytical test name, preservative added, the sampler's initials, client name, project name/number and location. If the lab has added a preservative, the preservative expiry date may also be indicated on the label.

Sample identifiers (IDs) should be consistent to ensure proper identification of each sample, validity of analytical results, and to ensure continuity between multiple phases of site investigations. Unique soil sample IDs should be designed to indicate the project name or sampling location and date. For example, the sample identified as *Okg-SS1-Mar20* was collected from Okanagan Lake, south shore location 1, during the March sampling event of 2020. Other sample ID nomenclatures are acceptable, as long as they are consistently applied and allow for proper identification once the data is received. Sample duplicates should be identified with a name that does not distinguish it from regular samples. Duplicate sample ID’s must however be traceable to their parent sample (regular sample). Sample and duplicate sample ID’s and associated information must be recorded in field notes for subsequent identification once the analytical results are received. Field QA/QC samples such as equipment blanks, field blanks, and trip blanks should be identified using the same protocol developed for duplicate samples.

4.7.7.4 Laboratory Chain-of-Custody

Soil samples collected as part of an environmental monitoring program and submitted for laboratory analysis are required to be recorded on a Chain-of-Custody (CoC) form. This form, which is typically provided by the laboratory, is a legal document used to record the collection of samples and to document the control, transfer, analysis and disposition of those samples to assure regulatory sample integrity and legal defensibility (ASTM D4840, 2010). The Chain-of-Custody form ensures that all individuals in possession of a sample and or sample container, such as a cooler, can be identified. The CoC is also used to provide sample identification, the number of containers included in a sample, date of collection and to indicate which analytical tests are to be conducted on each sample submitted.

All areas of the Chain-of-Custody form must be accurately completed. Incomplete or inaccurate forms, missing bottles, mislabelled containers, or broken shipments can cause unnecessary delays at the laboratory and put the reliability of the sample information into question. In general, the following Chain-of-Custody procedures should be followed when preparing and shipping environmental soil samples:

- Complete the Chain-of-Custody form as samples are acquired in the field;
- Complete a separate Chain-of-Custody form for each shipping container (cooler). All samples including laboratory prepared QA/QC samples must be included on the Chain-of-Custody;
- Ensure that each field on the Chain-of-Custody form has been completed as required and is correct (e.g., project and client specific information, as well as the sampler’s name, sample IDs, sample dates and times, the sample matrix, the number of containers used for each sample, a list of analyses to be conducted, preservatives used, requested turn-around times, requested regulatory criteria, and hold requests);
- Ensure that each sample bottle is labelled correctly and that each label matches its entry on the Chain-of-Custody form;
- Sign and date each Chain-of-Custody form upon release of the samples (coolers) to the shipping company or the laboratory if the samples are delivered directly to a laboratory; and
- At least one copy of the Chain-of-Custody must accompany the samples at all times. One copy should be retained by the sampler.

4.7.7.5 Sample Packing and Delivery/Shipment

Sampling events that require shipping should be scheduled to ensure that samples do not sit in a courier's warehouse during weekends or holidays. Always consult with the shipping company and the laboratory to ensure that the samples will be received by the laboratory without undue delay, within the shortest hold time prescribed for all of the analytical tests requested and at a temperature that ensures they are fit for those tests.

The following products should be brought to the field to package and prepare environmental samples for transport to a laboratory:

- Shipping containers capable of holding water (melted ice) and capable of providing protection against normal abrasive actions encountered during shipping. Select a cooler size that accommodates the upright storage of sample containers plus the volume of ice required to maintain a temperature at or below 10º C. Sampling events that generate more than a few samples commonly deploy 45 litre hard-bodied coolers.
- Chilled containers. These can be the same containers that will later be used for shipping however these containers are used specifically to provide a chilled receptacle for storage as the samples are collected and as such should be chilled with ice or ice packs prior to sample collection.
- Extra ice (stored in a cooler); this is especially important during warm weather periods. The cooler containing the extra ice should remain closed until the samples are ready to be packaged for shipping to maintain the integrity of the ice.
- Packing materials such as bubble wrap and sealable bags made of bubble wrap. Never use paper or other water absorbing materials for packing.
- Large sealable plastic bags for ice and documentation.
- Wide durable tape to seal the shipping container.
- Chain of custody forms and Ministry requisition forms. Pens and indelible, VOC-free markers.

Care should be taken to ensure that sample packaging and shipment procedures are adequate to maintain the physical, chemical, and legal integrity of the samples.

Packaging and Shipping Procedure

The following procedure must be followed to maintain the integrity of the samples during transit.

1. Place each sample in a pre-chilled cooler as soon as they are processed. Ensure the lids of each sample container are firmly closed. Individual glass sample containers should be placed in bubble wrap bags or otherwise adequately protected with bubble-wrap or an equally protective product.
2. To ensure the samples are maintained at a temperature at or below 10º C during transport, repack the shipping container (cooler) in preparation for transport and replace the ice with fresh ice using the extra ice brought to the field.
3. Place the ice in a plastic sealable bag. Place this bag of ice into a second sealable plastic bag and ensure each bag is fully sealed. Fill as many bags as needed based on the total volume of sample material in the cooler, the ambient temperature and the duration of travel to the laboratory. In cold to mild weather conditions the ratio of ice to sample material should at a minimum, be 1:1 by volume.
4. Ensure the bags of ice are placed on the bottom of the shipping container.
5. Place the samples upright in the shipping container. Do not overfill the container with samples.
6. Intersperse/alternate the glass sample containers with the plastic sample containers and bags of ice.

7. Arrange the sample containers and ice in a manner that provides a measure of physical protection for the glass sample containers.
8. Use packing material to provide further protection by filling any voids left in the shipping container. This will reduce shifting during transport. It is important to keep in mind that as the ice melts space will result which in turn will provide opportunity for the samples to shift and move about during transport. Densely packed bubble-wrap will provide a partial compensation as this occurs.
9. Complete the chain of custody and or Ministry requisition form/s and enclose it/them in a sealed plastic bag. Place the bag in the cooler on top of the samples. The recommended minimum information that should be included in each requisition form is listed below:
   - Site name;
   - EMS site number/s;
   - Date and time of sample collection;
   - Name of sampler/collector;
   - Field measurements;
   - Comments on sample appearance;
   - Weather conditions; and,
   - Any other observations that may assist in interpreting data.
10. Seal the cooler with heavy duty packing tape to reduce the possibility of it accidentally opening and to prevent tampering. Coolers arriving at the laboratory with torn or absent tape should be noted by lab staff with notification sent by lab reception to the sample submitter.
11. Attach a shipping label on top of the cooler to prominently display the destination.

Note 1: The storage temperatures provided on the "Summary of Sample Preservation and Hold Time Requirements" table published on BC's Laboratory Standards and Quality Assurance webpage and available at: https://www2.gov.bc.ca/gov/content?id=A9BE9DDAB0674DD29D1308C4BEE7FBB4 are **laboratory storage temperatures**. Samples collected for analytical tests where laboratory storage is listed at ≤ 6º C should be maintained at a temperature of ≤ 10º C during transport to the laboratory.

Note 2: Certain sample types can be or should be preserved by freezing. Frozen samples should be transported separately from non-frozen samples.

Note 3: Bagged ice cubes are strongly recommended for cooling. Loose ice poses a potential source of sample contamination. Always double-bag ice and place it in the bottom of the cooler in a manner that maximizes package integrity.

Note 4: Do not use ice packs for cooling during moderate to hot weather periods. Ice packs do not provide enough cooling to maintain a temperature at or below the 10º C temperature point prescribed for the preservation of most sample types. Broken ice packs pose a potential source of contamination. If ice packs are used, ensure they are sealed within a sturdy bag.

Note 5: Do not use blocks of ice. Ice blocks are heavy, will shift during transport, and in doing so may break glass sample bottles.

Note 6: Do not use dry ice. Dry ice may freeze sample materials, potentially compromising a samples fitness for its intended analytical test and may shatter glass sample containers. Dry ice may be a safety hazard and may contravene courier protocols and TDG requirements.

4.7.8 Soil Sample Storage and Disposal

The laboratory will store and dispose all of the samples that are submitted. If samples are retained by the sampler for later laboratory submittal or for other purposes, the sample containers should be wrapped in a double sealed bag and placed in a cooler with frequent ice replacement, or in a clean refrigerator designated for sample storage.

Under no circumstances should soil samples be disposed of with municipal garbage. The preferred method is to ship the samples to the laboratory for disposal or place them in a drum and have a licensed waste hauler handle the disposal. It is important to note that licensed waste haulers require analytical data for disposal purposes.

4.8 Soil Vapour Sampling

This section of the manual addresses volatile hazardous compounds such as methane, gasoline and solvents. The collection of soil samples containing these compounds is generally conducted to assess the presence or absence of semi-volatile or volatile compounds in the subsurface. The primary objective of soil vapour sampling is to obtain samples that are representative of *in situ* soil vapour concentrations. It is important to differentiate the term soil vapour from soil gas. The term soil vapour is typically used to imply volatile organic compounds in the subsurface whereas soil gas is the total air in the subsurface which includes gases such as oxygen and carbon dioxide but may include vapours such as VOCs. For the purpose of the methodologies described in this section, soil vapour and soil gas are considered interchangeable.

The objectives of the site investigation’s sampling program will define the soil vapour parameters to be analyzed. A soil vapour sampling program is typically influenced by regulatory requirements, known site conditions, known COCs, known depths and phases (e.g., sorbed or dissolved) of COCs and the potential for soil vapour intrusion into overlying or adjacent buildings. The test results of soil vapour samples are typically utilized to calculate concentrations of volatile vapours within the study area. Calculations can be compared with prescribed standards, used to develop risk assessments or identify “hot spots” over a large study area. Soil vapour samples are usually obtained from dedicated soil vapour wells installed exclusively for this purpose.

Sample quality can be affected by such issues as; well construction, ambient air leakage, and excessive vacuum generation, which can bias sample results. Typically, depth discrete samples are collected over a relatively short period of time (i.e., 2 to 30 minutes); however, site specific sampling objectives may require longer sample intervals (i.e., 2 to 8 hours). Site specific conditions that should be considered include site geology, COCs, applicable regulatory standards, potential for soil vapour intrusion, potential for repeat sampling, the capabilities of the sampling techniques deployed and the complexity of the equipment and procedures (ASTM D7663, 2012).

The application of suitable and consistent sample methods can improve the quality of the soil vapour sample.

4.8.1 Soil Vapour Probe Installation

Each method of soil vapour probe/well installation has advantages and disadvantages. When deciding on the most appropriate installation method aspects such as the needs of the client, regulatory requirements, and site specific conditions, including stratigraphy (vadose zone), depth to vapour source and sampling frequency should be considered.

Dedicated soil vapour probes are preferred over the use of groundwater monitoring wells (discussed below) since these installations can target the area(s) where soil vapours are likely to be present in the highest concentrations. The locations where dedicated soil vapour probes are installed are determined through a site characterization process which yields information such as site history, and soil and groundwater details.

Temporary probes are adequate where only one sampling event is required and where the vapour source is relatively shallow (e.g., less than 2 m below ground surface). Temporary probes can be installed by hand or with the use of direct push techniques which are discussed in Section 3.1.5. These probes are usually driven to the sample depth or raised a few centimetres to expose a sampling tip or create an "opening" around the probe end. The sample is collected through drive rods or tubing which can be inserted to the exposed sampling location. Once sampling is complete the rods are removed.

The usefulness of temporary probes includes the following (API, 2005):

- Installed where access restrictions prevent permanent installations;
- Can be installed with minor ground disturbance and a minimal disturbance of *in situ* vapours reducing the equilibration time between installation and sampling (see Section 4.8.5 for equilibration times);
- Used for field decisions when using an on-site laboratory or to determine the location of permanent probes or the location of "hot spots" requiring further investigations, and,
- Consideration for potential cross-contamination of samples when the same probe is used at multiple locations.

Although permanent or semi-permanent probes are better suited for repeat sampling and are preferred over temporary installations subsurface disturbance can be significant. Subsurface disturbance will affect *in situ* vapours and require an equilibrium time between a probe's installation and vapour sampling. Permanent probes are typically constructed and installed in a similar method as groundwater monitoring wells. Specific installation techniques are provided in Section 3.1.

Several benefits of permanent probes are provided below (API, 2005):

- Can be sampled over time to develop a temporal record of vapour concentrations;
- Can install multi-level (nested) probes in one augered borehole;
- Installation time for direct push is typically shorter than for an augered borehole. Also, direct push techniques involve minimal ground disturbance, which reduces the time required to re-establish equilibrium prior to sampling;
- Typically, direct push techniques do not generate waste soils that must be disposed of;
- The depth of installation is dependent only on the drilling method used. Direct push techniques can be limited in depth, especially in coarser-grained soils (e.g., cobbles); and,
- The competency of the seal to isolate sampling location(s) is considerably better when the installation uses an augering method, than seals produced for drive point or temporary probes.

As illustrated in Figure 4.1 a soil vapour well installed in a drilled borehole should include a sand pack around the screen, bentonite above the sand pack and a seal to surface, typically with a slurry or properly hydrated granular bentonite. The screen or probe tip should be placed midway in the sand pack and have at least 6 inches of sand above and below the screen or probe tip.

A dry granular bentonite seal should be placed above the sand pack, which will prevent any overlying water or hydrated bentonite from infiltrating the sand pack. The hydrated bentonite prevents air from the upper portions of the borehole from entering the sample (aka "short circuiting").

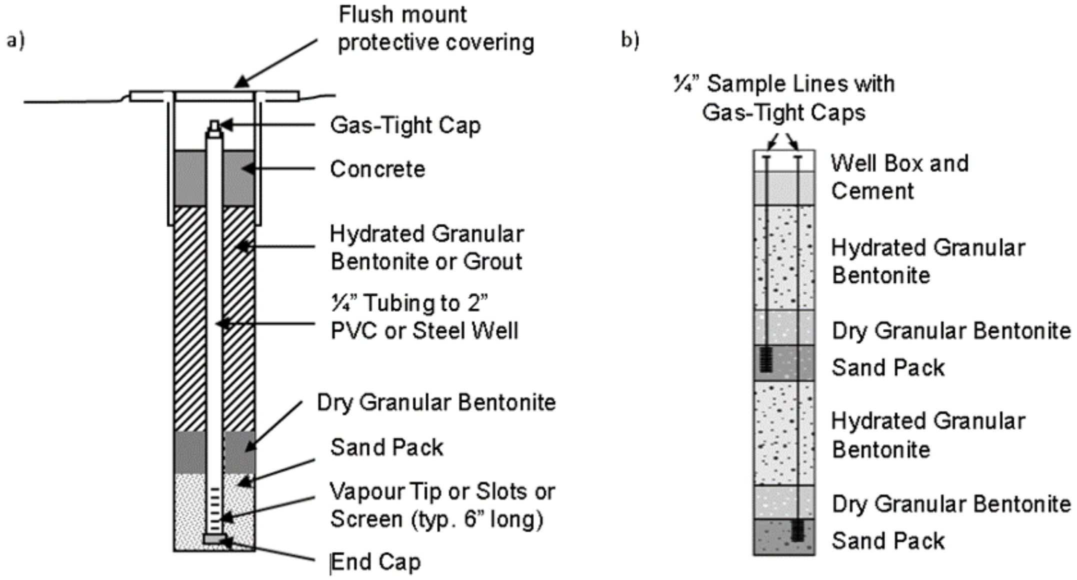

Figure 4.1: Typical drilled vapour well completion details: a) Single well, and b) Multi-well (ASTM D7663, 2012).

Note that screen lengths for all types of soil vapour probes should be minimized to ensure that the sample produced is representative of the soil vapour in the immediate vicinity of the sampling probe. Typical screen lengths are 0.15 m to 0.3 m (6" to 12") or a discrete sample tip can be used. Sample depths will depend on the objectives of the site investigation's sampling program but should be installed 0. 5 m to 1 m above the water table so that the screen is above the capillary fringe (i.e., tension saturated zone).

The sample depth below ground surface should be greater than 0.45 m unless there is supporting evidence that collecting such a shallow sample will not bias the results (CSAP, 2009). If a shallow soil vapour sample must be collected consider an alternative method (e.g., flux chamber). Also, note that the sample depth is considered the bottom of the seal above the sand-pack or the top of the screen for a direct push installation.

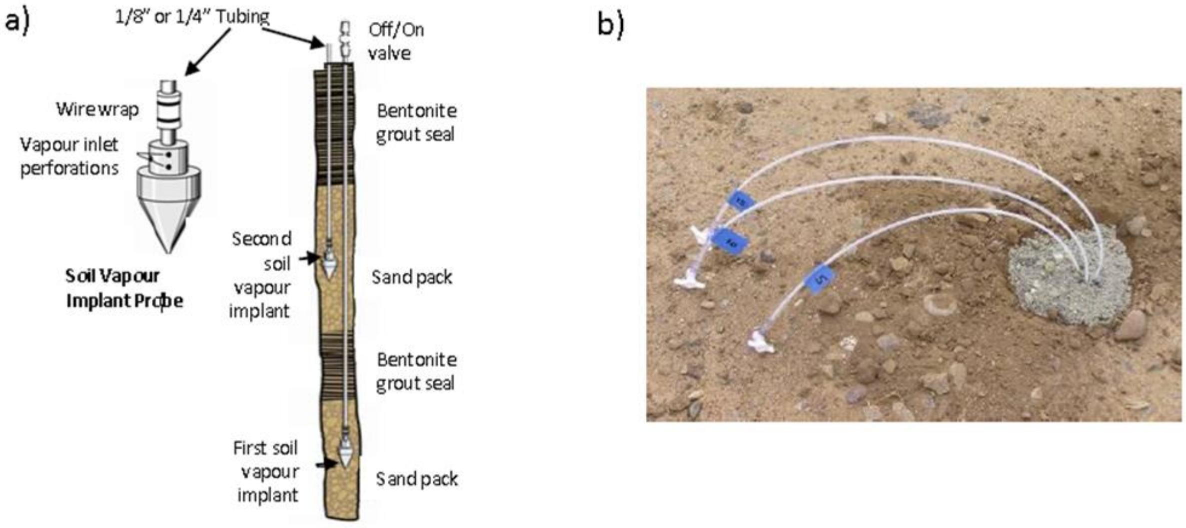

Figure 4.2: Example of multi-level soil vapour well installations (adapted from IRTC, 2014),
a) Schematic of tip and tubing system; and, b) Surface completion of a temporary multi-level installation.

Other installations include, implanting a vapour tip with attached tubing, also known as a post run tubing (PRT) installation. The advantage of using a tip and tubing installation is that purge times are significantly reduced due to the small diameter of the tubing. Depending on the installation method either temporary or permanent probes can be installed as multi-level or nested installations in order to assess vapours at different vertical intervals.

Direct push installations should be completed with a surface seal, typically hydrated bentonite. Note that pure bentonite seals will desiccate over time and will not re-hydrate once desiccation has occurred (CalEPA, 2015). For sub-slab or other installations in concrete or asphalt (e.g., roads and sidewalks) the surface seal around the probe should consist of a VOC-free material that can provide a good seal. These materials include sculpting clay, swelling (“hydrating”) concrete, bentonite, wax, Teflon tape and some epoxy’s although not all epoxies are VOC-free.

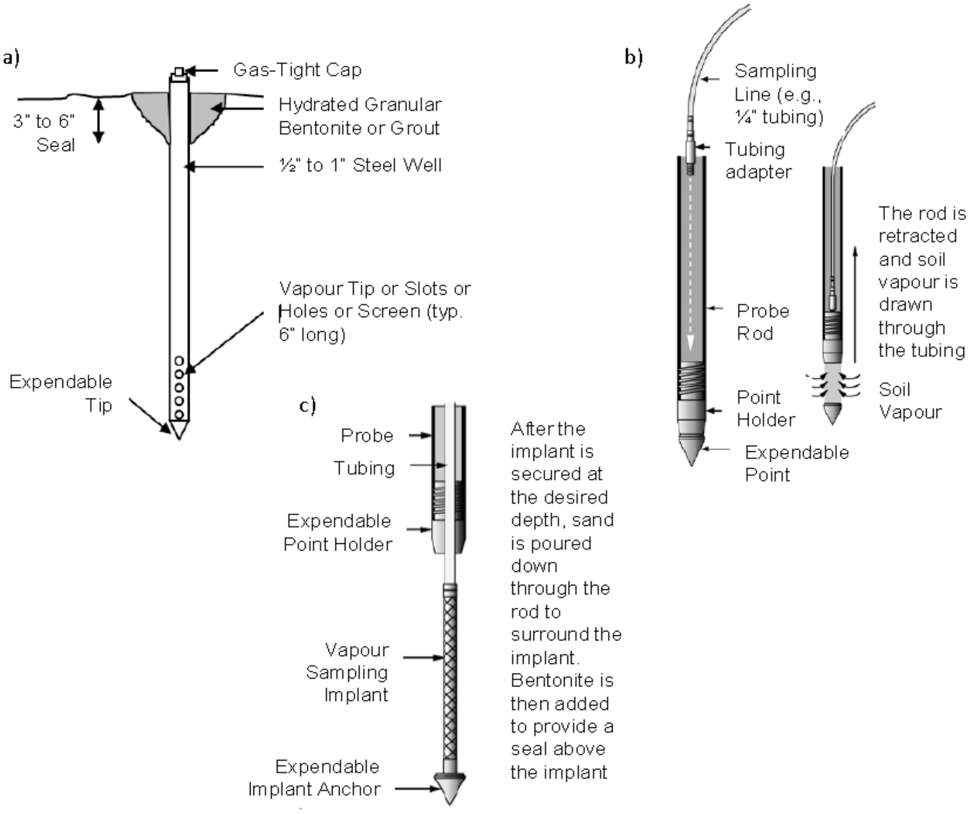

Figure 4.3: Direct-push and hand-driven Soil Vapour Well schematics (Figure adapted from ASTM D7663, 2012) a) Vapour tip and tubing installation; and, b) Drive point installation.

A surface cover (i.e., seal) is required when sampling less than 1 m below ground surface (CSAP, 2009). The surface seal should consist of a VOC free 1.5 m by 1.5 m plastic sheet. In order to obtain representative vapour samples, the surface seal should be placed 24 hours prior to sampling, which will allow for barometric flushing of the subsurface. Additionally, the surface seal material should be tough enough that perforations and openings will not result from normal field activities. As illustrated in Figure 4.4 the surface seal should be secured to the vapour probe and along the edges to prevent ambient air from entering under the seal or along the probe.

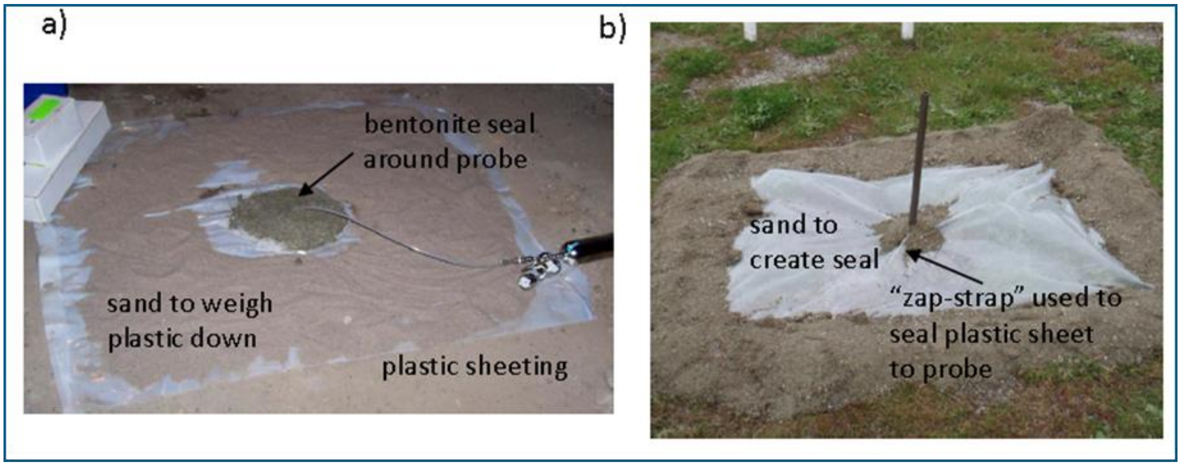

Figure 4.4: Temporary soil vapour well surface seals a) Hand-driven, b) Direct-push, and c) Direct-push screened interval. (Figure adapted from NY DOH, 2005).

4.8.2 Soil Vapour Probe Materials

There is a wide range of commercially available materials for use in the construction of soil vapour probes/wells. Probe materials should be composed of stainless-steel (e.g., solid, braided, wire), ceramic (glass), polyetheretherketone (PEEK) or Teflon (PTFE), high density polyethylene (HDPE) or Chemfluor™ (CCME, 2008).

PVC is acceptable for probe construction with the threaded couplings wrapped in Teflon tape. Implants or probe tips which are typically prefabricated can be constructed from stainless steel or rigid PVC. Cutting oils should not be used on metal components of a probe as the oils will interfere with the soil vapour samples.

Low density polyethylene (LDPE), silicone, flexible PVC, tygon, and neoprene are examples of tubing materials that adsorb or desorb VOCs and therefore should be avoided. Short sections (i.e., <5 cm) of flexible tubing such as silicone or tygon can be used to temporarily connect sampling equipment. Note that the sampling system's volume (i.e., sample tubing or probe diameter) should be as small as possible to minimize the "dead volume" that must be purged prior to sampling.

Table 4.1 summarizes the findings of a study of available tubing products conducted by CARO Analytical Services in Richmond, BC.

Table 4.1: Summary of Tubing (CARO, 2009)

Material	Acceptability	Comment
Tygon and LDPE (low density polyethylene)	Avoid	Emits "appreciable"[1] levels VOCs
Silicone and PVC tubing (flexible)	Minimize lengths (use as connecting tube)	Emits moderate concentrations of VOCs
Nylon (Nylaflow and Extra-Flex)	Good – Nylaflow Acceptable – Extra-Flex	Nylaflow no emissions Extra-Flex emits acetaldehyde
Teflon (nylon material, not all nylons are the same)	Good	No emissions

Material	Acceptability	Comment
PVC Pipe (rigid)	Avoid scratched PVC	Unscratched PVC emits acetaldehyde Freshly scratched PVC emits numerous VOCs

[1] Appreciable refers to VOCs greater than 20% of the numerical standard.

Once completed the soil vapour probes should be capped with an air-tight fitting constructed of brass, a Swagelok® fitting or plastic valves (e.g., stop cocks) (ITRC, 2014).

4.8.3 Use of Monitoring Wells as Soil Vapour Probes

Groundwater monitoring wells can be used to obtain soil vapour data; however, prior to conducting any vapour sampling the following criteria must be met:

- The well's screen extends above the tension-saturated zone (i.e., capillary fringe). It is recommended that well screens be 3 m or less and have an open screen section 0. 5 m to 1 m above the water table. That is, there should be an open screen section above the capillary fringe. Also, long well screens above the water table can lead to rapid biodegradation of some contaminants in the unsaturated zone, which will bias the vapour results.
- A seal (e.g., bentonite or grout) must be present to prevent leakage of ambient air or soil vapour from other depths from entering the sampling point. As mentioned previously the depth of the vapour sample is considered to be at the bottom of the seal.
- The "vented" well cap must be replaced with an airtight cap/fitting. Vented well caps allow for air exchange with ambient sources that can bias soil vapour results.
- A leak test, as discussed in the following section, must be conducted. At least one leak test per monitoring well sampled should be conducted during the first soil vapour sampling event.

Due to the larger casing diameters (typically 4" to 8") of groundwater monitoring wells the purge volumes can be significant, thereby requiring longer purge times and in some cases increased purging rates.

If the site investigation's objectives require both groundwater and soil vapour sampling from the same location, a nested groundwater and soil vapour well can be installed as a multi-level point.

4.8.4 Sub-Slab Vapour Probes

Sub-slab soil vapour samples are collected from the unsaturated zone beneath the lowest slab of a building. These are typically installed using a hammer drill and a 5 cm to 15 cm stainless steel tube.

Figure 4.5 illustrates two options for sub-slab installations.

As previously discussed, a non-VOC emitting surface seal around the probe is required to prevent leakage of ambient air. Surface seal materials include sculpting clay, swelling ("hydrating") concrete, bentonite, wax, Teflon tape and some epoxy's (not all epoxies are VOC-free).

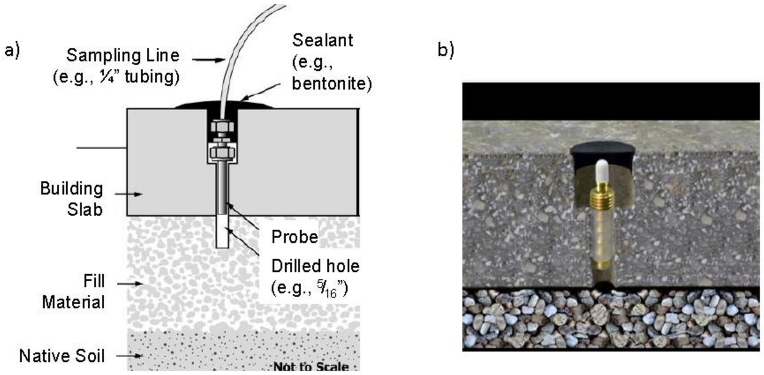

Figure 4.5: Soil vapour probe sub-slab installations: a) sub-slab probe (adapted from ASTM D7663, 2012), and; b) Vapour Pin® (Cox Colvin).

4.8.5 Flow Restriction and Leak Testing

Soil vapour wells and probes should be tested prior to sampling to identify potential flow restrictions and leaks. It is possible to incorporate these tests into the purging process, but due care must be taken to ensure the probe is sealed between tests/purging and sampling to prevent ambient air from entering the sampling train.

A flow test is conducted to verify that an adequate flow of soil vapour can be maintained throughout the sample collection period. Typically, a larger flow rate results in creating a larger vacuum around the sampling point, since the flow rate and vacuum are related to the air-permeability of the subsurface materials (ASTM D7663, 2012). If an excessive vacuum forms in the subsurface VOCs may partition from other phases (e.g., sorbed and dissolved) into the vapour phase, thereby biasing the soil vapour results.

The induced vacuum should not exceed 10” of water column (10” H_2O) (ASTM D7663, 2012). Also, sampling at high flow rates (i.e., above 2 L/min) can result in a high bias of the vapour concentrations. If an excessive vacuum forms during testing, the flow rate can be reduced to see if the vacuum will dissipate. The flow and vacuum tests should be conducted at the same flow rate as the sampling flow rate.

Given that moisture conditions vary between sampling locations and sampling events and that moisture and barometric pressure have an effect on vacuum test results, a vacuum test should be conducted prior to every soil vapour sampling event.

The magnitude of moisture and barometric pressure is considered minimal at sampling depths greater than 1.5 m; however, pre-sampling testing should be conducted regardless of sample depth (ASTM D7663, 2012).

Figure 4.6 illustrates a typical system setup for a flow and vacuum test, although other configurations may be acceptable.

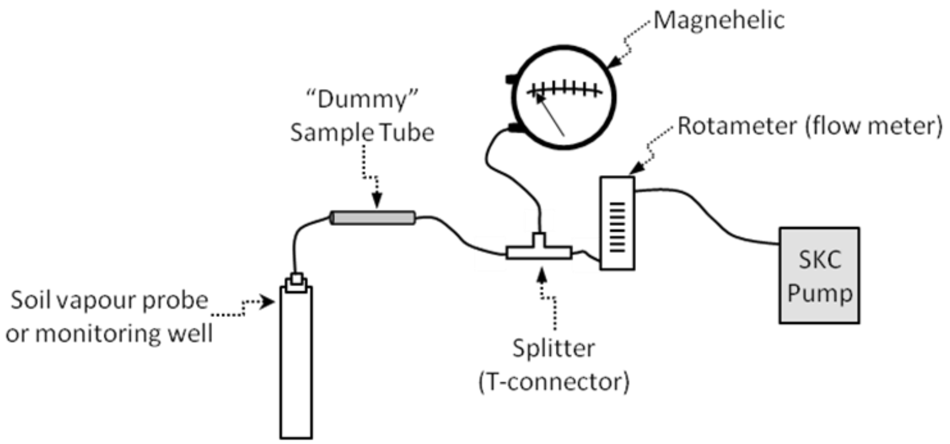

Figure 4.6: Schematic / Configuration of apparatus for a flow and vacuum test.

In addition to assessing the air-permeability of the subsurface material, the vacuum test can also be used as a leak test. If a vacuum is induced during pre-testing observe the vacuum for at least 1 minute and if the vacuum remains less than approximately 5” H_2O, the system leakage is acceptable. However, if the observed vacuum changes more than 5” H_2O, tighten or replace fittings or connections and repeat the test. If unacceptable system leakage remains, samples collected from the system will be biased.

A leakage test should also be performed to determine if the sample apparatus has leaks and whether there is leakage around the probe. These tests involve a tracer gas around the probe to test the integrity of the air-tight cap and ground seal around the probe, along with sample system connections. Typically, helium is used as the tracer gas since it is readily available, easy to use and reasonably priced. In addition, the detector is easy to calibrate and use in the field. A shroud is placed over the probe and helium is injected into it until 50% or more of the tracer gas is contained in the shroud. If the tracer gas concentration in the sample is less than 10% of the concentration in the shroud, the sampling system integrity is acceptable. If the concentration exceeds 10% all seals, connections and fittings should be checked, and the leak test re-run.

Sulphur hexafluoride (SF_6) can also be used as the tracer gas; however, it is more difficult to use (both injection protocol and detector), is not as readily available as helium and costs significantly more than helium.

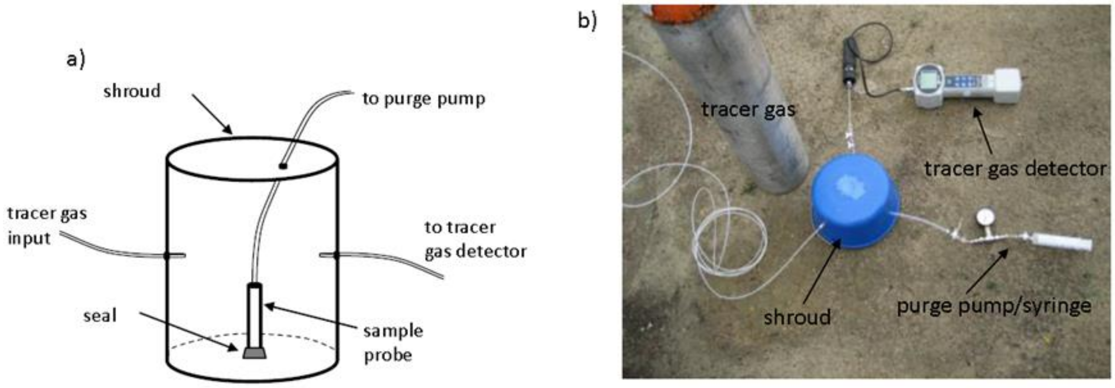

Figure 4.7: Example of a typical leak test set-up using a tracer gas. (Figure adapted from H&P Mobile Chemistry)
a) schematic and b) example of tracer gas shroud over vapour probe

In addition to a tracer gas leak test, a shut-in vacuum test is recommended to assess the sampling train for leakage. During this test a vacuum of approximately 100” H_2O is applied to the sampling train with the valve to the sampling probe closed and the sampling vessel attached but with its valve closed; effectively isolating the sampling train between the probe and sampling vessel. The applied vacuum should be observed for at least 1 minute and preferably for 5 minutes. The vacuum loss should be equal to or less than 5% of the applied vacuum for an acceptable test. If the test fails (i.e., greater than 5% loss) all fittings/connections should be checked, tightened (replaced if necessary) and the shut-in test repeated (ASTM D7663, 2012).

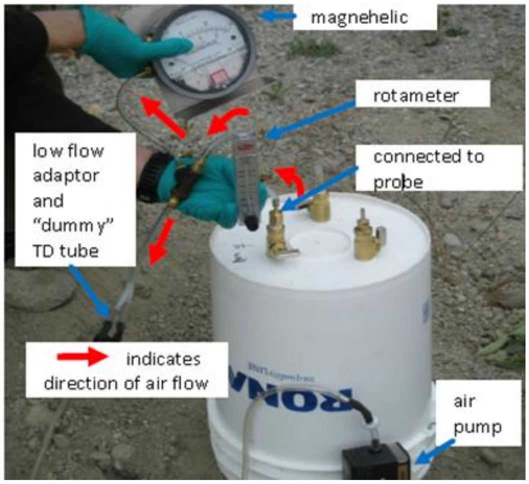

Figure 4.8: Field set-up for a flow and vacuum test.

The pre-tests not only indicate acceptability of the sampling system but also suggest if a collected soil vapour sample will be biased high or low. That is, if the induced vacuum is too high then the sample will likely be biased high. If the leak test fails, the resulting sample could be biased high if the ambient air contains a high concentration of VOCs compared to the subsurface or biased low if the ambient air has a low concentration of VOCs compared to the subsurface. In addition, for shallow vapour samples, inducing a high vacuum in the subsurface could result in surface leakage.

4.8.6 Soil Vapour Sample Collection

After the installation of soil vapour probes, allow sufficient time for hydration of bentonite seals or curing of cement seals and the re-establishment of pre-installation vapour conditions prior to purging and sampling. Recommended minimum equilibrium times are shown in the table below.

Table 4.2: Recommended Minimum Equilibrium Times

Drilling Method	Min. Equilibrium Time (prior to sampling)	Comments
Direct push (from ground surface) Equilibrium times have been increasing as more research is completed. From 20 minutes in 2003 to 2 hours in 2015 (IAVI, 2017)[+]	2 hours	Rod is pushed >5 ft into undisturbed soil (up to 48 hours in fine-grained material)
	48 hours	Rod is pushed <5 ft into undisturbed soil
Direct push (in day-lighted pre-hole)	2 hours	Rod is pushed >5 ft into undisturbed soil
	48 hours	Rod is pushed <5 ft into undisturbed soil
Auger (hand, hollow stem, solid stem, etc.)	48 hours	
Sonic (rotosonic), air rotary	Several weeks	Varies from a few days to a few weeks Empirically show equilibrium established by collecting time series data[1].
Sub-slab	2 hours	

[+] To verify equilibrium conduct time-series information. Oxygen and carbon dioxide shortly after installation, then frequency will depend on drill method. If in similar soil type, one installation can represent other locations.

If equilibrium has not been established prior to sample collection, soil vapour concentrations will increase as vapour around the sample point is replaced with more contaminated vapour from the "formation". If unsure whether equilibrium has been reached a probe can be developed.

During development, both the flow and vacuum must be monitored and typically gasses, such as oxygen and carbon dioxide, are also monitored until equilibrium conditions have been reached.

Purging is required to remove stagnant air from the vapour probe and the above ground sample train to produce representative sample material. It is important to note that in some cases the stagnant air will have higher concentrations of VOCs than the subsurface. A default of three purge volumes should be used, where a purge volume includes the internal probe and tubing, sand pack (if applicable) and dry bentonite above the sand pack (if applicable) (CalEPA, 2015). An alternative to using three well volumes is to purge until the purged gas concentrations stabilize (e.g., O2, CO2, CH4 or vapours analyzed on a portable detector).

Purging should be conducted prior to sampling regardless of whether the probe is new or old, shallow or deep. During purging, the flow and vacuum tests can be conducted. Another option is to collect total vapour samples during purging using Tedlar™ bags (field detectors should not be connected directly to a probe).

Purging should be conducted at the same flow rate as the sample collection flow rate. Flow rates should be between 0.1 L/min and 0.2 L/min and should not exceed 0.2 L/min (200 mL min). Low flow rates and low vacuums will minimize the potential for VOCs to partition from soil and or pore water to vapour and prevent the introduction of ambient air into the sample. In the case of deeper probes or large diameter probes (e.g., groundwater monitoring wells) a higher flow rate (up to 5 L/min) can be used to reduce the purging time; however, the vacuum should be maintained at less than 10" H2O (if the vacuum is greater reduce the flow rate) (SABCS, 2011). When purging large volumes VOCs should be measured (total VOCs) measured with hand-held detector at the start and every 30 minutes thereafter, along with soil gasses (e.g., O_2 and CO_2) every 10 minutes to determine stability and if a breakthrough of ambient air has occurred.

Once purging is complete the sampling train should be closed to prevent ambient air from entering while the sampling vessel is connected. Also, prior to sampling allow any vacuum developed during purging to dissipate and equilibrium conditions to be re-established (SABCS, 2011). If the vacuum does not dissipate within a time frame of a few minutes to an hour, sampling may not be practical.

If during purging the sample lines show evidence of liquids (i.e., water) then sampling should be discontinued.

When purging and field data collection is complete sample collection can begin. The method of sample collection will depend on the contaminants of concern, analytical reporting limits, soil air permeability and data quality objectives CCME, 2008). Vapours can be collected as “whole gas” or adsorptive samples. The following summary provides a variety of available sampling vessels (CalEPA, 2015 and SABCS, 2011):

- **Syringes** – air-tight syringes with Teflon® seals are preferred. Glass syringes should be leak tested to verify integrity (especially as syringes age). Plastic syringes should not be used due to their interaction with some contaminants of concern.
- **Stainless steel canisters** (e.g., Summa™) – these require a flow regulator and vacuum gauge. The canisters come passivated (i.e., under vacuum) and vacuum readings should be taken prior to sampling to ensure integrity of the canister. Typically, the canister is returned to the laboratory under a slight vacuum (i.e., 2” to 4” Hg). All vacuum measurements should be recorded. Summa™ canisters are constructed of electropolished stainless steel.
- **Glass-lined steel canisters** (e.g., SilcoSteel™) – these canisters are similar to the stainless steel canisters (i.e.,) except that they are glass-lined. Like the stainless steel canisters, these also require a flow regulator and vacuum gauge and all vacuum readings should be recorded.
- **Glass bulbs** – these need to be leak tested to verify integrity (especially as the glass bulb ages). Samples should be analyzed within six hours after collection.
- **Polymer bags** (e.g., Tedlar™ bags) – these are typically used for fixed gas analysis (O_2, CO_2, N_2, etc.). If vapour samples are collected they should be analyzed within six hours after collection.
- **Sorbent tubes** – these vary based on the sorbent material that line the tubes. These are also known as thermal desorption tubes (TD tubes) or volatile organic sampling train (VOST) tubes. The volume of vapour drawn through the tube will depend on the sorbent material (the laboratory can help select sorbent material) and analytical reporting limits. Any pumps (or field meters) should be downstream of the sorbent tube to avoid cross-contamination. If high concentrations are expected, two tubes should be connected in series to detect potential breakthrough concentrations.

All sample vessels should be air-tight and handled in a manner which ensures the integrity of the sample. Do not keep samples in a chilled cooler. Sorbent tubes (e.g., TD tubes) should be stored at a temperature of about 4°C. All samples should be handled and stored to minimize sun exposure, especially transparent sampling vessels, to prevent photodegradation of the sample (CalEPA, 2015).

Field conditions that may affect vapour sample integrity include:

- **Rainfall** – the air-filled porosity of shallow soil decreases due to rain entering the pore spaces. This can result in vapours being “pushed” out of the soil and replaced by water or partitioning of vapours into the dissolved phase. Both of these may bias soil vapour results. Therefore, sampling should not occur during a significant rainfall event or shortly after a significant rainfall event. Where a significant rainfall event is defined as 1 cm (SABCS, 2011). The time for rain to drain through the sampling zone will depend on sample depth and soil type. For coarse-grained soils sampling should not commence for at least 24 hours and several days for finer-grained soils. Consideration should also be given to the precipitation pattern prior to sampling. That is, 1 cm of rain every day for a week will require a longer wait time than no rainfall for a week followed by one day with 1 cm of rain. Vapour sampling can occur in areas not affected by rainfall, such as under buildings or high-integrity pavement.

- **Barometric Pressure** – daily fluctuations and frontal systems may affect shallow vapour samples. During high pressure periods ambient air can enter the subsurface, while during low pressure period's soil vapour may be drawn upwards. Typically, barometric pressure does not have to influence the timing of vapour sampling; however, barometric readings from a nearby weather station should be reviewed prior to sampling to determine any potential effects from pressure changes (ASTM D7663, 2012).
- **Wind Speed and Direction** – wind speed and direction can have significant impacts on soil vapour samples collected under or adjacent to buildings. Sub-slab samples should not be installed near the edges of foundations and an evaluation of stack and wind effects should be conducted prior to sampling. Also, windy conditions should be avoided when collecting shallow soil vapour samples (i.e., <1.5 m).
- **Tidal Conditions** – depending on the extent of water table fluctuations due to tidal action there may be no significant effect on soil vapour sampling. Sampling during low tide or on a rising tide should produce conservative soil vapour results. Note that water table fluctuations less than a few centimetres do not have a significant effect on soil vapour samples (H&P Mobile Geochemistry).
- **Low Permeability Soils** – these are soils where 0.1 L/min (100 mL/min) cannot be maintained and the vacuum test fails. If these conditions prevail consider re-drilling in a more permeable location or using passive soil gas/vapour sampling.

The collection of duplicate/replicate samples should follow the objectives of the site investigation's sampling program. QA/QC best practices suggest a 10% duplicate collection, with no less than one duplicate sample per sampling event. Duplicates are to be collected simultaneously, whereas replicate samples are collected in sequence. Duplicate/replicate samples should be collected from areas of known contamination where ever possible. Duplicate samples can be collected using a T-splitter to divide the sample. When collecting two samples simultaneously, the total flow rate at the probe should not exceed 0.2 L/min (200 mL/min). In this case, the sample and duplicate will be collected at 200 L/min or 100 mL/min each. Due to the inherent variability of soil vapour samples a Relative Percent Difference (RPD) of 50% is generally considered acceptable.

Trip blanks should also be considered when setting data quality objectives but are typically only required when polymer bags (i.e., TedlarTM) or sorbent tubes are used, depending on the analysis method. Trip blanks when collecting canister samples are not necessary (ASTM D7663, 2012).

4.8.7 Alternative Sampling Methods

Passive soil vapour sampling can be used to determine the presence of VOCs as a screening tool or to locate “hot spots”. In low permeability soils where active soil vapour sampling is difficult or not applicable passive soil vapour sampling may be used. These samplers rely on the diffusion of vapours through a hydrophobic sorbent material that collects VOCs over time. Passive vapour samplers are typically installed in a grid pattern over the investigation site.

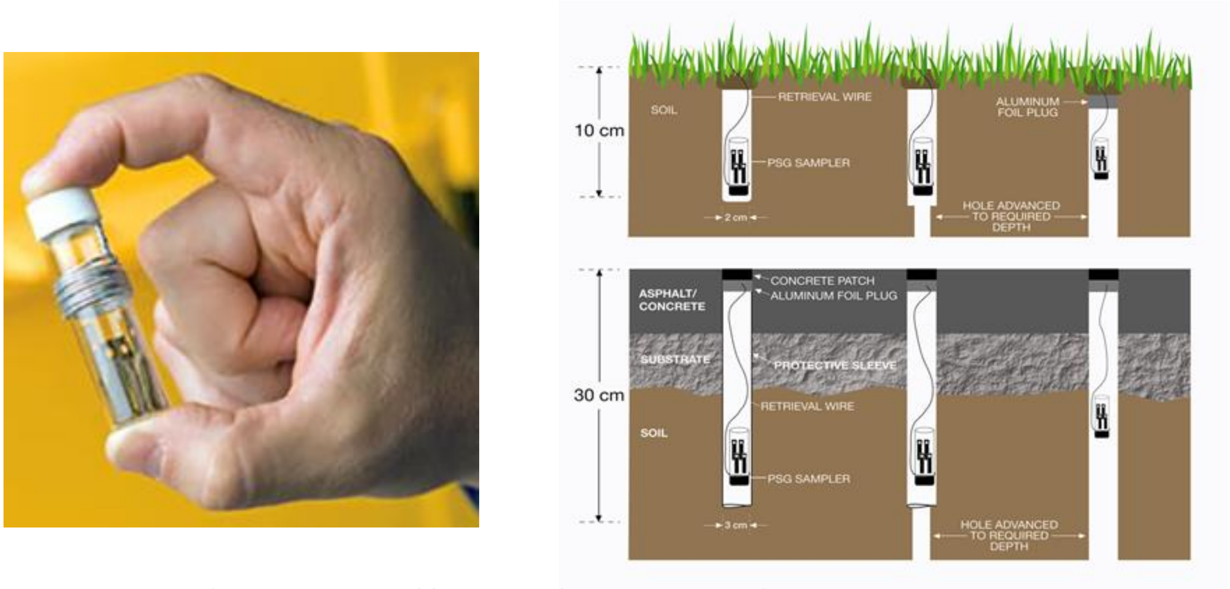

Figure 4.9: Example of a passive soil gas (PSG) sampler (left), and a schematic of passive sampling installations (right) (Figure adapted from: O’Neill, Harry, (2018) Passive Soil Gas Testing: Standard for Site Characterization).

The samplers are buried directly into a small diameter borehole, a tube placed in a small borehole, or a borehole drilled into a buildings slab or concrete floor. Samplers are installed to depths of less than 1 metre where they remain undisturbed for a period of 7 to 14 days to allow the VOCs to sorb onto the cartridge/s.

Passive sampling installations are considerably less expensive than active sampling installations, are relatively simple to complete and result in a very limited disturbance of the target zone. Purging and leak tests are not required and as such sample collection is fast and efficient. As most passive samplers are self-contained units the opportunity for contamination is significantly reduced. One draw-back of passive sampling is that analytical results are reported in units of mass which is useful for screening but does not provide concentrations of contaminants of concern as required for most compliance projects.

5 Quality Assurance and Quality Control

As stated in Part A - Quality Control and Quality Assurance, of this manual, a thorough program of quality assurance/quality control will enable the collection of meaningful and scientifically credible samples. Soil sampling programs require a quality assurance (QA) and quality control (QC) component in their design in order to ensure that only unbiased and representative samples are used to inform the decisions and outcomes of a project. The quality control component of a sampling program ensures that all field activities are controlled and that potential contaminant sources are identified. Duplicate QC samples collected in the field provide an assessment of the repeatability and precision of laboratory analyses. The field QA/QC program is a systematic process which, together with the laboratory and data storage quality assurance programs, ensures a specified degree of confidence in the data produced.

The Field Quality Assurance program involves a series of steps, procedures and practices specific to an investigation or program. A field QA program should include as a minimum:

- Use of trained and experienced personnel;
- Controls that ensure that sampling equipment is free of contaminants;
- Controls that ensure the consistent deployment of standard operating procedures or protocols with comprehensive field notes identifying any variations from the procedures;
- Maintenance and cleaning of field equipment in accordance with techniques described by the manufacturer;
- Calibrations are completed prior to the sampling event and performed under the same instrumental and chemical conditions as those that will exist at the sampling site. The frequency of calibration will depend on the accuracy requirements of the investigation and the stability of the instrument. A log should be kept for each item of equipment to document calibration, exposure, maintenance, and service;
- Confirm all information recorded on the Chain-of-Custody form when collecting and transporting samples (i.e., double check sample labels and ensure that everything in the Chain-of-Custody matches the samples included on the CoC);
- Sampling should begin in locations that are hypothetically less contaminated and progress to locations with higher anticipated levels of contamination;
- Use only the recommended type of sample bottle for each analysis. Sample bottles, including bottle caps, must be obtained from the laboratory and certified by the issuing laboratory as ‘contamination free’ for the intended analysis. Bottles must be supplied with caps in place. ENV lists required sample containers, storage temperatures, preservation requirements and holding times on their website:

  https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf;
- The preservatives used should be supplied by the analytical lab in ampoules. The lab will verify their purity and provide an expiration date, beyond which they should not be used. If possible, the lab should prepare the sample bottles with the required preservative;
- Reagents and preservatives must be analytical grade and certified by the issuing laboratory to be contamination free. Containers holding chemical reagents and preservatives should be clearly labeled both as to contents and expiry date. No reagent or preservative should be used after the expiry date. Return expired reagents to the laboratory for proper disposal;

- The inner portion of sample (and preservative) bottles and caps must not be touched with anything (e.g., bare hands, gloved hands, thermometers, probes, preservative dispensers, etc.). Remove caps just before sampling and re-cap as soon as sampling is complete;
- Keep sample bottles in a clean environment, away from dust, dirt, fumes and grime. Bottles must be capped at all times and stored in clean shipping containers (coolers) both before and after the collection of the sample. Vehicle cleanliness is an important factor in eliminating contamination problems. During sample collection, store bottle caps in a clean, sealable plastic bag, not in pockets, etc.;
- Petroleum products and by-products such as gasoline, oil, and exhaust fumes are prime sources of contamination. Spills or drippings must be contained and removed immediately. Exhaust fumes and cigarette smoke can contaminate samples with lead and other heavy metals. Air conditioning units are also a source of trace metal contamination. Samples should always be collected upwind from these sources, and a field blank should be collected if contamination from ambient conditions is suspected;
- Cool samples as quickly as possible after collection. Place samples in a chilled cooler and keep the cooler chilled throughout the sampling event. A common mistake is to forget that a large volume of “warm” sample water quickly melts a small amount of ice;
- Wrap glass sample bottles in bubble wrap or other appropriate material to avoid breakage during transit;
- Do not allow samples to freeze unless freezing is part of a specific preservation protocol. Samples placed in the back of a pickup truck in winter may freeze, resulting in bottle breakage;
- Samples should be stored in a cool, dark place. Coolers packed with double bagged ice are recommended. Most samples are required to be maintained at a temperature of ≤10°C during transit to the laboratory;
- Samples must be shipped to the laboratory without delay so that they arrive within 24 hours of sampling. Certain analyses must be conducted within 48 hours or within specified time limits as determined by the laboratory; and,
- Sample collectors should keep their hands clean and refrain from eating or smoking while working with samples.

To assess the repeatability and accuracy of laboratory analyses and reporting, the following measures are typically undertaken:

- Collection of blind duplicate samples at a target frequency of approximately 10% for all analytes. Duplicates should be independently labeled and analyzed to eliminate possible laboratory bias;
- Laboratory Quality Control analyses which include with every batch of samples, as appropriate, Method Blanks, Duplicates, Certified Reference Materials and Spikes at a frequency of between 10% to 30%; and,
- It is preferred that electronic copies of the analytical results are downloaded directly into a database to avoid transcription errors. The downloaded data should still be checked with printed laboratory reports to ensure accuracy.

QA/QC field procedures include the preparation and analysis of the following samples:

Blind Duplicate Samples: Blind duplicate samples are submitted to the laboratory to assess the precision of laboratory analyses as well as the quality (i.e., representativeness) of the samples collected. Due to heterogeneity, there is no true soil duplicate; however, by carefully selecting the sample and duplicate, heterogeneities can be minimized. If the sample is present in a split spoon barrel, then the soil from the zone of interest can be split vertically into two sections, with soil from one section being placed in the jar as the original sample and the soil from the second section placed in a second jar as the duplicate sample. Both soil samples should be collected at the same depth and from the sample material. The blind duplicate sample label should not indicate that it is a duplicate. The duplicity of the sample can be identified in field notes or blindly through an established nomenclature. Note that the time of sampling should not be altered to hide the fact that it is a duplicate as there could be legal issues related to tampering with data (Nielsen, 2006).

Analytical results for the original samples and corresponding blind duplicate samples are compared using the calculated variability of the results, as expressed by the Relative Percent Difference (RPD_{DUP}). The RPD value is defined as the absolute value of the difference between the results for the original and duplicate samples, divided by the average of the results. Because of the poor precision near the laboratory detection limit, RPD_{DUP} values are only calculated where the analytical results of the original or the duplicate sample is greater than five times the laboratory method detection limit. As such, it is important to collect blind duplicate samples from locations that have known impacts and detectable contaminant concentrations.

The RPD_{DUP} should be reviewed to indicate if there is a problem with precision. Samples that produce RPD_{DUP} values of >20%, may indicate a possible issue. Significant RPD values may be caused by cross-contamination, samples that aren’t truly representative or an issue with laboratory precision. Significant RPD values should be discussed with the laboratory to better evaluate the magnitude and potential implications of the RPD value. If it is determined that the reliability of the analytical results are unacceptable further investigations should be conducted to identify the source of the heterogeneity, and the impact upon the sample data ascertained. A special evaluation study may well be required. Note that situations where non-representative samples are common call for specialised methods of sample collection.

Trip Blanks: A trip blank is used to identify contamination that may have occurred during the handling, storage and or shipment of samples. The trip blank is a laboratory-prepared water sample (typically distilled or deionized water) whose quality is known and documented. The trip blank is labelled by the lab and kept with the sample containers for the entire duration of the field program. Typically, one trip blank is kept in each cooler and treated exactly like regular samples for temperature control and shipment back to the laboratory. The trip blank should never be opened. Coolers containing samples collected for VOC analysis should also contain a trip blank pre-charged with methanol.

Equipment Blanks: Equipment blanks are used to identify contamination of the equipment used in the collection of sampling which includes sample containers. After thorough decontamination, laboratory-prepared deionized or distilled water is passed over and through the cleaned equipment (e.g. split spoon) and collected directly into a sample container, which is then submitted to the lab for analysis of the contaminants of concern. In the same way deionized water is used to fill sample containers which are labelled and submitted for analysis.

Field Blanks: Field blanks are used to determine if the ambient sampling environment has affected the quality of the samples. They are used to determine the existence and magnitude of contamination present in the ambient environment that may have been carried by wind or by physical contact into a sample. Although field blanks are more commonly used for water sampling programs, they can be used for soil sampling in the same way. To collect a field blank, laboratory-prepared deionized or distilled water is poured into an appropriate sample container with preservative where warranted, at the same location and at the same time as regular samples are collected. The filled containers are sealed and submitted to the laboratory.

It is essential that field blanks be collected when collecting soil samples for VOC analysis. This is achieved simply by opening up a sample jar pre-charged with methanol from the lab for approximately ten seconds (the amount of time needed to place a typical soil sample in a jar) and resealing the jar.

Detectable field blank values should be checked to determine the source of contamination, and to determine the impact of this contamination upon the sample data. This evaluation may require analyses of additional field blanks, laboratory blanks, or equipment blanks. Sample results may require rejection or qualification based upon the degree and source of contamination. Note that field blanks results may not be subtracted from reported results.

The frequency of QA samples to be submitted to the lab, along with the recommended analyses for each type of sample is indicated in Table 4, below.

Table 5.1: Collection Frequency of QA Samples

QA Sample Type	Frequency	Applicable Parameters
Blind Duplicates	every 10 samples	all parameters
Equipment Blank	1 per day or 1 per each type of sampling equipment used (for non-dedicated equipment)	all organic parameters
Trip Blank	1 per shipment/cooler	volatiles only
Field Blank	1 per day	all parameters

The quality of data generated in a laboratory depends, to a large degree, on the integrity of the samples that arrive at the laboratory. Consequently, the field investigator must take the necessary precautions to protect samples from contamination and deterioration.

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8 Revision History

July 21, 2020: Initial Publication of Part D1 Soil Sampling and Investigations.

October 10, 2013: Part D republished without change. Appendix 2 of Part D - Sample containers, Storage™, Preservation and Holding Times updated.

February 28, 2001: Part D republished without change. Note added to Appendix 2 requiring use of glass or Teflon™ containers for samples to be analyzed for mercury.

November 1996: Initial publication of the B.C. Field Sampling Manual.

Appendix 1

Standard Operating Procedures

Sampling Method/Media: **Field Classification/Soils**	**Standard Operating Procedure for the Field Identification and Classification of Soils**
Revision No: Original **Revision Date: 15 July, 2020**	**Reference No: SOP-D1-01** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

Figure 1. Surficial soil sample collection for soil classification.

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the field identification and classification of soils. The information and guidance provided in this document is based on ASTM D2487-17 (Unified Soil Classification) and ASTM D2488-17 (Visual-Manual Procedures). Information provided in the two standards were used to develop this procedure with a scope that is primarily limited to environmental investigations but may be used in other applications.

Soil classification is based on nine soil properties that must be examined and recorded in a consistent manner. Competent and articulate soil stratigraphy logs or records are an integral component of Preliminary and Detailed Site Investigations (PSI and DSI). The information contained in these records is used to form the basis of many important decisions such as the choice of samples to be submitted for analysis and the design of remedial action plans. Instructions for field activities that typically accompany soil classification such as sampling techniques, sample handling practices, and sample storage are provided in subsequent SOPs.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on soil classification is provided in Part D1 – Soil Sampling and Investigations of the BCFSM, which must be used in conjunction with the information provided in this SOP. This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information regarding soil investigations is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Soil sampling and classification conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Quality Control

- Refer to individual SOPs for appropriate quality control requirements for sample collection and handling.
- A sample should be representative of the stratum from which it was obtained.
- Submit selected samples for laboratory identification of physical soil properties as required.
- The sample depth interval should be accurately recorded.
- Follow equipment decontamination procedures outlined below to minimize the potential for cross contamination between samples or boreholes.

- Careful notes should also be kept with respect to observations made during sample collection (e.g., test pitting, drilling) such as the presence of cobbles/boulders, difficulty in drilling, blow counts during split spoon sampling, sample recovery and anything else which may provide information regarding in situ characteristics of the soil.
- Ensure that field notes (including field logs) are legible (recorded in ink where possible) and complete.
- Retain all field notes to ensure the information reported is accurate and defensible.

4. Recommended Equipment and Materials

Field equipment should include the following:


Figure 1. Chip tray used for sample storage.

1. Results of any previous field investigations;
2. Blank field logs or other note paper;
3. Field soil description card;
4. At least two pencils;
5. Two pens and two permanent markers;
6. Camera;
7. Site plan and underground utility location plan(s);
8. A knife or spatula to split recovered sample for inspection and/or collection of laboratory samples;
9. Tape measure and/or ruler;
10. Rock hammer;
11. 5% HCl solution (for determining $CaCO_3$);
12. Hand lens;
13. Rock chisel;
14. Sieves;
15. Chip trays for sample storage (for later description or to ensure consistency between locations);
16. Clean (tap or distilled) water to rinse sample tools and perform qualitative estimation of silt and clay ratio/content;
17. Paper towels;
18. Sample containers and labels, preservatives and equipment as needed;
19. Nitrile gloves and required PPE;
20. Munsell colour chart or equivalent; and,
21. Sample submission and chain-of-custody forms.

5. Procedures

Material comprised of organic matter in any stage of decomposition is considered peat. The texture of peat can vary from fibrous to amorphous. It is usually dark brown to black in colour and has an organic odour. No further description is necessary for peat.

Fine-grained soils are identified as silts and clays which are classified as those soil particles that will pass through a No. 200 sieve. Fine-grained soil particles are indistinguishable with the naked eye and can only be distinguished by their behavioural characteristics (plasticity). Clay exhibits plasticity, or putty-like properties, over a range of moisture contents, and has considerable strength when air-dried. Silt exhibits little to no plasticity, and little to no strength when air dried. Techniques for classifying plasticity are described in Step 4.3.

Coarse-grained soils are identified as gravel if the percentage of gravel is estimated to be more than the percentage of sand in the composition. Conversely, coarse-grained soil is considered to be sand if the percentage of sand is estimated to be equal to or greater than the percentage of gravel.

5.1 Composition and Gradation

The first steps in classifying soils requires distinguishing soil grain sizes as either fine or coarse, determining the predominant grain size, and describing the composition of the matrix.

5.1.1 ***Predominant Grain Size***: Soils are first characterized by the predominant grain size of the matrix which can be determined using a No. 200 sieve and scale or the field methods described in Section 6. Predominant grain size is divided into fine-grained soil and coarse-grained soil as described below.

- **Fine-grained soil** - Soil is described as fine-grained if 50% (by weight) or more of the the soil particles are smaller than the No. 200 sieve.
- **Coarse-grained soil** - If 50% (by weight) or more of the the soil particles are larger than the No. 200 sieve the soil is described as coarse-grained.

Gradation Table

	Component	Size Category	Approximate Particle Size Range	Approximate Particle Scale Size	Observation/Behaviour
Fine-Grained	Clay	Fines	<0.04 mm (passing No. 200 sieve)	Flour-sized and smaller	Grains not visible, shiny, slippery, not gritty, can be rolled into long ribbons when moist to wet
	Silt		0.04 mm - 0.075 mm (passing No. 200 sieve)	Flour-sized and smaller	Grains not visible, gritty like talc or flour, may form a short ribbon when moist but breaks apart easily
Coarse-Grained	Sand	Fine	0.075 - 0.4 mm (No. 200 to No. 40 sieve)	Flour to sugar-sized rock	Grains are visible
		Medium	0.4 - 2 mm (No. 40 to No. 10 sieve)	Sugar to rock salt-sized	
		Coarse	2 - 5 mm (No. 10 to No. 4 sieve)	Salt-sized to peasized	
	Gravel	Fine	5 - 20 mm (0.2 to 0.75 in)	Pea to thumb-sized	
		Coarse	20 - 75 mm (0.75 to 3 in)	Thumb-size to fist-sized	
	Cobbles	n.a	75 - 300 mm (3 to 12 in)	Fist to basketball sized	
	Boulders	n.a.	> 300 mm (12 in)	Larger than a basketball	

Note: Methods for determining grain-size percentages are provided in Section 6.

Soils are then described according to the composition of the matrix and the gradation of both the predominant and secondary grain sizes.

5.1.2 ***Composition/gradation:*** Describe the composition of the soil matrix identifying the predominant grain size first followed by the relative quantity of the remaining grain sizes, and grain size distribution characteristics according to the criteria described below.

Composition Table

Component	Descriptor	Criteria
Distribution of the **Predominant Grain Size**	Well graded	A wide, uniform distribution of grain sizes and substantial amounts of intermediate sizes (e.g., coarse gravel to fine sand)
	Poorly graded	A narrow distribution of grain sizes (i.e. uniformly graded - e.g., fine sand only), or has a wide range of grain sizes, but with some intermediate sizes obviously missing (i.e., gap graded soil)
Distribution of the **Secondary grain sizes**	trace	0% to 10%
	some	10% to 20%
	y/ly/ey	20% to 35%
	and	35% to 50%

5.2 ***Physical Characteristics:*** Describe the physical characteristics of angularity, colour, consistency and density according to the criteria described below. Standard Penetration Test (SPT) resistance values (N) are inferred by assessing the physical characteristics of the soil.

Physical Characteristics Table

Aspect	Descriptor	Criteria
Angularity	Rounded	Approximation of dominant characteristic
	Sub-Rounded	
	Angular	
	Sub-Angular	

Colour	Red, Brown, etc.	Use the Munsell colour chart if available
Consistency (for intact fine-grained soils that exhibit plasticity - cohesiveness)	Very Soft	Thumb penetrates soil more than 25 mm; exudes between fingers when squeezed; SPT "N" value less than 2
	Soft	Thumb penetrates soil about 25 mm; easily molded with fingers; SPT "N" value 2 to 4
	Firm	Thumb penetrates soil more than 6 mm with some effort; molded by strong pressure; SPT "N" value 4 to 8
	Stiff	Thumb indents soil no more than 6 mm; penetrated only with great effort; SPT "N" value 8 to 15
	Very Stiff	Thumb will only imprint soil, but readily indented with thumbnail; SPT "N" value 15 to 30
	Hard	Thumbnail will not indent soil, or indented with difficulty; brittle; SPT "N" value greater than 30
Density (for coarse-grained soil, and non-plastic fine-grained soil - non-cohesive)	Very Loose	Easily dug by hand; SPT "N" value less than 4
	Loose	Can be dug with a spade, 12 mm dia. reinforcing rod easily driven; SPT "N" value between 4 and 10
	Medium Dense	12 mm dia. reinforcing rod pushes 50 mm to 100 mm; SPT "N" value between 10 and 30
	Dense	12 mm dia. reinforcing rod pushes in less than 50 mm, 12 mm dia. reinforcing rod driven less than 30 cm with 5 lb hammer, needs pick for excavation; SPT "N" value between 30 and 50
	Very Dense	12 mm reinforcing rod hard to drive with 5 lb hammer; SPT "N" value greater than 50

5.3 ***Plasticity:*** For fine-grained soils, or for the fine-grained fraction of a soil, describe the plasticity according to the following. Add water to the sample to aid in testing:

Plasticity Table

Descriptor	**Criteria**
Non-plastic	A 3 mm (1/8 inch) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be re-rolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be re-rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

5.4 Structure: The soil structure should be described in accordance with the following:

Structure Table

Descriptor	**Criteria**
Stratified	Alternating layers of varying material or colour, with layers at least 6 mm thick (note thickness)
Laminated	Alternating layers of varying material or colour, with layers less than 6 mm thick (note thickness); typically applies to fine-grained soil horizons
Fissured	Breaks along definite planes of fracture, soil around fractures often discoloured (oxidized), near ground surface fractures often contain rootlets
Slickensided	Breaks along definite planes of fracture, fracture planes appear polished or glossy due to movement, sometimes striated (fractures typically infilled with clay)
Blocky	Cohesive fine-grained soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay (note thickness)
Massive or homogeneous	Same colour and appearance throughout

5.5 ***Moisture Content*****:** Describe the moisture content of the soil as dry, moist, wet or saturated, in accordance with the following:

Moisture Content Table

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Damp	Slight soil moisture
Moist	Obvious moisture, but no visible water
Wet (or Saturated)	Visible free water

5.6 ***Inclusions*****:** Note the presence of inclusions such as rootlets, grass or reeds, shell fragments, wood, mica, or man-made debris.

5.7 ***Visual and olfactory characteristics*****:** Describe any apparent visual or olfactory evidence discernable such as sheens, organic, septic or hydrocarbon odours. Odour should be observed without unnecessary exposure to vapours from potential contaminants. Odour descriptors include gas-like, oil-like, mothball-like, solvent-like, weathered, sulphurous, faint, strong, sweet, organic (i.e., peat).

5.8 ***Interpretation*****:** If appropriate, include a local, commercial or geologic interpretation of the soil (e.g., till-like).

5.9 ***Reporting*****:** Report the description of the stratigraphy on the field borehole logs in the following order: Gradation, Primary Soil Component, Minor Soil Component(s) and Gradational Characteristics, Angularity, Colour, Consistency or Density, Plasticity (if applicable), Structure, Moisture, Inclusions, Evidence of Contamination, and Interpretation (if possible and applicable). Where minor soil components comprise 20% or more of the matrix it is acceptable to include them in the opening segment of the description; for example, silty sand or sand and gravel.

EXAMPLE DESCRIPTIONS:

Eg.1 ***– poorly graded SAND AND GRAVEL*** - some silt, trace cobbles to 150 mm dia, subangular to subrounded gravel, dark grey with reddish mottling, dense to very dense, fissured in upper 2 m, moist, 50 mm thick fine sand seam at 2 m depth, damp, no apparent odour, till-like.

Eg.2 ***– well graded SAND*** - medium to fine grained, trace sub-rounded gravel, grey, loose, contains lenses of silt with some sand to 50 mm thick, damp becoming wet below 1 m, brick fragments, strong gas-like odour at 1 m.

Eg.3 ***– well graded SILTY CLAY*** - trace sand, fine grained, reddish brown, soft, low plastic, moist, trace organics - reeds and shell fragments, slight stale oil-like odour.

The following is a list of additional descriptors for reporting:

Descriptors	Description
Stratum	Generally greater than 300 mm (12 inch) thickness
Pocket	Small (limited area), erratic deposit, usually less than 300 mm thick
Layer	13 mm to 300 mm (1/2 inch to 12 inch) thickness
Seam	2 mm to 13 mm (1/16 inch to 1/2 inch) thickness
Parting	0 mm to 2 mm (0 to 1/16 inch) thickness
Varved clay	Alternating seams or layers of sand, silt and clay (laminated)
Occasional	One or less per 300 mm of thickness
Frequent	More than one per 300 mm of thickness

6. Methods for Classifying Fine-grained Soils

The following three test procedures allow for a more accurate classification of fine-grained soil. These tests are carried out on the fraction of soil with grain sizes of fine sand (No. 40 sieve) and less.

6.1 Dry Strength**:** Mold material until it has the consistency of putty, adding water if necessary, and form into a 25 mm ball. Allow the test specimen to dry by air, sun or artificial means, provided the temperature remains less than 60°C.

The dry strength is determined in accordance with the criteria provided in the following table:

Descriptors	Criteria
None	The dry specimen crumbles into powder with the mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure, but breaks into pieces between thumb and hard surface
Very High	The dry specimen cannot be broken between the thumb and a hard surface

6.2 ***Dilatancy:*** Mold material until it is has soft, but sticky, consistency, adding water if necessary, and form into a 12 mm ball. Shake horizontally, striking the side of the hand vigorously against the other hand several times and note the water appearing on the surface. Squeeze the sample by pinching it and note the reaction of the disappearance of water on the surface.

Describe dilatancy as follows:

Descriptors	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

6.3 ***Toughness:*** Roll material between hands, or on a smooth surface, into a thread about 3 mm (1/8 inch) in diameter, adding water or allowing to dry by evaporation as necessary. Re-form the material and re-roll repeatedly until the thread crumbles at a diameter of about 3 mm which is at about the material plastic limit. Note the pressure required to roll the thread and the strength of the thread at this time. After the thread crumbles, lump the pieces together and knead the lump until it crumbles.

Describe toughness as follows:

Descriptor	Criteria
Low	A thread can barely be rolled and a lump cannot be formed when drier than the plastic limit
Medium	A thread is easy to roll and little time is required to reach the plastic limit. A thread cannot be re-rolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be re-rolled several times after reaching the plastic limit. A lump can be formed without crumbling when drier than the plastic limit

6.4 Classification

The classification of fine-grained soil can then be assigned using the table below:

Soil Type (Name)	Group Symbol	Dry Strength	Dilatancy	Toughness
inorganic silts and very fine sands, silty or clayey fine sands or clayey silts with slight plasticity (low plastic silt)	**ML**	None to low	Slow to rapid	Low or thread cannot be formed
inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays (low plastic clay)	**CL**	Medium to high	None to slow	Medium
inorganic silts and organic silt-clays of low plasticity (elastic silt)	**MH**	Low to medium	None to slow	Low to medium
inorganic clays of high plasticity (high plastic clay)	**CH**	High to very high	None	High

Mineral soil which contains enough organic particles to influence soil properties is considered organic fine-grained soil. Organic soils are often dark brown to black, and often change colour when exposed to air. Organic soils will normally not have high toughness or plasticity, and the thread for the toughness test will be spongy.

7. Methods for Determining Grain-size Percentages

1) ***Jar Method*** - The relative percentage of coarse-grained and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a jar, and then allowing the mixture to settle. Sand sizes will fall out of suspension in 20 sec to 30 sec. The relative proportions can be estimated from the relative volume of each separate size. This method does not replace a proper laboratory grain size distribution determination.
2) ***Wash Test*** - The relative percentage of sand and fines may be estimated by moistening enough sample to form a 25 mm cube of material. Cut the cube in half, set one half aside, and place the other half in a small dish. Wash and decant the fines out of the material in the dish (including breaking up lumps of fines if necessary) until the wash water is clear. Compare the unwashed and washed samples to estimate the percentage of sand and fines. This method does not replace a proper laboratory grain size distribution determination.

8. References

ASTM D2487-17, 2017. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM International, West Conshohocken, PA.

ASTM D2488-17, 2017. Standard Practice for Description and Identification of Soils (Visual-Manual Procedures), ASTM International, West Conshohocken, PA.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Soil Vapour Screening/Soil**	**Standard Operating Procedure for Field Screening Vapour Concentrations in Soil (Dry Headspace Method)**
Revision No: Original **Revision Date: 15 July, 2020**	**Reference No: SOP D1-02** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the field screening of vapour concentrations in soil using the dry headspace method. Field screening by this method provides an indication of presence and approximate concentrations of Volatile Petroleum Hydrocarbons (VPH) and Volatile Organic Compounds (VOCs) in soil samples using hand-held instruments. This procedure describes the use of organic vapour meters (OVM), combustible gas meters (CGM) and photo-ionization detectors (PID).

Values produced by hand held instruments are based on a correlation of the instruments response to a specific calibration gas and as such analytical testing is required to identify and fully quantify the concentration of a target analyte. Correlation between the vapour concentrations measured by this procedure and laboratory analytical results depends on field procedures, the type and relative concentrations of volatile constituents, instrument response, soil grain size, moisture content, sample volume/headspace ratio, temperature, and equilibration time.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on soil vapour screening is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP.

This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information regarding soil quality and testing is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Soil vapour screening conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Principle of the Sampling Method

The field screening of soil samples using an OVM, CGM, or PID is conducted to obtain semi-quantitative (presence and approximate concentration) information regarding specific compounds. The process allows for rapid screening of a large number of samples in a relatively short period of time. Screening results are used as a tool to help define the lateral and vertical extents of potential VOC and or VPH contamination, to help determine the placement of monitoring well screens and to determine which soil samples to submit for analytical testing. The following descriptions summarize the function of each instrument:

Figure 1. RKI Eagle Combustible Gas Meter

Organic Vapour (OVM) and Combustible Gas Meters (CGM)

OVM/CGM are used to measure combustible vapours so that fire and explosion hazards may be evaluated. They measure the presence of compounds by measuring the heat produced by combustion at a catalytic detector, which provides a relative measure of explosivity of the contaminant in air. Since different compounds produce different amounts of heat when they are burned, there can be wide ranges of responses with different compounds. Therefore, the accuracy of these instruments can be low. In addition, both meters require atmospheric levels of oxygen to work correctly. Combustible vapour meters measure combustible gases within the concentration range of 0 - 100% of the Lower Explosive Limit (LEL) of the specific gas used for instrument calibration. These meters are usually calibrated to hexane. Some instruments have the ability to detect multiple gases including oxygen, hydrogen sulphide and carbon monoxide.

Most instruments can be operated in methane elimination mode, when the primary contaminant of concern is not methane.

Photo-Ionization Detectors (PID)

Figure 2. RKI MiniRae 3000 PID

The PID is mainly used to detect VOCs, such as chlorinated solvents. They can also detect some inorganics, such as ammonia and hydrogen sulphide. The detector measures the current produced by emitting high-energy photons that break molecules into positively charged ions. PIDs are typically calibrated to isobutylene.

The PID will only respond to compounds that have ionization potentials equal to or lower than that produced by its lamp. This lamp is interchangeable and can be replaced. The most common lamps are the 10.6 electron volt (eV) and 11.7 eV lamps. These are usually stated in the manual that accompanies the instrument. The 11.7 eV lamp measures the widest range of compounds however, the lamp is expensive and deteriorates quickly. For most uses, including the detection of tetrachloroethene (PCE), trichloroethene (TCE) and vinyl chloride (VC), the 10.6 eV lamp is suitable. If you need to use an 11.7 eV lamp, use it for as short a time as possible and store it in an air tight container.

PIDs are extremely sensitive to humidity which can result in a reduction in response, as well as condensation build up in the sensor. Soil dust can exacerbate this effect. A 4.5 cm hydrophobic particulate filter is typically used to minimize this effect; however, the filters have to be changed frequently. Oxygen is not required for a PID to function correctly, although the amount of available oxygen can affect the readings, with higher readings usually observed under low oxygen conditions.

4. Quality Control

- Ensure that all instruments are functioning before starting and that all required information is recorded in the field.
- Ensure the instrument is calibrated (daily minimum) prior to use in accordance with manufacturer's specifications and maintain the instrument regularly.
- Replace the hydrophobic (water trap) particulate filter frequently, since the presence of moisture influences readings.
- Ensure that variables such as measurement position/depth, temperature, and time to equilibrium are as consistent as possible to minimize bias due to external factors, such as ambient conditions and instrument response time.

Figure 3. Hydrophobic and Particulate Filter

5. Recommended Equipment and Materials

Field equipment should include the following:

1. Reference documents and writing tools:
   - Site plan/Health & Safety plan/Work plan; and,
   - Field book/appropriate sample field log (i.e. sample log or borehole log).
2. Monitoring Equipment/Tools:
   - Combustible vapour meter to measure petroleum and combustible hydrocarbons;

- Photoionization Detector (PID) to measure volatile organic compounds (VOCs), typically chlorinated solvents, but can also be utilized for specific petroleum hydrocarbons such as benzene, toluene, ethylbenzene, and xylenes (BTEX);
- Operations manual for each selected instrument;
- Soil scoop; and
- Re-sealable 1L polyethylene bags.

6. Sampling Considerations

- Screening instruments should be selected based on the potential contaminants suspected of being present at a site:
  - Petroleum hydrocarbon vapours: either the OVM/CGM or PID is acceptable but less commonly used.
  - Halogenated hydrocarbons (e.g. chlorinated solvents): a PID must be used; halogenated hydrocarbons will affect the OVM/CGM sensor.
- Headspace vapour readings are correlated to the concentrations of VOCs in equilibrium with those present in the soil of the unsaturated zone and in groundwater at the water table in the vicinity of the well.
- Vapour readings can be significantly affected if light non-aqueous phase liquid (LNAPL) is present in the monitoring well.
- All instrument types provide poor response to semi-volatile and non-volatile contaminants including mid-distillate petroleum hydrocarbons (e.g. diesel, heating oil, fuel oil) and heavy petroleum hydrocarbons (e.g. lubricating and motor oils).

7. Procedures

Note: The use of “meter” herein refers to an OVM, CGM, or PID.

1. Calibrate the meter at the beginning of every field day in accordance with manufacturer’s specifications. Calibrate the meter only when it is sufficiently warmed (approximately 5 minutes) and is zeroed in the absence of VOCs. **The meter should be calibrated with all attachments used for measurements (filters, extensions, etc.).** The combustible vapour meter should be calibrated and operated in methane elimination mode (unless specifically used to measure methane, for instance during landfill gas monitoring). A recheck of the calibration during the day is recommended if the meter is subjected to varying or unusual site conditions, such as significant changes in temperature and humidity, or when the meter has been handled roughly.

2. Attach the hydrophobic particulate filter, to prevent water and dust from entering and damaging the active sensing element. Note that the filter will not stop all liquids, which will damage or contaminate flow components if drawn into the instrument. Test for satisfactory air flow through the meter by placing a gloved finger over the end of the probe inlet and blocking off the flow. If the low flow alarm does not activate, check connections, hoses and fittings and repair as necessary. A quick way to confirm that the meter is working is to uncap a marker and place it near the end of the meter probe.

3. Record site conditions, meter unit number and weather conditions (including ambient temperature).

4. Collect a sample of soil with a clean scoop and place into polyethylene bag. Place a consistent volume of sample material into each sample screening bag (typically 1 L of soil for a 4 L bag). **The exact amount of sample collected is not as important as assuring that the amount collected is consistent for all analyses conducted at a site.** Incorporate air into the bag and seal the bag immediately thereafter. Collect a split (i.e., duplicate) sample for laboratory analysis if required. **Note that if you are collecting samples for VOCs, collect and field preserve the soil sample <u>before</u> conducting the field screening procedure.**

5. Record the sample identification on the polyethylene bag.

6. Record sample information in a field book or soil sample log, including sample identification, meter type, sample type (discrete/composite), location (grid coordinates or scale drawing), depth, soil type, and sample date.

7. Break up and agitate the soil within the polyethylene bag, making sure not to puncture the bag or break the seal. Let the bag equilibrate for 15 minutes (minimum of five minutes) after agitation. Longer equilibration times may be required during periods of cold weather. **The exact equilibration time is not as important as assuring that the equilibration time is consistent for all analyses conducted at a site.**

8. When the soil sample has sufficiently equilibrated within the bag, insert the probe tip into the bag through the seal or puncture the bag and insert the probe tip. To minimize the loss of volatiles keep the opening just large enough to accommodate the probe's tip. **Ensure that the probe does not come in contact with the soil.**

9. Record the vapour reading once the meter has stabilized. This may take up to 30 seconds.

- For vapour readings below the lower explosive limit (LEL), the meter will often stabilize momentarily at a "peak" reading and then decrease; in this case, record the peak reading.
- If the vapour reading is between the LEL and upper explosive limit (UEL), the meter reading will be above scale (i.e. greater than 10 000 ppm or greater than 100% LEL) of the least sensitive range. For vapour readings above the UEL, the reading will initially be above scale and then return to a range below 100% LEL; this is due to oxygen deficiency which does not enable all of the vapour to oxidize across the catalytic element. These last two cases should be recorded as >10,000 ppm or > 100% LEL depending on the instrument used.

10. If the bag accidentally opens or other inconsistencies are identified (i.e., low soil volume), record these details in a field book.

11. After completing a measurement, purge the instrument with fresh air. The higher the vapour reading, the longer the purge time required. After a high reading (greater than 500 ppm) or after completing all measurements, purge the instrument sensor with fresh air for approximately one minute.

12. Dispose of all wastes (liquids, used gloves etc.) in an appropriate manner. Leave the site in a tidy condition.

8. References

Robbins, Gary A. et al., "A Field Screening Method for Gasoline Contamination Using a Polyethylene Bag Sampling System", *Ground Water Monitoring Review* (Ground Water Publishing Co., 6775 Riverside Dr., Dublin Ohio 43017, U.S.A.), Fall 1989.

USEPA, 1990. Field Measurements: Dependable Data When You Need It. Office of Underground Storage Tanks, Washington, DC. EPA/530/UST-90-003.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Excavation, Test Pit and Stockpile Sampling/Soil**	**Standard Operating Procedure for Soil Sample Collection from Excavations, Test Pits and Stockpiles**
Revision No: Original **Revision Date: 15 July, 2020**	**Reference No: SOP-D1-03** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the collection of soil samples from excavations, test pits and stockpiles. Sample collection equipment includes shovels, excavator buckets, and hand augers. Analysis of the samples for specific contaminants may be completed for confirmatory testing following the excavation of contaminated soil, assessment during a test pitting investigation, or the initial, interim, or final characterization of excavated soil.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on soil sampling from excavations, test pits and stockpiles is provided in Part D1 – Soil Sampling and Investigations, of the BCFSM which must be used in conjunction with the information provided in this SOP. This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Soil sampling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Quality Control

Quality control begins with thorough pre-trip preparation.

Ensure the sample plan considers and incorporates the requirements for sample containers, preservation, and hold times. The required sample containers, storage temperatures, preservation requirements and holding times are available from laboratories providing environmental testing. This information is also provided on the ENV website at:

https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf.

While enroute and in the field:

- Prior to sampling, avoid smoking, pumping gas, using hand sanitizers, or coming into contact with sharpies or solvents, to prevent sample contamination.
- Carefully document all field activities, sample locations and observations,
- Accurately document sample locations with reference to an established grid.
- Decontaminate sampling equipment before sampling and between samples,

- Submit an appropriate number of blind field duplicate samples (typically 1 for every 10 samples, minimum of 1 per day) for laboratory analysis.
- A laboratory-prepared travel blank should accompany each cooler containing VOC/SVOC samples.
- Disposable nitrile gloves must be worm when collecting samples. New gloves are required for each sample location.

4. Recommended Equipment and Materials

The following is a list of documents and equipment that may be required during soil sampling:

Reference Documents:

1. Site plan and results of previous field investigations, field screening correlations, etc.;
2. Soil sample logs;
3. Underground utility location plan(s);
4. Copies of any permits (e.g., lane closure, street area) required;
5. Field book and indelible felt pen (fine point); and
6. Sample submission and chain-of-custody forms.

Field Equipment:

7. Appropriate PPE;
8. Tape measure, 50 m tape or odometer wheel;
9. Fluorescent orange spray paint (not used for VOC sampling) or nails to mark sample locations;
10. Survey stakes;
11. Flagging tape;
12. Disposable nitrile gloves;
13. Hand trowel;
14. Shovel;
15. Hand augers if required (helical style bit, Dutch style bit or bucket-style bit);
16. Core barrel with slide hammer;
17. Stainless steel coring device (preferred), trowel or spoon, if sampling for non-volatile compounds;
18. Syringe sampler (e.g. Terra Core™, Easy Draw Syringe™, Power Stop Handle™) or disposable sampler (e.g. EnCore™), if sampling for volatile compounds;
19. Sealable plastic bags (e.g. Ziploc®);
20. If field screening is required, field screening instrument appropriate for the PCOCs;
21. Calibration equipment and gas for field screening instrument;
22. Laboratory detergent (e.g. Alconox™ or Liquinox™ and water solution or solvents [as necessary]);
23. Distilled water in squeeze bottle dispensers;
24. Paper towels;
25. Appropriate laboratory-supplied containers;
26. Sample labels;
27. Double-bagged ice;
28. Clean cooler; and,
29. Camera.

5. Sampling Considerations

- Do not use an acid rinse in the field decontamination procedure if pH is an analytical parameter.
- Stainless steel equipment is recommended for sampling; however, nickel has been found to leach from stainless steel. If nickel is a Potential Contaminant of Concern (PCOC) at a site, sample contact with stainless steel should be minimized. Plastic (e.g., PVC) tools are a good alternative to stainless steel.
- If field screening based on headspace vapour reading is required consult SOP D1-2 for appropriate equipment and procedures.

6. Procedures

General organics are more stable (i.e., less volatile and/or bio-degradable) than volatile organic compounds such as BETX. For this reason, samples collected for laboratory analysis of volatile compounds should be collected first.

1. Obtain authorization from the owner for site access, if needed, and confirm that physical access to the site is possible (e.g., gates unlocked).
2. Confirm accuracy of the existing site plan or keep sufficient notes so that a site plan can be developed or improved. For excavation and test pit sampling, review and ensure the accuracy of the grid system. Mark each grid line for easy reference during the field program.
3. Organize sample containers and prepare labels.
4. Decontaminate sampling equipment. Scrub the equipment in a mild detergent (e.g., Alconox®) water solution, and rinse with distilled water. Repeat this step for each sampling location.
5. Calibrate field screening instrument, if needed.
6. Determination of sample depth: a tape should be advanced into the test pit or excavation to determine the depth of the sample.
7. For samples obtained directly from equipment (e.g., trowel, shovel, hand auger, backhoe or excavator bucket), the outermost soil cuttings are scraped away to remove soil potentially cross-contaminated from overlying contaminated zones. A sample is then obtained from the remaining soil. Some contractors have sampling tools which can be attached to the bucket for sampling.
8. For samples obtained in-situ (e.g., from an excavation wall or floor), scrape the surface to a depth of approximately 0.05 m to expose fresh soil for sampling.
9. For samples obtained ex-situ (stockpile), collection of soil samples from the surface of the stockpile should be avoided, due to the potential loss of volatile compounds at the surface.
10. If there is any uncertainty with the quality of the sample, discard the sample and repeat the sample collection procedure.
11. Samples collected for the analysis of volatile compounds should be collected prior to the collection of non-volatile samples. Samples collected for the analysis of volatile compounds should be collected with a syringe style sampler (e.g., Terra CoreTM, Easy Draw SyringeTM, Power Stop HandleTM) and immediately placed into methanol pre-preserved vials; or with a disposable sampler (e.g., EnCoreTM). If these devices are not feasible for your project, a trowel or spoon can be used in consultation with your laboratory.

    Note: Preserved samples should be accompanied by a non-preserved sample for moisture content analysis. Samples collected with an EnCoreTM device are not preserved and must be cooled to ≤ 4◦C and received by the laboratory within 48 hours for processing. Consult your laboratory to ensure you collect the required number of vials or EnCoreTM samples. Samples should be collected in accordance with SOP D1-9.

12. Samples collected for the analysis of non-volatile compounds should be collected with a coring device. For coarse grained material the diameter of the coring device should be a minimum of 3 times the diameter (3d) of the largest particulate in the matrix. For fine grained material the coring diameter should be at least 3d + 10 mm. Generally, the coring device should be at least 1.6 cm in diameter. If coring devices are not suitable for the soil composition and undisturbed sampling is not feasible due to sample locations (e.g. excavation floor or wall), a trowel or spoon can be used.

    Note: Composite samples must be comprised of equal aliquot volumes. Homogenization of the aliquots must be completed before filling the sample bottles. The soil sample should be collected in accordance with SOP D1-10 non-volatile compounds.

13. Once the jar is filled, use a clean paper towel to scrape off excess soil. Using your fingertips (with nitrile gloves), ensure that all the threads on the jar are clean, and then fasten the lid securely.
14. Label the sample jar and lid separately using the appropriate sample nomenclature. Information included on the container label should include: Sampler's initials, sample collection date, company name, sample site identification and/or the unique Sample Identifier, desired analytical parameters, and preservation method. Wrap the label and container with clear packing tape.

15. Place the sample in a cooler chilled with ice for transport to the laboratory. If using ice, be aware that melted ice can result in damaged or destroyed labels and can also be a significant pathway for cross-contamination of samples. As such either the ice or the samples should be double-bagged and sealed.
16. Complete sample submission and chain-of-custody forms. Chain-of-custody forms should be filled out in their entirety and each cooler shipped should have its own chain-of-custody form listing only those samples contained in the cooler. Chain-of-custody forms should be enclosed in their own plastic bag to protect them from possible water damage during shipment. Be sure to specify to the laboratory the analytical detection limit desired. Samples should be delivered to the laboratory within 24-hours if possible.
17. Record sample information including observations in the field book, soil sample log, or test pit log. Sample information should include sample identification, sample type, equipment used (i.e. excavator bucket), location (grid coordinates or scale drawing), depth, soil type, and sample date, visual and olfactory observations. Document site conditions and key observations using a camera.
18. For field screening, place a replicate sample from each sampling location/depth into a sealable plastic bag and conduct vapour screening in accordance with SOP D1-2.
19. Label a survey stake with the unique sample identifier and date and drive it firmly into the ground at the sampling location. In undeveloped areas, label survey flagging tape and hang from a nearby tree branch for better visibility and duplication of labelling. In developed areas, locations may be marked on nearby concrete or asphalt surfaces. Collect GPS co-ordinates of the sample location, if possible.
20. If applicable mark off excavations in a clearly visible manner and ensure the site is secure. If applicable ensure that tarps are adequately secured at the end of the day to prevent blow off from stockpiles due to windy conditions.
21. Dispose of all wastes (liquids, used gloves and materials) in an appropriate manner. Leave the site in a tidy condition.

7. Technical Notes

SAMPLING FROM AN EXCAVATOR BUCKET:

Excavator bucket sampling is usually required to obtain samples from locations unsafe for entry (i.e., excavations or test pits over 1.2 m in depth). This type of sampling is also often used to collect samples from large soil stockpiles.

Ensure that a representative sample can be collected bearing in mind the excavator bucket's reach and angle. Difficulties may be encountered when sampling walls opposite to the excavator. If the bulk soil sample falls to the floor of the excavation, monitor the sample recovery carefully to ensure that mixing has not occurred. If there is any uncertainty with the quality of the sample, discard the sample and repeat the sample collection procedure.

HAND AUGER SAMPLING:

Hand augers are ideal for collecting soil samples from various depths (up to 3 m) in both disturbed and undisturbed soils. The auger will cause some disturbance to the sample. Remember to clean/decontaminate the auger between sample locations. If an undisturbed sample is desired, a core barrel attached to a slide hammer may be used. The choice of auger bit style depends on application and soil conditions. The following table provides a summary of bit styles and their associated uses.

Method	Advantages	Disadvantages
Helical Style Bit 	Very good for augering in dense (undisturbed) soil, including soil with coarse gravel	In general, not very well suited for collecting soil samples
Dutch Style Bit 	Very good for collecting samples from soil piles (disturbed soil) and for augering in rooty or boggy soil conditions	Not very well suited for augering and collecting samples in loose material (sand, gravel) or for augering in dense (undisturbed) soil with gravel

Bucket Style Bit 	Very good for collecting samples from soil piles (disturbed soil) and for augering and collecting samples in loose material (includes sand and fine to medium gravel) and clays (use open sided bucket auger)	Not very well suited for soils with coarser gravel

8. References

ASTM D4700-15, 2015. Standard Guide for Soil Sampling from the Vadose Zone, ASTM International, West Conshohocken, PA.

Canadian Council of Ministers of the Environment (CCME), 2016. “Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment”. V.3, Suggested Operating Procedures.

The Interstate Technology and Regulatory Council (ITRC), 2012. *Incremental Sampling Methodology. ISM-1.* Washington, D.C.: Interstate Technology & Regulatory Council, Incremental Sampling Methodology Team. www.itrcweb.org.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Surficial Soil Sampling**	**Standard Operating Procedure for** **Surficial Soil Sampling**
Revision No: Original **Revision Date: 15 July, 2020**	**Reference No: SOP-D1-04** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for surficial soil sampling. This procedure was developed to assist in assessing the potential impacts to surficial soils that may be caused by spills or leaks, airborne fallout on developed or undeveloped areas, and general impacts from industrial operations. Soil samples collected using this SOP can be used to define background conditions and evaluate impacts over wide areas. This procedure is applicable to both organic and inorganic contaminants. It is important to note that without an adequate sampling strategy sample bias may result due to natural heterogeneity.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on surficial soil sampling is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP. This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), are available on the Contaminated Sites webpage at:

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Soil sampling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Quality Control

Quality control begins with thorough pre-trip preparation.

Ensure the sample plan considers and incorporates the requirements for sample containers, preservation, and hold times. The required sample containers, storage temperatures, preservation requirements and holding times are available from laboratories providing environmental testing. This information is also provided on the ENV website at:

https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf.

While enroute and in the field:

- Prior to sampling, avoid smoking, pumping gas, using hand sanitizers, or coming into contact with sharpies or solvents, to prevent sample contamination.
- Carefully document all field activities, sample locations and observations.
- Accurately document sample locations with reference to an established grid.
- Decontaminate sampling equipment between samples.
- Disposable nitrile gloves must be worm when collecting samples. New gloves are required for each sample location.

- Submit an appropriate number of blind field duplicate samples (typically 1 for every 10 samples, minimum of 1 per day) for laboratory analysis.
- A laboratory-prepared travel blank should accompany each cooler containing VOC/SVOC samples.
- Disposable nitrile gloves must be worn when collecting samples. New gloves are required for each sample location.

4. Recommended Equipment and Materials

The following is a list of documents and equipment that may be required during soil sampling:

Reference Documents:

1. Site plans and results of previous field investigations, field screening correlations, etc.;
2. Soil sample logs;
3. Underground utility location plan(s);
4. Copies of any permits (e.g. lane closure, street area) required;
5. Field book and indelible felt pen (fine point); and,
6. Sample submission and chain-of-custody forms.

Field equipment:

7. Appropriate PPE;
8. Tape measure, 50 m tape or odometer wheel;
9. Fluorescent orange spray paint (not used for VOC sampling) or nails to mark sample locations;
10. Survey stakes;
11. Flagging tape;
12. Disposable nitrile gloves;
13. Stainless steel coring device (preferred), trowel or spoon, if sampling for non-volatile compounds;
14. Syringe sampler (e.g. Terra Core™, Easy Draw Syringe™, Power Stop Handle™) or disposable sampler (e.g. EnCore™), if sampling for volatile compounds;
15. Re-sealable bags;
16. If field screening is required, field screening instrument appropriate for the PCOCs;
17. Calibration equipment and gas for field screening instrument (if required);
18. Laboratory detergent (e.g. Alconox™ or Liquinox™ and water solution or solvents [as necessary]);
19. Distilled water in squeeze bottle dispensers;
20. Paper towels;
21. Appropriate laboratory-supplied containers;
22. Sample labels (samples collected for VOCs will be placed in laboratory-supplied pre-labelled containers);
23. Ice or freezer packs;
24. Cooler; and,
25. Camera.

5. Sampling Considerations

- Do not conduct an acid rinse during field decontamination if pH is an analytical parameter.
- Stainless steel equipment is recommended for sampling; however, nickel has been found to leach from stainless steel. If nickel is a Potential Constituent of Concern (PCOC) at a site, sample contact with stainless steel should be minimized. Plastic (e.g., PVC) tools are a good alternative to stainless steel.
- If field screening of samples, appropriate equipment should selected based on PCOC.

6. Procedures

General organics are more stable (i.e., less volatile and/or bio-degradable) than volatile organic compounds such as BETX. For this reason, samples collected for laboratory analysis of volatile compounds should be collected first.

1. Obtain authorization from the owner for site access, if needed, and confirm that physical access to the site is possible (e.g. gates unlocked).
2. Confirm accuracy of the existing site plan or keep sufficient notes so that a site plan can be developed or improved. Review and ensure the accuracy of the grid system if used.
3. Organize sample containers and prepare labels.
4. Decontaminate sampling equipment. Scrub the equipment in a mild detergent (e.g., Alconox®) water solution, and rinse with distilled water. Repeat this step for each sampling location.
5. Calibrate field screening instrument, if needed.
6. Select sampling location. Locations should have sufficient soil cover for sampling and not be located in local low areas were ponding of water may occur. Mark each sampling location for easy reference during the field program.
7. Scrape surficial vegetation, forest litter and humus from ground surface in a 0.3 m square area until the uppermost mineral soil horizon is exposed.
8. Confirm the appropriate sampling procedure. For a typical concentration range determination, excavate soil from a circular area to a depth of 0.5 m or 0.1 m, ensuring that a representative volume of material is collected over the entire depth range. In gardens, sample the top 0.15 m (tilled soil) and the next 0.15 m (native soil) separately. If sampling in grassed areas to assess contamination from atmospheric fallout (area-wide contamination), it is recommended to collect separate samples from the following layers (0 m - 0.5 m, 0.05 m - 0.10 m, 0.10 m - 0.20 m, and 0.20 m - 0.30 m).
9. Samples collected for the analysis of **volatile compounds** should be collected prior to the collection of non-volatile samples. Samples collected for the analysis of volatile compounds should be collected with a syringe style sampler (e.g., Terra Core^{TM}, Easy Draw Syringe^{TM}, Power Stop Handle^{TM}) and immediately placed into methanol pre-preserved vials; or with a disposable sampler (e.g., EnCore^{TM}). If these devices are not feasible for your project, a trowel or spoon can be used in consultation with your laboratory.

   Note: Preserved samples should be accompanied by a non-preserved sample for moisture content analysis. Samples collected with an EnCore^{TM} device are not preserved and must be received by the laboratory within 48 hours for processing. Consult your laboratory to ensure you collect the required number of vials or EnCore^{TM} samples. Samples should be collected in accordance with SOP D1-9.
10. Samples collected for the analysis of **non-volatile compounds** should be collected with a coring device. For coarse grained material the diameter of the coring device should be a minimum of 3 times the diameter (3d) of the largest particulate in the matrix. For fine grained material the coring diameter must be at least 3d + 10 mm. Generally, the coring device should be at least 1.6 cm in diameter. If coring devices are not suitable for the soil composition and undisturbed sampling is not feasible due to sample locations (e.g. excavation floor or wall), a trowel or spoon can be used.

    Note: composite samples must be comprised of equal aliquot volumes. Homogenization of the aliquots must be completed before filling the sample bottles. The soil sample should be collected in accordance with SOP D1-10 non-volatile compounds.
11. Once the jar is filled, use a clean paper towel to scrape off excess soil. Using your fingertips (wearing nitrile gloves), ensure that all the threads on the jar are clean, and then fasten the lid securely.
12. Label the sample jar and lid separately using the appropriate sample nomenclature. Information included on the container label should include: Sampler's initials, sample collection date, company name, sample site identification and/or unique Sample Identifier, desired analytical parameters, and preservation method. Wrap the label and container with clear packing tape.
13. Place the sample in a cooler chilled with ice (preferred) or ice packs for transport to the laboratory. If using ice, be aware that melted ice can result in damaged or destroyed labels and can also be a significant pathway for cross-contamination of samples. As such either the ice or the samples should be double-bagged and sealed.
14. Complete the sample submission and chain-of-custody forms. Chain-of-custody forms should be filled out in their entirety. Each cooler shipped should have its own chain-of-custody form listing only those samples contained in the cooler it pertains to. Chain-of-custody forms should be enclosed in their own re-sealable bag to protect them from possible water damage during shipment. Be sure to specify to the laboratory the analytical detection limit desired. Samples should be delivered to the laboratory within 24-hours if possible.

15. For field screening, split the sample or collect a replicate sample from each sampling location and place it in a sealable plastic bag and conduct vapour screening in accordance with SOP D1-2.
16. Record sample information including observations in the field book, soil sample log, or test pit log. Sample information should include sample identification, sample type, location (grid coordinates or scale drawing), depth, soil type, and sample date, visual and olfactory observations. Document site conditions and key observations using a camera.
17. Clean all sampling tools and replace gloves before collecting new samples.
18. Label a survey stake with the unique sample identifier and date and drive it firmly into the ground at the sampling location. In undeveloped areas, label a length of survey flagging tape and hang it from a nearby tree branch for better visibility and duplication of labelling. In developed areas, locations may be marked on nearby concrete or asphalt surfaces.
19. Dispose of all wastes (liquids, used gloves and materials) in an appropriate manner. **Leave the site in a tidy condition.**

7. References

ASTM D4700-15, 2015. Standard Guide for Soil Sampling from the Vadose Zone, ASTM International, West Conshohocken, PA.

Canadian Council of Ministers of the Environment (CCME), 2016. “Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment”. V.3, Suggested Operating Procedures.

The Interstate Technology and Regulatory Council (ITRC), 2012. *Incremental Sampling Methodology. ISM-1.* Washington, D.C.: Interstate Technology & Regulatory Council, Incremental Sampling Methodology Team. www.itrcweb.org.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Solid Stem Auger/Soil**	**Standard Operating Procedure for Solid Stem Auger Drilling Investigations**
Revision No: Original **Revision Date: 15 July, 2020**	**Reference No: SOP-D1-05** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for drilling investigations using a solid stem auger. Solid stem auger drilling is a rotary drilling method which advances an auger assembly below the ground surface at a low velocity rotation. As drilling progresses additional auger flights can be added to form a continuous flight. Soil samples can be collected from the lead auger after it is brought to the surface. Monitoring wells can be installed in the borehole as long as sloughing is limited. This drilling method is well suited for relatively soft or loose, shallow unconsolidated soil deposits. Drilling and/or sampling difficulties may be encountered during drilling in dense soils or soils with cobbles and boulders, and in loose sandy deposits below the water table. The workable maximum drilling depth of the solid stem auger (SSA) method is dependent on soil type, depth of water table, characteristics of the drill rig, and the drillers' technique, but is commonly about 20 m to 30 m in good conditions and much less in some soil types. Deeper penetrations may be achieved with the combination of ideal drilling conditions, and drill rig. Disturbed samples are collected directly from the augers' flights or, alternatively, less disturbed samples can be obtained from down-hole techniques provided the borehole does not collapse when the augers are removed.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on solid stem drilling investigations is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP. This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

The Water Sustainability Act (WSA) and the Groundwater Protection Regulation (GPR) are available at the following webpage:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/groundwater-protection-regulation.

Solid stem drilling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the WSA, the GPR, the CSR, Part D1 and Part E2 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Quality Control

- Refer to individual SOPs for appropriate quality control requirements for soil sample collection and handling and/or monitoring well installation.
- Follow equipment decontamination procedures outlined below to minimize the potential for cross contamination between samples or boreholes.
- Ensure that field notes (including field logs) are legible (recorded in ink where possible) and complete.
- Retain all field notes to ensure information reported is accurate and defensible.

4. Recommended Equipment and Materials

Field Equipment provided by driller:

1. Drill rig with solid stem augers and associated equipment;
2. High pressure washing equipment;
3. Methanol and mild detergent solution;
4. Bentonite and/or grout; and
5. Monitoring well construction materials (PVC pipe, silica sand, bentonite/grout, well protection casing, cement).

Field Equipment provided by personnel:

6. Results of previous field investigations, including borehole logs;
7. Other sample tools as appropriate (refer to SOP's as appropriate);
8. Suitable sample storage containers for the potential contaminants of concern (PCOC);
9. Digital camera/cell phone camera;
10. Site plan and underground utility location plan(s);
11. Field notebook;
12. Field log sheets;
13. Writing and marking utensils; and
14. Sample submission and chain-of-custody forms.

Personal Protective Equipment (PPE) and Safety Equipment:

15. CSA approved steel toed work boots or steel toed rubber boots;
16. Hard hat;
17. High visibility safety vest (when working around heavy equipment and traffic areas);
18. Long sleeves and long pants;
19. Gloves (appropriate to potential contaminants of concern; typically new, clean nitrile);
20. Eye protection (must meet client or site specific requirements for potential hazards, i.e., goggles if splash hazard, etc.);
21. Hearing protection (if heavy equipment or other potential sources of noise will be present);
22. First aid kit applicable to size of project;
23. Eye wash station;
24. Respirator (if applicable); and,
25. Fire/chemical retardant coveralls (if applicable).

5. Procedures

1. ***Preparation:*** Obtain authorization to access the site if needed and confirm that physical access to the site is possible (e.g., gates unlocked). Arrange subcontractors for traffic control, if required. Notify BC OneCall to confirm the locations of underground and above ground services. Have an underground utilities survey completed and have the contractor mark all underground services on the Site and produce an underground utilities locates drawings. Mark the locations of desired boreholes where possible and ensure the locations are at a safe distance from underground and overhead utilities and structures. Confirm that these locations are consistent with site plans. Confirm meeting time with the drilling subcontractor and review the list of required equipment. Assemble personal protective equipment, sampling tools, and data collected previously at or near the site. Review and understand the drilling objectives and scope of work. Ensure that arrangements have been made for the storage and or disposal of soil cuttings and fluids from decontamination/washing. Review the safety plan and ensure it is adequate for the site and scope of work.

2. ***Arrival On Site:*** If this is the first site visit, complete a reconnaissance of the project area, noting safety hazards, overhead services, site layout, topography, adjacent property, and equipment on site. Confirm the accuracy of the existing site plan and the utilities locates drawing. Record sufficient notes so that the site plan can be defended or improved. Take photographs and observe unexpected conditions which may impact the planned investigation (e.g., access problems). Note the names of subcontractors and record the equipment used on site. Visually inspect the subcontractor's equipment for cleanliness and proper working order. Ensure that cables are not frayed, and hydraulic lines do not exhibit leakage. Confirm that each piece of equipment has a properly functioning power kill switch and fire extinguisher, etc. If working in an ecologically sensitive area, insist that the drill rig be thoroughly cleaned prior to accessing the site, and inspect the drill rig for presence of soil, vegetation or seed pods, as invasive species may be introduced. Organize sample containers and prepare labels.

3. **Drilling Description:** When borehole locations are positioned on hard surfaces such as concrete or asphalt the surface must be cut before the auger is deployed. A concrete coring device is required to complete a clean cut through concrete while a fabricated cutting bit can be attached to the drill rig to cut through asphalt.

   A solid stem auger flight comprises a plugged or solid steel cylinder around which is welded a steel strip in the form of a helix. When connected, the flights form a continuous helix. The lead auger is equipped with a cutting head which typically is slightly larger in diameter than the auger column. The entire drilling assembly is connected to a drill head on the drill rig, and boreholes are advanced by a combination of rotation and downward pressure. Additional auger sections are added as required to form a continuous auger string. Auger fights are typically in 1.5 m (5 ft) sections, but drilling may be stopped at any depth for sampling. Solid stem auger sections are available in a range of diameters and are specified by the nominal diameter of the drill head. Borehole advancement is usually in 1.5 m to 3.0 m (5 ft to 10 ft) increments depending on in-situ soil conditions. Between increments the entire auger string is withdrawn for sample collection and soil classification.

4. ***Core Logging and Sampling:*** Begin drilling at the ‘clean background’ location if included in the drilling program. If a background location is not included in the drilling program drilling should begin at a location that theoretically is the site’s cleanest location proceeding to more contaminated locations. For a reasonable determination of sample depth, the augers must be advanced into the ground at a rate equal to the pitch of the helix (i.e., ensure that the augers are not over or under rotated). If the turning rate of the augers is too fast relative to the auger advancement, soil cuttings are "stretched" upwards from the drill bit, and accurate depth determination is not possible. Consideration should be given to collecting samples at changes in stratigraphy which can be inferred from changes in drilling action or cuttings, where visual or olfactory evidence of contamination is present, or at predetermined depths. Samples are obtained from the soil retained on the auger flight of the lead auger. To obtain representative sample material, scrape the face of the soil on the flight and collect samples from the freshly exposed material. Refer to soil collection SOP’s for specific sampling details.

   If the borehole remains open and clean (i.e., minimal sloughing or caving) samples may be collected by pushing or driving a sampling device into the undisturbed formation in front of the auger head, using the drill rig hydraulics, or a drop hammer. Sampling devices which can be used include the split spoon sampler (split-barrel drive sampler), Shelby tubes, piston samplers, Geoprobe®, ring-lined barrel sampler, or modified versions of the above. Precaution should be taken to avoid drilling through low permeable soil horizons resulting in cross contamination of underlying soils and groundwater.

5. ***Drill Cuttings:*** Excess drill cuttings are typically produced during drilling, or upon auger removal. Drill cuttings should be stockpiled, covered with plastic, or placed in barrels for later characterization and/or disposal. If placed in barrels, the barrels should be clean, open top steel drums, suitable for storing and transporting the type and weight of material (typically 17H standard) produced on site. The barrels should be labeled with the consultants’ and clients' names, the date, and a list of boreholes from which the cuttings originated. The location and number of barrels used should be recorded in field notes. In certain circumstances, cuttings may be returned to the borehole as backfill; however, this is only to occur with the client’s approval, and requires that the cuttings be uncontaminated and of a granular nature suitable for use as backfill.

6. ***Borehole Completion:*** If a monitoring well is to be installed, refer to SOP E2-2 for instruction. Otherwise, the borehole should be backfilled with bentonite/grout as site-specific conditions or client preferences warrant. In accordance with the Groundwater Protection Regulation a surface seal of bentonite or grout, at least 1 m thick if possible, should be placed at the ground surface of the drill hole to minimize infiltration of surface water to the drill hole. Backfilling with drill cuttings is to be avoided. A borehole filled with cuttings may result in a preferential vertical pathway, and contaminated cuttings placed in a borehole can result in groundwater contamination. Cuttings used as backfill in drill

holes often consolidate and or settle with time and can create a safety hazard to pedestrian traffic where a divot can form as the backfill settles or if the borehole is not properly completed near the ground surface. As such, in areas of pedestrian traffic, the drill hole should be completed with a concrete plug at the ground surface if cuttings are used in whole or in part as backfill.

7. ***Location Survey*:** At a minimum the borehole/monitoring well location should be accurately located relative to permanent site features and recorded in field notes and site plans. Generally, the location's northing, easting, ground elevation and top of casing elevation will also be surveyed or recorded with a GPS (including the level of accuracy).
8. ***Equipment Decontamination:*** Between each use, sampling devices must either be manually cleaned or cleaned with a high pressure steam cleaner to remove visible contamination or residual soil attached to the core barrel. Sampling devices should be visually inspected for cleanliness after washing. If an oily or tar-like residual film or smearing remains scrub the equipment with methanol, followed by scrubbing/rinsing using a laboratory grade detergent solution, followed by a double rinse with water. At some sites, it may be required that wash liquids are collected for later disposal.

   At the completion of each borehole, all down-hole equipment (augers) must be cleaned with a high pressure steam cleaner to remove visible contamination and residual soil stuck to the augers. The augers should be elevated off the ground (e.g., on lumber or work horses) during and after cleaning to prevent recontamination from the ground or spray-back during cleaning. If necessary, manual cleaning with stiff brushes, solvents and/or water may be required to remove stubborn soil and/or contamination. At some sites, it may be appropriate to collect wash liquids for later disposal.
9. *Store or dispose of all* ***wastes*** (liquids, cuttings, used gloves and materials) in an appropriate manner and leave the site in a tidy condition.

6. References

ASTM D1452 / D1452M-16, 2016. Standard Practice for Soil Exploration and Sampling by Auger Borings, ASTM International, West Conshohocken, PA.

ASTM D4700-15, 2015. Standard Guide for Soil Sampling from the Vadose Zone, ASTM International, West Conshohocken, PA.

CCME, 2016. Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment, Vol. 1: Guidance Manual, 331 pp.

Nielsen, D.M. (ed). 2006. Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring. 2nd Edition. CRC Press, Taylor & Francis Group, 1,318 pp.

ENV, 2018. British Columbia Field Sampling Manual. Environmental Protection Department, BC Ministry of Environment, Lands and Parks (BC ELP), Victoria, BC, Canada.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Hollow Stem Auger/Soils**	**Standard Operating Procedure for Hollow Stem Auger Drilling Investigations**
Revision No: Original Revision Date: 16 July, 2020	**Reference No: SOP-D1-06 Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for drilling investigations using a hollow stem auger. Hollow stem auger drilling is a common drilling method used for soil sampling and groundwater monitoring well installation. Hollow stem augers are constructed with an outer helical flight wound around and welded to a hollow shaft. The leading end of the auger is fit with a cutting head and plug. A drill rod may be inserted inside the hollow stem to accommodate various tools. The auger is rotated and forced downward to create and advance the borehole. As the borehole is advanced drill cuttings are brought to surface by the rotation of the auger flight. Additional auger sections are added to the drilling assembly as required to form a continuous auger flight. Auger fights are typically in 1.5 m (5 ft) sections, but drilling may be stopped at any depth for sampling. Samples may be obtained, and monitoring wells can be installed through the hollow shaft.

This SOP describes procedures associated with hollow stem auger drilling investigations. This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on hollow stem auger drilling is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP.

This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

The Water Sustainability Act (WSA) and the Groundwater Protection Regulation (GPR) are available at the following webpage:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/groundwater-protection-regulation.

Hollow stem auger drilling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the WSA, the GPR, the CSR, Part D1 and Part E2 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Quality Control

- Refer to individual SOPs for appropriate quality control requirements for sample collection and handling.
- Follow equipment decontamination procedures outlined below to minimize the potential for cross contamination between samples or boreholes.
- Ensure that field notes (including field logs) are legible (recorded in ink where possible) and complete.
- Retain all field notes to ensure information reported is accurate and defensible.

4. Recommended Equipment and Materials

Field Equipment provided by driller:

1. Drill rig with hollow stem augers and associated equipment;
2. Concrete corer if required;
3. Safety equipment (safety cage, cones, signage, etc.);
4. Clean water or accessibility to a clean water source;
5. High pressure washing equipment;
6. Methanol and mild detergent solution;
7. Bentonite and/or grout;
8. Cement and or asphalt patch if drilling through roads, pads or parking lots; and,
9. Monitoring well construction materials (PVC pipe, silica sand, bentonite/grout, well protection casing, cement).

Field Equipment provided by personnel:

10. Results of previous field investigations, including borehole logs;
11. Other sample tools as appropriate (rock hammer, hand lens, scraper, rock chisel, etc.);
12. Suitable sample storage containers for the potential contaminants of concern (PCOC);
13. Digital camera/cell phone camera;
14. Site plan and underground utility location plan(s);
15. Field notebook;
16. Field log sheets;
17. Writing and marking utensils; and,
18. Sample submission and chain-of-custody forms.

Personal Protective Equipment (PPE) and Safety Equipment:

19. CSA approved steel toed work boots or steel toed rubber boots;
20. Hard hat;
21. High visibility safety vest (when working around heavy equipment and traffic areas);
22. Long sleeve shirt and long pants;
23. Gloves (appropriate to potential contaminants of concern); typically, new, clean nitrile;
24. Eye protection (must meet client or site specific requirements for potential hazards, i.e., goggles if splash hazard, etc.);
25. Hearing protection (if heavy equipment or other potential sources of noise); and
26. First aid kit applicable to size of project.

5. Procedures

1. ***Preparation:*** Obtain authorization from the Owner for site access, if needed, and confirm that physical access to the site is possible (e.g., gates unlocked). Arrange subcontractors for traffic control, if required. Notify BC OneCall to confirm the locations of underground and above ground services. Have an underground utilities survey completed and have the contractor mark all underground services on the Site and produce an underground utilities locates drawing. Mark the locations of desired boreholes where possible and ensure the locations are at a safe distance from underground and overhead utilities and structures. Confirm that these locations are consistent with site plans. Confirm meeting time with the drilling subcontractor and review the list of required equipment. Assemble personal sampling tools. Review and understand the drilling objectives, previous data collected at, or near the site and the scope of work. Ensure that a competent plan is in place to deal with the cuttings from the investigation and fluids from decontamination/washing. Review the safety plan and ensure it is adequate for the site and scope of work.

2. ***Arrival On Site:*** If this is the first time on site, complete a reconnaissance of the project area, noting safety hazards, overhead services, site layout, topography, adjacent property, structures and equipment on site. Confirm the accuracy of the existing site plan, and the utility locates drawings. Record sufficient notes so that the site plan can be defended or improved. Take photographs and observe unexpected conditions such as limited access which may impact the planned investigation. Note the names of subcontractors and record the equipment used on site. Visually inspect the subcontractor's equipment for cleanliness and proper working order. Ensure that cables are not frayed, and hydraulic lines do not exhibit leakage. Confirm that each piece of equipment has a properly functioning power kill switch and fire

extinguisher, etc. If working in an ecologically sensitive area, insist that the drill rig be thoroughly cleaned prior to accessing site, and inspect drill rig for presence of soil, vegetation or seed pods, as invasive species may be introduced. Organize sample containers and prepare labels.

3. ***Drilling Description:*** When borehole locations are positioned on hard surfaces such as concrete or asphalt the surface must be cut before the auger is deployed. A concrete coring device is required to complete a clean cut through concrete while a fabricated cutting bit can be attached to the drill rig to cut through asphalt.

   Hollow stem drilling involves an inner and outer drilling assembly. The outer drilling assembly consists of a lead hollow stem auger fit with a cutter head equipped with carbide teeth. A drill rod is typically fit inside the hollow stem auger. The drill rod is fit with a plug equipped with carbide teeth. The entire drilling assembly is connected to a drill head on the drill rig which rotates the drill string and forces it downward to cut through the surface and advance the borehole. Additional augers and rods are added as required to reach the target depth of investigation. Augers are typically in 1.5 m (5 ft) in length, but drilling may be stopped at any depth for sampling. Hollow auger sections are available in a range of diameters, which are specified by the inside diameter of the auger.

4. ***Core Logging and Sampling:*** The first borehole should be drilled at a location that is deemed to be “cleanest”. To mitigate the potential for cross contamination, drilling should proceed from the cleanest location to the most contaminated location. Consideration should be given to collecting samples at changes in stratigraphy or at predetermined depths.

   The entire drill assembly is positioned over the borehole location where it is rotated and lowered by hydraulic force to advance the borehole to the top of the desired sample depth. When the drill assembly has reached the top of the sample depth or “interval”, the drill assembly rotation and downward pressure halts and the inner assembly (rods and plug) is withdrawn. A sample device is attached to the drill rods or wire line and lowered through the centre (hollow stem) of the augers and cutter head (outer drill assembly). A sample is collected by pushing or driving the sampler into the exposed and undisturbed formation using the drill rig’s hydraulics or drop hammer. The most common sampling device used is the split spoon sampler (split-barrel drive samplers). Other types of samplers which are more commonly used in geotechnical investigations include Shelby tubes, piston samplers, Geoprobes®, ring-lined barrel samplers, or modified versions of the above.

5. ***Drill Cuttings:*** Excess drill cuttings are typically produced during drilling, or upon auger removal. Drill cuttings should be stockpiled and covered with plastic or placed in barrels for later characterization and/or disposal. If placed in barrels, the barrels should be clean, open top steel drums with securable lids, suitable for storing and transporting the type and weight of material (typically 17H standard). The barrels should be labeled with the client's name, the date, and a list of boreholes from which the cuttings originated, as a minimum. The location and number of barrels used should be recorded in field notes. In certain circumstances, cuttings may be returned to the borehole as backfill; however, this is only to occur with client approval, and requires that the cuttings be uncontaminated and of a granular nature suitable for use as backfill.

6. ***Borehole Completion:*** If a monitoring well is to be installed, refer to SOP E2-2 for instruction. Ensure that the amount of water used during drilling is recorded, as this volume will have to be removed during well development. Otherwise the borehole may be backfilled, typically with bentonite/grout. If the borehole extends below the water table, the use of bentonite pellets or grout through the saturated interval is recommended to ensure a good seal and to prevent bridging. Bentonite chips may also be placed in the borehole using a tremmie pipe, to limit the possibility of bridging. In areas where recontamination may occur, it is recommended that the borehole be backfilled to near ground surface with bentonite or grout. In accordance with the Groundwater Protection Regulation (GPR) a surface seal of bentonite or grout, at least 1 m thick if possible, should be placed at the ground surface of the borehole to minimize infiltration of surface water into the borehole. Backfilling with drill cuttings is to be avoided. A borehole filled with cuttings may result in a preferential vertical pathway, and contaminated cuttings placed in a borehole can result in groundwater contamination. Cuttings used as backfill in boreholes often consolidate and or settle with time and can create a safety hazard to pedestrian traffic where a divot can form as the backfill settles or if the borehole is not properly completed near the ground surface. As such, in areas of pedestrian traffic, the drill hole should be completed with a concrete plug at the ground surface if cuttings are used in whole or in part as backfill.

7. ***Location survey*:** At a minimum the borehole/monitoring well location should be accurately located relative to permanent site features and recorded in field notes and site plans. Generally, the location’s northing, easting, ground elevation and top of casing elevation will be surveyed or recorded with a GPS unit (including the level of accuracy).

8. ***Equipment Decontamination:*** Sample devices must be cleaned by scrubbing or high pressure steam to remove visible contamination and or residual soil that may be attached to the device. Decontamination must be conducted between each use. The sample device/s should be visually inspected for cleanliness after each cleaning procedure. If an oily film, tar-like residual film or smearing persists the device must be scrubbed with methanol, then scrubbed or rinsed with a laboratory grade detergent solution, followed by a double rinse with water. If contamination is suspected, wash liquids should be collected for proper disposal.

   At the completion of each borehole the drill assembly parts, including the inside and outside of the hollow augers, must be cleaned with a high pressure steam cleaner to remove visible contamination and residual soil. The drill assembly parts should be elevated off the ground during and after cleaning to prevent recontamination from the ground or spray-back during cleaning. If necessary, manual cleaning with stiff brushes, solvents and/or water may be required to remove stubborn soil and/or contamination. At some sites, it may be appropriate to collect wash liquids for later disposal.

9. ***Store or dispose of all wastes:*** liquids, cuttings, used gloves and other spent materials must be stored or disposed of in an appropriate manner. **Leave the site in a tidy condition.**

10. **Site security:** Boreholes not completed by days end must be secured to ensure that precipitation cannot enter the borehole. Additionally, cuttings, drill rigs and other materials left on site should be reasonably secured against vandalism; specifically acts that may impact the investigation and or environmental integrity of the site. Boreholes in public space such as roadways and sidewalks must further be secured to protect human health.

6. References

ASTM D5784 / D5784M-13, 2013. Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices, ASTM International, West Conshohocken, PA.

ASTM D4700-15, 2015. Standard Guide for Soil Sampling from the Vadose Zone, ASTM International, West Conshohocken, PA.

CCME, 2016. Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment, Vol. 1: Guidance Manual, 331 pp.

Nielsen, D.M. (ed). 2006. Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring. 2nd Edition. CRC Press, Taylor & Francis Group, 1,318 pp.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Vibrasonic/Soil**	**Standard Operating Procedure for Vibrasonic Drilling Investigations**
Revision No: Original **Revision Date: 16 July, 2020**	**Reference No: SOP-D1-07** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for vibrasonic drilling investigations. Vibrasonic drilling is a rapid drilling method that can provide continuous core samples in most geologic settings. The vibrasonic drill rig is similar to a conventional rig, although the drill head has an oscillator which applies a high frequency vibration as well as a mechanism for rotary motion. The operator controls the vibration frequency to obtain a balance between a high drilling rate and optimal core recovery. In unconsolidated material, the drill bit vibrations cause the surrounding soil to act as a fluid, allowing borehole advancement. In bedrock, the vibratory movement causes the rock to fracture, which creates rock dust and small rock fragments as the drill bit is advanced. Borehole advancement using an outer casing can mitigate cross-contamination and borehole collapse. Continuous core samples are collected directly from the recovered core.

Figure 1 - Vibrasonic drill rig.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on vibrasonic drilling investigations is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP.

Additional information is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

The Water Sustainability Act (WSA) and the Groundwater Protection Regulation (GPR) are available at the following webpage:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/groundwater-protection-regulation.

Vibrasonic drilling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the WSA, the GPR, the CSR, Part D1 and Part E2 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

This SOP and the B.C. Field Sampling Manual are available at: www2.gov.bc.ca.

3. Quality Control

- Refer to individual SOPs for appropriate quality control requirements for sample collection and handling.
- Follow equipment decontamination procedures outlined below to minimize the potential for cross contamination between samples or boreholes.
- Ensure that field notes, including field logs, are legible (recorded in ink where possible) and complete.
- Retain all field notes to ensure that the information reported is accurate and defensible.

4. Recommended Equipment and Materials

Figure 2. Vibrasonic core barrels.

Field Equipment provided by driller:

1. Drill rig;
2. Safety equipment (safety cage, cones, signage, etc.);
3. Core barrel;
4. Drill bit;
5. Drill casing and associated equipment;
6. High pressure washing equipment;
7. Clean water or accessibility to a clean water source;
8. Methanol and mild detergent solution;
9. Bentonite and/or grout; and
10. Monitoring well construction materials (PVC pipe, silica sand, bentonite/grout, well protection boxes, cement).

Field Equipment provided by personnel:

Figure 3. Vibrasonic drill bit.

11. Results of previous field investigations, including borehole logs;
12. Sharp knife;
13. Other sample tools as appropriate (rock hammer, hand lens, scraper, rock chisel, etc.);
14. Suitable sample storage containers for the potential contaminants of concern (PCOC);
15. Digital camera/cell phone camera;
16. Site plan and underground utility location plan(s);
17. Field notebook;
18. Field log sheets;
19. Writing and marking utensils; and,
20. Sample submission and chain-of-custody forms.

Personal Protective Equipment (PPE) and Safety Equipment:

21. CSA approved steel toed work boots or steel toed rubber boots;
22. Hard hat;
23. High visibility safety vest (when working around heavy equipment and traffic areas);
24. Long sleeve shirt and long pants;
25. Gloves (appropriate for potential contaminants of concern; typically, new, clean nitrile);
26. Eye protection (must meet client or site specific requirements for potential hazards, i.e., goggles if splash hazard, etc.);
27. Hearing protection for heavy equipment and other potential sources of noise; and,
28. First aid kit applicable for the size of project.

5. Procedures

1. ***Preparation:*** Obtain authorization from the Owner for site access, if needed, and confirm that physical access to the site is possible (e.g., gates unlocked). Arrange subcontractors for traffic control, if required. Confirm the locations of underground and above ground service structures and ensure they are marked with spray paint or other products. Mark the locations of planned boreholes where possible and ensure the locations are at a safe distance from underground and overhead structures. Confirm that these locations are consistent with site plans. Confirm meeting time with the drilling subcontractor and review the list of required equipment. Assemble personal sampling tools. Review and understand the drilling objectives, previous data collected at, or near the site and the scope of work. Ensure that a competent plan is in place to deal with the cuttings from the investigation and fluids from decontamination/washing. Review the safety plan and ensure it is adequate for the site and scope of work.

2. ***Arrival On Site:*** If this is the first time on site, complete a reconnaissance of the project area, noting layout, topography, adjacent property, and equipment on site. Confirm the accuracy of the existing site plan, and the utility locates drawings. Record sufficient notes so that the site plan can be defended or improved. Take photographs and observe unexpected conditions such as access limitations which may impact the planned investigation. Note the names of subcontractors and record the equipment used on site. Visually inspect subcontractor equipment for cleanliness and proper working order. Ensure the equipment does not exhibit frayed cables, leaking hydraulics, etc., and that required safety equipment such as power kill switches and fire extinguishers are present and operational. If working in a sensitive ecological area, insist that the drill rig be thoroughly cleaned prior to accessing the site, and inspect the drill rig for presence of soil, vegetation and seed pods to mitigate the potential for invasive species contamination. Organize sample containers and prepare labels.

Figure 4. Recovery of Vibrasonic core.

3. ***Drilling Description:*** The vibrasonic drilling technique, referred to as "Core and Case", involves advancing a core barrel with an inner string and over casing with an outer string, which prevents borehole collapse during core barrel retrieval. The over casing is only needed if the borehole does not remain open. The core barrels are available in single wall for dry coring, dual wall for hard rock sampling with either water, air or drilling mud, and are also available with clear lexan liners. Typically, drilling involves a 3 m (10 ft) long, 115 mm OD core barrel and optional 1.5 m (5 ft) and 3 m (10 ft) long, 165 mm OD outer casings, although smaller rigs may use shorter core barrels. The core barrel is fitted with a bit and, if necessary, a core catcher. For drilling to depths of less than 2.4 m (8 ft) depth, the core barrel is connected directly to the vibrasonic drill head. For deeper boreholes core barrel extensions are added between the drill head and the core barrel. Advancement is achieved by a combination of variable, high frequency vertical vibrations, variable rotation, and/or downward pressure. The first run can reach a depth of 2.4 m (8 ft). Beyond that depth borehole advancement is achieved in intervals of up to 3 m (10 ft). Boreholes can also be advanced by plugging the core barrel and displacing soil as the core barrel is advanced until a target depth is reached, at which point the plug can be removed and the core collected. This technique is useful for installing monitoring wells without soil sampling, or to advance the borehole to the top of a zone of interest.

4. ***Use of a hydrovac:*** If water is used during vibrasonic drilling, a hydrovac unit can be deployed to collect excess water and sediment as it leaves the borehole. This is usually required if contamination is expected, or where drilling takes place in an area where waste cannot be left on ground surface.

5. ***Core Logging and Sampling:*** Begin drilling in the suspected "cleanest" location and proceed to the more contaminated locations. Core sample recovery is highly dependent on the drillers' technique and experience, and subsurface conditions. To minimize uncertainties associated with lost core material, borehole advancement should initially be limited to 1.5 m (5 ft) intervals, until adequate recovery is demonstrated, or noticeable changes in stratigraphy are observed. After the core barrel is advanced to the limit of the run, the core barrel and extensions are withdrawn from the borehole. The recovered core is extruded from the core barrel into a polyethylene (plastic) sock. The extruded core is moved to a suitable horizontal location and the plastic sock is cut longitudinally to expose the core. As a result of the drilling technique, the outer surface of the core may be smeared or disturbed, and stratigraphic detail may be obscured. For this reason, the core should be split longitudinally to expose a fresh surface for logging.

Figure 5. Vibrasonic core sample.

   The exposed core should be photographed with markers placed to identify the depth at top and bottom of the core run, and to identify the borehole number and the project number.

   Consideration should be given to collecting samples at changes in stratigraphy as inferred from changes in drilling action or cuttings, or at predetermined depths (e.g., continuous, every 0.75m or 1.5 m). Samples collected for laboratory or headspace analysis can be collected directly from the recovered core. Laboratory and headspace samples should be collected from the inner portion of the core where possible to minimize the potential for outer core surface contamination that can result from shallower soils or from liquids co-recovered in the core run.

Information specific to this method of drilling which should be recorded include the length of run and the length of core recovered. During extrusion, the core will have a tendency to compress or lengthen and these details should be recorded in field notes and or borehole logs to account for this. If possible, an opinion should be made of the depth interval in the run in which missing core material occurs if core recovery is not 100%. Core recovery should be recorded on the borehole log. In some cases, this may be obvious, for instance drilling from a dense material into a softer material may result in core displacement rather than recovery. Precautions should be taken to avoid drilling through low permeable soil horizons which may result in cross contamination of underlying soils and groundwater. Discuss procedures with project manager if these geological conditions are expected (i.e., before drilling begins).

6. **Drill Cuttings:** Excess soil is typically produced during borehole advancement. Drill cuttings should be stockpiled and placed in drums or soil bags for later characterization and/or disposal. If placed in drums or soil bags, the containers should be labeled. Labels should as a minimum include the client's name, drilling date, and a list of boreholes from which the cuttings originated. For ease of removal, soil bags should be placed on pallets, particularly where ground freezing is possible. The location and number of drums/soil bags used should be recorded in field notes. In certain circumstances, cuttings may be returned to the borehole as backfill; however, this is only to occur with cuttings that are not contaminated and are of a granular nature suitable for use as backfill. Appropriate cuttings should only be used as borehole backfill material with the approval of the project manager and the client.

7. ***Borehole Completion:*** If a monitoring well is to be installed, refer to SOP E2-2 for detailed instruction. Ensure that the amount of water used during drilling is recorded, as this volume will have to be removed during well development. Otherwise the borehole may be backfilled, typically with bentonite/grout, although intervals of clean sand may be acceptable as site-specific conditions or client preferences warrant. If the borehole extends below the water table, the use of bentonite pellets or grout through the saturated interval is recommended to ensure a good seal and to prevent bridging. Bentonite chips may also be placed in the borehole using a tremmie pipe, to limit the possibility of bridging. In areas where recontamination may occur, it is recommended that the borehole be backfilled to near ground surface with bentonite or grout. In accordance with the Groundwater Protection Regulation (GPR) a surface seal of bentonite or grout, at least 1 m thick if possible, should be placed at the ground surface of the drill hole to minimize infiltration of surface water to the drill hole. Backfilling with drill cuttings is to be avoided. A borehole filled with cuttings may result in a preferential vertical pathway, and contaminated cuttings placed in a borehole can result in groundwater contamination. Cuttings used as backfill in boreholes often consolidate and or settle with time and can create a safety hazard to pedestrian traffic where a divot can form as the backfill settles or if the borehole is not properly completed near the ground surface. As such, in areas of pedestrian traffic, the drill hole should be completed with a concrete plug at the ground surface if cuttings are used in whole or in part as backfill.

8. ***Location survey***: At a minimum the borehole/monitoring well location should be accurately located relative to permanent site features and recorded in field notes, and on the site plan. Generally, the location's northing, easting, ground elevation and top of casing elevation will be surveyed or recorded with a GPS unit (including the level of accuracy).

9. ***Equipment Decontamination:*** Between each use, sampling devices must be cleaned manually or cleaned with a high pressure steam cleaner to remove visible contamination or residual soil attached to the core barrel. The sampling devices should be visually inspected for cleanliness after washing. If an oily film, tar-like residual film or smearing remains the device should be cleaned by scrubbing with methanol, followed by scrubbing/rinsing using a laboratory grade detergent solution, followed by a double rinse with water.

   If the sampling device was used in potentially contaminated soils the wash liquids should be collected for proper disposal by a qualified waste hauler.

   At the completion of each borehole, all down-hole equipment (core barrel, casing, extensions) must be cleaned with a high pressure steam cleaner to remove visible contamination and residual soil stuck to the equipment. The inside and outside of the core barrel and core barrel extensions should be cleaned. The equipment should be elevated off the ground (e.g., on lumber or work horses) during and after cleaning to prevent recontamination from the ground or spray-back during cleaning. If necessary, manual cleaning with stiff brushes, solvents and/or water may be required to remove stubborn soil and/or contamination. At some sites, it may be appropriate to collect wash liquids for later disposal.

10. ***Store or dispose of all wastes:*** Liquids, cuttings, used gloves and materials must be stored in an appropriate manner in preparation for proper disposal. **Leave the site in a tidy condition.**

11. **Site security:** Boreholes not completed by days end must be secured to ensure that precipitation cannot enter the borehole. Additionally, cuttings, drill rigs and other materials left on site should be reasonably secured against vandalism; specifically acts that may impact the investigation and or environmental integrity of the site. Boreholes in public space such as roadways and sidewalks must further be secured to protect human health.

6. References

ASTM D6914/D6914M – 16, 2016. Standard Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices, ASTM International, West Conshohocken, PA, 2016.

ASTM D4700-15, 2015. Standard Guide for Soil Sampling from the Vadose Zone, ASTM International, West Conshohocken, PA.

Nielsen, D.M. (ed). 2006. Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring. 2nd Edition. CRC Press, Taylor & Francis Group, 1,318 pp.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Direct Push/Soil**	**Standard Operating Procedure for Direct-Push Borehole Investigations**
Revision No: Original **Revision Date: 17 July, 2020**	**Reference No: SOP-D1-08** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for direct-push borehole investigations. Direct push technology, also known as direct drive, drive point, or push technologies, refers to a family of tools used for subsurface investigations by driving, pushing, or vibrating narrow tooling into the ground.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on Direct Push Technologies for drilling investigations is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP. This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information on soil investigations is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

The Water Sustainability Act (WSA) and the Groundwater Protection Regulation (GPR) are available at the following webpage:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/groundwater-protection-regulation.

Direct push drilling investigations conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the WSA, the GPR, the CSR, Part D1 and Part E2 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Principle of the Sampling Method

Direct-push technology includes a wide range of tools mounted on steel rods that are driven into the subsurface using hydraulic, percussive, or vibratory/sonic methods. Direct-push technology is used to investigate soil, soil vapour, and groundwater properties. This type of technology offers a number of advantages over traditional drilling methods, including rapid, high density data collection, acquisition of continuous logs (e.g., soil description, permeability, conductivity, NAPL presence, volatile parameters), and the collection of discrete soil-gas, soil, and groundwater samples while drilling. Very little excess soil cutting material is produced with this investigation technique. In addition to improved soil logging capabilities, the method can be used to install conventional monitoring wells using prepacked screens, as well as small diameter temporary monitoring wells. Direct push equipment can be track mounted, mounted on a pickup truck, or can be manually handled in limited access situations.

The maximum depth achievable with direct push methods depends on the weight of the carrying vehicle and the density and consistency of the soil. Penetration depth in soils with gravel or cobbles or in dense, highly compacted soil will be limited, and may result in equipment damage. In appropriate soil (e.g., clay, silt, sand), penetration depths of 20 to 50 m can typically be achieved.

4. Quality Control

- Refer to individual SOPs for appropriate quality control requirements for sample collection and handling.
- Follow equipment decontamination procedures outlined below to minimize the potential for cross contamination between samples or boreholes.
- Ensure that field notes, including field logs, are legible (recorded in ink where possible) and complete.
- Retain all field notes to ensure that the information reported is accurate and defensible.

5. Recommended Equipment and Materials

Field Equipment provided by driller:

1. Drill rig with core barrel and associated equipment;
2. Safety equipment (safety cage, cones, signage, etc.);
3. Clean water or accessibility to a clean water source;
4. High pressure washing equipment;
5. Methanol and mild detergent solution;
6. Bentonite and/or grout; and,
7. Monitoring well construction materials (PVC pipe, silica sand, bentonite/grout, well protection casing, cement) if required.

Field Equipment provided by personnel:

8. Results of previous field investigations, including borehole logs;
9. Other sample tools as appropriate (refer to SOP's as appropriate);
10. Suitable sample storage containers for the potential contaminants of concern (PCOC);
11. Digital camera/cell phone camera;
12. Site plan and underground utility location plan(s);
13. Field notebook;
14. Field log sheets;
15. Writing and marking utensils; and,
16. Sample submission and chain-of-custody forms.

Personal Protective Equipment (PPE) and Safety Equipment:

17. CSA approved steel toed work boots or steel toed rubber boots;
18. Hard hat;
19. High visibility safety vest (when working around heavy equipment and traffic areas);
20. Long sleeve shirt and long pants;
21. Gloves (appropriate for potential contaminants of concern; typically new, clean nitrile);
22. Eye protection (must meet client or site specific requirements for potential hazards, i.e., goggles if splash hazard, etc.);
23. Hearing protection (if heavy equipment or other potential sources of noise may be encountered);
24. First aid kit applicable to size of project;
25. Eye wash station;
26. Respirator (if applicable); and,
27. Fire/chemical retardant coveralls (if applicable).

6. Sampling Considerations

- Direct-push drilling methods are best suited to shallow soil investigations (i.e., less than 30 m), where the expected deposits are predominantly clay, silt, and sand.
- A multitude of tooling and combinations of tooling are available. Selection of tools should be based on the projects objectives. There is a considerable cost when using continuous logging methods (e.g., MIP), however, the near real-time data acquisition can be valuable at complex sites and may in these circumstances be cheaper in the end.
- Potential tooling includes:
    - Dual tube (for collecting soil cores);
    - Electrical conductivity (to screen for presence/distribution of inorganic impacts);

- Laser induced fluorescence (to visually identify NAPL);
- Membrane interface probe (to screen for presence/distribution of volatile organics);
- Hydraulic profiling (to identify layers of high and low permeability); and,
- Direct-push monitoring wells (used to obtain groundwater samples during investigation, can be removed and re-used, or left in place).

7. Procedures

Figure 8. Direct push track-mounted drilling rig.

1. ***Preparation:*** Obtain authorization from the Owner for site access, if needed, and confirm that physical access to the site is possible (e.g., gates unlocked). Arrange subcontractors for traffic control, if required. Notify BC OneCall to confirm the locations of underground and above ground services. Have an underground utilities survey completed and have the contractor mark all underground services on the Site and produce an underground utility locates drawing. Confirm the locations of underground and above ground services. Confirm meeting time with the drilling subcontractor and review the list of required equipment. Assemble personal sampling tools. Review and understand the drilling objectives, previous data collected at, or near the site and the scope of work. Ensure that a competent plan is in place to deal with the cuttings generated from the drilling investigation and the fluids from decontamination/washing. Also note that several types of direct push tooling and specifications exist; the specific system being used at the site and the project specific objectives should be established and understood prior to the commencement of field work.

2. ***Arrival On Site:*** If this is the first time on site, complete a reconnaissance of the project area, noting safety hazards, layout, topography, adjacent property, and equipment on site. Confirm the accuracy of the existing site plan and the utility locates drawings. Record sufficient field notes so that the site plan can be defended or improved. Take photographs and observe unexpected conditions such as access problems which may impact the planned investigation. Note the names of subcontractors and record the equipment used on site. Visually inspect subcontractor's equipment for cleanliness and proper working order. Ensure equipment does not exhibit frayed cables, leaking hydraulics etc. and ensure that required safety equipment such as power kill switches and fire extinguishers are functional. If working in an ecologically sensitive area, insist that the drill rig be thoroughly cleaned prior to accessing the site, and inspect the drill rig for presence of soil, vegetation and seed pods to mitigate the potential for invasive species contamination. Organize sample containers and prepare labels.

3. ***Drilling Description:*** Most often the direct push method is used to provide a continuous soil core, which can be described and logged, field screened for indicators of contamination, and sampled for detailed laboratory analysis. For these programs, the Geoprobe® DT45 (dual tube 4.5") tooling and sampling system is the most commonly used tool and is described herein. The DT45 outer casing has a 114 mm (4.5") OD with either a fixed 127 mm (5") sampling cutting shoe or a 127 mm (5") expendable cutting shoe holder. Samples are typically collected by a 1.5 m (5 ft) long, 76 mm OD sample sheath with a hydrocarbon resistant PVC liner. The sheath and liner are placed against the cutting shoe within the outer casing and held in place with either 1.25" or 2.25" probe rods. The sample sheath will be fitted with a core catcher if necessary. Advancement is achieved by a combination of percussion and downward pressure generally in 1.5 m intervals. An expendable cutting shoe holder and shoe will be required in order to install a monitoring well within the outer casing. The expendable cutting shoe will be pushed out of the holder after soil sampling has been concluded and before the monitoring well is installed. The shoe which is composed of stainless steel will remain below the monitoring well. Boreholes can also be advanced by plugging the expendable cutting shoe with a point drive tip, displacing soil as the outer casing and sample sheath are advanced until a target depth is reached, at which point the drive tip can be pushed from the expendable cutting shoe holder. The point drive tip which is composed of stainless steel will remain below the monitoring well. This technique is useful for caving ground conditions, or to advance the borehole to the top of a zone of interest but does not allow for all samples to be collected as the borehole is advanced.

4. ***Core Logging and Sampling:*** Begin drilling in the suspected "cleanest" location and proceed to the more contaminated locations. Core sample recovery is highly dependent on the drillers' technique and experience, and subsurface conditions. After the sample sheath is advanced to the limit of the run, the core barrel is withdrawn from the outer casing. The PVC or brass sleeve inserted into the sample sheath contains the core sample and is extracted from the

sample sheath. The core sample is moved to a suitable horizontal location for examination and logging. In most cases, PVC is used for collection and then cut laterally along two opposing sides to expose the core for examination and sampling. In some situations, it may be desirable not to split the sleeve and core longitudinally. It is important to note that inherent with this drilling technique, the outer surface of the core may be smeared or disturbed which in turn may obscure stratigraphic detail. As such, the core should be split longitudinally to expose a fresh inner surface for logging. Soil should be logged in accordance with SOP D1-1: Soil Classification.

After cutting the PVC sleeves longitudinally the cores soil is exposed and accessible for transfer into appropriate sample containers. Field screening can take place to identify indicators of contamination such as conductivity and volatile organics. The outer surface of the core may include contamination from soils above the target depth and from liquids co-recovered in the core run. To mitigate the potential of including contamination which may be present on the outer core, laboratory and field samples should be collected from the inner portion of the core. Field screening and sampling should be conducted in accordance with applicable SOPs.

5. ***Record Keeping:*** Information specific to this method of drilling which should be recorded includes the length of the run and the length of core recovered. If possible, an estimate should be made of the depth interval in the run in which non-recovered (i.e., missing) core material occurred in situations when core recovery is not 100%. In some cases, this may be obvious, for instance drilling from a dense material into a softer material may result in core displacement rather than recovery. Precautions should be taken to avoid drilling through low permeable soil horizons that could result in the cross-contamination of underlying soils and groundwater. Confirm expected geological conditions prior to drilling.

6. ***Drill Cuttings:*** Excess soil core material is typically produced during drilling. Drill cuttings should be stockpiled and covered with plastic or placed in barrels for later characterization and/or disposal. If placed in barrels, the barrels should be clean, open top steel drums, suitable for storing and transporting the type and weight of material (typically 17H standard). The barrels should be labeled with the names of the consultant and the client, drilling date, and a list of the boreholes from which the cuttings originated, as a minimum. The location and number of barrels used should be recorded in field notes. In certain circumstances cuttings that are uncontaminated and of a granular nature suitable for use as backfill may be returned to the borehole as backfill; however, this is only to occur with the approval of both the project manager and client.

7. ***Borehole Completion:*** If a monitoring well is to be installed, refer to SOP E2-2 for instruction. However, with this investigation technique, monitoring well construction is limited to the use of small diameter (e.g., 18 mm) casings and screens. In caving ground conditions, monitoring wells are installed through the core barrel and extension rods which are then withdrawn, otherwise the monitoring wells are installed in the open hole. Controlled placement of filter packs and bentonite seals is possible, provided that the borehole does not collapse. Alternatively, a pre-packed screen assembly can be used if borehole collapse around the screen is anticipated.

   If a monitoring well is not required, the borehole should be backfilled with bentonite/grout as site-specific conditions or client preferences warrant. In accordance with the GPR, a surface seal of bentonite or grout, of at least 1 m thick if possible, should be placed at ground surface of the borehole to minimize infiltration of surface water. Backfilling with drill cuttings is to be avoided. A borehole filled with cuttings may result in a preferential vertical pathway, and contaminated cuttings placed in a borehole can result in groundwater contamination. Cuttings used as backfill in drill holes often consolidate and or settle with time and can create a safety hazard to pedestrian traffic where a divot can form as the backfill settles or if the borehole is not properly completed near the ground surface. As such, in areas of pedestrian traffic, the drill hole should be completed with a concrete plug at the ground surface if cuttings are used in whole or in part as backfill.

8. ***Location Survey*:** At a minimum the borehole/monitoring well location should be accurately located relative to permanent site features in field notes, and on the site plan. Generally, the location’s northing, easting, ground elevation and top of casing elevation will also be surveyed or recorded with a GPS (including the level of accuracy).

9. ***Equipment Decontamination:*** Between each use, sampling devices must be manually cleaned or cleaned with a high pressure steam cleaner to remove visible contamination or residual soil attached to the core barrel. The sample devices should be visually inspected for cleanliness after washing. If an oily film, tar-like residual film or smearing remains on the device it should be removed by scrubbing the equipment with methanol, followed by scrubbing/rinsing using a laboratory grade detergent solution, followed by a double rinse with water. At some sites, it may be required that wash liquids are collected for later disposal.

   At the completion of each borehole, all down-hole equipment must be cleaned with a high pressure steam cleaner to remove visible contamination and residual soil that may be stuck to the core barrel. If necessary, a manual cleaning with stiff brushes, solvents and/or water may be required to remove stubborn soil and/or contamination. At some sites, it may be appropriate to collect the wash liquids for later disposal.

10. ***Store or dispose of all wastes:*** liquids, cuttings, used gloves and materials must be stored or disposed of in an appropriate manner. **Leave the site in a tidy condition.**
11. **Site security:** Boreholes not completed by days end must be secured to ensure that precipitation cannot enter the borehole. Additionally, cuttings, drill rigs and other materials left on site should be reasonably secured against vandalism; specifically acts that may impact the investigation and or environmental integrity of the site. Boreholes in public space such as roadways and sidewalks must further be secured to protect human health.

6. References

ASTM D6282, 2014. Standard Guide for Direct Push Soil Sampling for Environmental Site Characterization. American Society for Testing and Materials. West Conshohocken, PA, 19 pp.

Geoprobe DT45 Dual Tube Sampling System, Standard Operating Procedure. Technical Bulletin No. MK3176. Geoprobe Systems. 2010.

Ohio Environmental Protection Agency. 2005. Chapter 15: Use of Direct Push Technologies for Soil and Ground Water Sampling. Division of Drinking and Ground Waters, 28 pp.

USEPA. 2005. Groundwater Sampling and Monitoring with Direct Push Technologies, 78 pp.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **VOC Soil Sampling/Soil**	**Standard Operating Procedure for Soil Sample Collection and Handling Volatile Organic Compounds**
Revision No: Original **Revision Date: 17 July, 2020**	**Reference No: SOP-D1-09** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the collection and handling of soil samples that will be tested for volatile organic compounds (VOCs). For the purposes of this procedure, VOCs are defined as organic compounds whose composition facilitates evaporation under normal atmospheric conditions. VOCs include low molecular weight aromatics, light aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylenes (BTEX), volatile petroleum hydrocarbons (VPH), trihalomethanes, ketones, acetates, nitriles, acrylates, ethers (e.g. 1,4-dioxane), and halogenated hydrocarbons (e.g. chlorinated solvents).

This SOP provides procedures designed to minimize losses of VOCs during soil sample collection, handling and storage, using methanol preservation or hermetically sealed field sampling devices. Methods of sampling for non-VOC compounds are provided in other SOPs that are included in Part D1 of the BC Field Sampling Manual.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on sampling for VOC analysis is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP.

This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information regarding soil investigations is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR) which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Soil sampling for VOC analysis conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Principle of the Sampling Method

Collecting a soil sample that accurately represents the undisturbed media under investigation is difficult. Collecting a representative sample of soil from a zone that contains volatile organic compounds (VOC) is significantly more difficult as these compounds are easily liberated and lost through volatilization and biodegradation. Compounds with high vapour pressures are more susceptible to volatilization, and aerobically degradable compounds are more susceptible to biodegradation. These processes can lead to sample results which are biased low or sample results that report detectable biodegradation products not present in the undisturbed media.

Methanol preservation or hermetically sealed field sampling methods are used to minimize VOC losses and ensure soil sample integrity, as described in US EPA Method 5035A. Methanol field preservation can extend hold times to 40 days and as such is typically preferred. Hermetic samples must be submitted to the lab and extracted within 48 hours or frozen to ≤ 6° C within 48 hours of sampling to extend the hold time to 7 days. Procedures for both methods are included in this standard operating procedure.

4. Quality Control

Quality control is an imperative component of environmental sampling and must be included in sampling and or monitoring plans. Quality control must include detailed and careful documentation of field information, attention to and deployment of each sampling method step, and proper decontamination of sampling equipment. Ensure that the requirements for sample containment, preservation, and holding times are understood and followed.

ENV maintains a list of required sample containers, storage temperatures, preservation requirements and holding times on their website at:

https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf.

Quality assurance is provided by submitting an appropriate number of blind field duplicate samples for laboratory analysis. The number of duplicate samples required to satisfy your projects quality assurance objectives depend on the number of field samples submitted (see Part A of the BC Field Sampling Manual for more detail). Field duplicates are collected using the same sample procedures deployed for regular samples as described in Section 7 of this SOP. Field duplicates should be identified in a similar manner as regular samples so that the laboratory is unaware of which samples are duplicates.

A new pair of disposable gloves must be worn for the collection of samples at each sampling location. If sampling for more than one type of analyte group (i.e. VOCs, inorganics), collect the samples in a sequence of most to least volatile compounds (e.g. BTEX first, metals last).

Since methanol is a polar solvent which has a very high affinity for numerous organic compounds, it is susceptible to absorbing vapour contamination that may be present in ambient air such as engine exhaust, gasoline and felt tip markers. Consequently, personnel should work upwind of potential sources of VOCs. In addition, the transfer of the soil sample into the sampling vial should be completed as quickly as possible. To prevent sample or methanol contamination, avoid smoking, pumping gas, using hand sanitizers, or coming into contact with solvents prior to and during sampling. Field blanks should be collected and submitted for analysis, especially when working near roads or other sources of contaminants, to capture and assess potential ambient environmental impacts and identify false positives. A laboratory-prepared travel blank pre-charged with methanol should also accompany each cooler submission. Travel blanks should remain with regular samples and be returned to the laboratory unopened.

5. Recommended Equipment and Materials

Field equipment should include the following:

1. PPE commensurate for the site, work plan which should include suspected contaminants and contaminant levels;
2. Pen, VOC-free indelible felt marker, field book, field logs;
3. Sample labels (note that the labels should be applied to sample containers by the lab and weighed by the lab after application);
4. Sealable/waterproof bags, chain-of-custody forms;
5. Cooler with ice (preferred) or freezer packs;
6. Nitrile gloves;
7. Site plan, utilities plan; and,
8. Laboratory-supplied glass containers for moisture analysis.

Methanol Preservation Method:

Figure 1. Terra-Core™ with soil plug and syringe samplers

1. Pre-weighed pre-labelled laboratory-supplied 40 mL glass jars (vials) with PTFE-lined septum caps. Vials are pre-charged with 10 mL of methanol preservative. Each sample requires two vials;
2. Equipment for soil subcore extraction (e.g. syringe or disposable Terra Core^{TM} sampler pre-calibrated to dispense approximately 5 g of sample, or EasyDraw Syringe® and PowerStop Handle®);
3. Laboratory-supplied 125 mL glass containers for moisture analysis.

Hermetically Sealed Method:

1. Disposable hermetic sample containers (e.g. En Core® or ESS Core N' OneTM) for collection of 5 g of soil (two containers per sample); and,
2. Reusable sample handle (e.g. En Core® T-handle).

Figure 2. EN Core© Sampler

Figure 3. ESS Core N' One™ Sampler

6. Sampling Considerations

- A primary objective of soil sample collection must be the preservation of sample integrity. Efforts must be made to mitigate potential losses. Generally, loses occur when the cohesive soil matrix is not preserved and when soil surface areas are exposed during drilling and sample collection. During drilling, losses of VOCs may occur due to sample compression and pore space loss, by the introduction of air into the sample, volatilization due to heat and through exposure to the atmosphere. Careful handling and transfer are critical to minimize losses due to volatility.
- Methanol must not spill or leak out of the sample vials during sampling or transport, as this will affect the weight of the sample and the effectiveness of the preservative. Ensure that the vial's threads and cap are clean and free of soil to prevent methanol leaks.
- Only use vials that have been pre-charged with methanol by the laboratory. Pre-charged vials have a shelf life and should be ordered specifically for a sampling event to ensure they are fit for purpose.
- Always inspect the vials before use to ensure the volume of methanol meets the 10 mL fill line.
- Methanol is a regulated substance under the Transportation of Dangerous Goods Act. A *Limited Quantity* label must be visibly placed on coolers if methanol vials are shipped by ground. Personnel must have IATA TDG training to ship methanol by air.

7. Procedures

The primary concern when sampling for VOCs is contaminant loss due to volatilization. The key to successful sampling is a quick and methodical execution of the sampling procedure to minimize exposure of the soil surface area to the atmosphere. Collect the VOC sample/s before you do any other activity including record taking or collecting headspace vapour measurements. Ensure you are familiar with the specific instructions provided by your laboratory and the device manufacturer before you head out into the field. If you have not used the VOC sampling device before carry out the following procedures in a controlled environment using clean soil to improve your efficiency with the device. It is recommended that at least two practice deployments take place prior to collecting samples.

The following procedures include instructions for deployment of the Terra Core® sampler (7.1) and the En Core® sampler (7.2).

7.1 Terra Core® Sampler:

Step 1
Have the appropriate laboratory-supplied sample jars and sampling equipment in a ready-state before retrieving soil samples.

Step 2
Check the black 10 mL fill line on the 40 mL sample vials to ensure that the methanol volumes are correct. Do not add additional labels to the vials as this may make it impossible for the lab to process the sample. Ensure that the Terra CoreTM plunger is seated into the handle.

Step 3
The soil to be sampled should be as undisturbed as possible. Soil samples may be collected from a test pit or excavation wall, or from soil collected with a split spoon, core barrel liners from direct push sampling systems, or vibrasonic cores. Remove or scrape away several cm of surface material to expose a fresh soil face.

Step 4
Push the Terra CoreTM sampling device into the soil face or representative soil sample to obtain approximately 5 g of soil. Avoid including gravel size soil particulates if possible/practical.


Figure 4. Check methanol fill line.

Step 5
Clean the outside of the Terra CoreTM sampler with a paper towel and ensure that the soil plug is flush with the base of the sampler. Remove any excess soil that extends beyond the mouth of the sampler.

Step 6
Rotate the plunger seated in the handle 90 degrees until it is aligned with the slots in the sampler body. Place the mouth of the sampler into the 40 mL sample vial. Apply pressure to the plunger to push the soil plug into the vial and then remove the sampler. Quickly clean the threads of the 40 mL glass vial, replace the cap and tighten it securely. Significant VOC losses can occur if the lid is not secured tightly to the jar and/or if a proper seal is not made.

Note: If methanol is lost during this step, the sample is rendered invalid and the entire procedure will have to be repeated with fresh sample material and a new sample vial.

Step 7
Collect a soil sample for moisture content analysis and place it in the 125 mL glass jar.

Step 8
Clean all sampling tools and dispose of gloves before collecting a new sample.


Figure 5. Release of soil plug into a 40 mL vial.

Step 9
Identify the sample containers and lids using appropriate sample nomenclature. Information included on the container's label should include: Sampler's initials, sample collection date, company name, sample site identification and/or sample number, desired analytical parameters, and preservation method.

Step 10
Repeat steps 2 through 9 to collect a second sample. Wrap the vials in bubble-wrap or an equivalent protective product and place the sample in a cooler chilled with freezer packs or ice (preferred) for transport to the laboratory. If using ice, be aware that ice and ice-melt can result in damaged or destroyed labels and can also be a significant pathway for cross-contamination of samples. As such, if using ice, either the ice or the samples should be double-bagged and isolated in sealable bags.

Step 11
Complete the sample submission and chain-of-custody forms. Chain-of-custody forms should be filled out in their entirety and each cooler shipped should have its own chain-of-custody form listing only those samples contained in the cooler it is shipped with. Chain-of-custody forms should be enclosed in their own sealable/water-proof bag to protect them from possible water damage during shipment. If not prearranged be sure to specify to the laboratory the analytical detection limit desired.

Step 12
Dispose of all wastes (liquids, used gloves and materials) in an appropriate manner. Leave the site in a tidy condition.

7.2 Hermetically Sealed Sampler (En Core®):

Step 1

Label the En Core® sample envelope. Open the envelope to access the sampler. Hold the coring body and push the plunger rod down until the small o-ring rests against the tabs, which will ensure that the plunger moves freely.

Step 2

Depress the locking lever on the En Core® T-handle. Place the coring body, plunger end first, into the open end of the T-Handle, and align the two slots on the coring body with the two locking pins in the T-handle. Twist the coring body clockwise to lock the pins in the slots. Make sure that the sampler is locked in place.

Step 3

The soil to be sampled should be as undisturbed as possible. Soil samples may be collected from a test pit or excavation wall, or from soil collected with a split spoon, core barrel liners from direct push sampling systems, or vibrasonic cores. Remove or scrape away several cm of surface material to expose a fresh soil face.

Step 4

Turn the T-handle with the T end up and the coring body down, which will position the base of the plunger flush with the bottom of the coring body. Push the sampler into the soil face using the T-handle until the coring body is full, which will occur once the small o-ring is centred in the T-handle viewing hole.

Step 5

Remove the Sampler from the soil and wipe any excess soil from the core body's exterior.

Step 6

Cap the coring body while in the T-handle, by pushing the cap over the flat area of the ridge. Push and twist the cap to lock the arm in place. The cap must be seated to seal the sampler.

Step 7

Remove the capped sampler by depressing the locking lever on the T-handle while twisting and pulling the sampler from the T-handle.

Step 8

Lock the plunger by rotating the extended plunger rod fully counter-clockwise until the wings rest firmly against the tabs.

Step 9

Return the En Core® sampler to the zipper bag, seal and store in a chilled cooler.

8. References

ASTM D4547-15, 2015. Standard Guide for Sampling Waste and Soils for Volatile Organic Compounds, ASTM International, West Conshohocken, PA.

ASTM D4687-14, 2014. Standard Guide for General Planning of Waste Sampling, ASTM International, West Conshohocken, PA.

ASTM D6418-09, 2009. Standard Practice for Using the Disposable En Core Sampler for Sampling and Storing Soil for Volatile Organic Analysis (Withdrawn), ASTM International, West Conshohocken, PA.

CCME, 2016. Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment.

En Novative Technologies, instructions for use of Terra CoreTM and En Core® samplers, https://www.ennovativetech.com/.

USEPA, 2002. Method 5035A (SW-846): Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples. Draft Revision 1. Washington, DC.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Soil Sampling (non-volatile)/Soil**	**Standard Operating Procedure for Soil Sampling for General non-volatile Organics and Inorganics**
Revision No: Original **Revision Date: 17 July, 2020**	**Reference No: SOP-D1-10** **Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the collection and handling of soil samples that will be tested for general non-volatile organic and inorganic compounds. For the purpose of this SOP, general organics are simply defined as non-volatile organics and inorganics which include metals, cyanide, anions and cations. This procedure does not include instructions for sampling volatile organic compounds (VOCs) in soil. Refer to SOP D1-9 for VOC sampling procedures.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on soil sampling for non-volatile organics and inorganics is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP.

This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information regarding soil investigations is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Soil sampling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Principle of the Sampling Method

Samples collected for the analysis of semi-volatile or non-volatile organics and inorganic parameters are more stable than VOCs and as such can be collected from devices such as a split spoon, vibrasonic, a solid stem auger or from a test pit or excavation wall or floor however unlike samples collected for VOC analyses, preservation is not required. The sample material is collected using a clean trowel or similar device and placed directly into laboratory-supplied soil jars which are larger than the vials used for VOC samples. These samples should be collected after the collection of samples for VOC analysis.

4. Quality Control

Quality control is an imperative component of environmental sampling and must be included in your sampling and or monitoring plans. Quality control must include detailed and careful documentation of field information, attention to and deployment of each sampling method step, and proper decontamination of sampling equipment. Ensure that the requirements for sample containers, preservation, and holding times are understood and followed.

ENV maintains a list of required sample containers, storage temperatures, preservation requirements and holding times on their website:

https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf.

Quality assurance is provided by submitting an appropriate number of blind field duplicate samples for laboratory analysis. The number of duplicates required, depend on the number of field samples submitted. Field duplicates are collected using the same sample procedures as regular samples and are collected at the same time as the regular samples. Duplicate samples should be identified in a nomenclature that conceals the duplicity of the sample from the laboratory.

Disposable gloves must be used when collecting samples. The disposable gloves must be changed between each sample. Prior to sampling, avoid smoking, pumping gas, using hand sanitizers, or coming into contact with sharpies tapes or solvents, to prevent sample contamination.

5. Recommended Equipment and Materials

Field equipment should include the following:

1. PPE appropriate for the site, work plan, contaminants and contaminant level;
2. Pen, indelible felt tip marker;
3. Sample labels;
4. Re-sealable waterproof bags;
5. Ice or freezer packs;
6. Cooler;
7. Field book and field logs;
8. Site plan, utilities locates plan; and,
9. Appropriate laboratory-supplied containers.

6. Sampling Considerations

- Samples collected for inorganic analyses do not need to be chilled; however, it is generally good practice to do so.
- It is not necessary to fill the sample container to zero headspace; although, it is generally good practice to do so, provided there is a sufficient volume of sample material.
- It may not be necessary to collect individual samples for each parameter being analyzed; confirm minimum sample volumes with the laboratory.
- Soil samples should be collected from individual formations and should not be composed of different formations.

7. Procedures

General organics are more stable, i.e. less volatile and/or bio-degradable, than volatile organic compounds such as BETX. Therefore, these samples should be collected after collecting samples for the analysis of volatile organics. If necessary, they can be collected after the soil sample has been logged.

Step 1
Have the appropriate laboratory-supplied sample jars at hand before collecting the targeted soil material. Remove or scrape away a layer of surface material to expose a fresh soil surface. Use a spoon, jar or trowel to collect enough sample material from the target location (i.e. excavation wall, split spoon) for the full suite of analytical tests to be performed and place the material into a glass or stainless steel container.

Step 2
Homogenize the sample material by mixing thoroughly with the trowel or other tool made of inert material.
Note: samples collected for VOCs should not be homogenized, please follow SOP D1-9 for VOC sampling.

The sample material is divided and mixed as follows:

- **a.** Divide the soil into quarters and mix each quarter individually
- **b.** Mix two quarters to form a half, mix the remaining two quarters to form a half,
- **c.** Mix the two halves to form a homogenous matrix.
- **d.** Repeat until the sample is adequately mixed.
- **e.** Soil materials such as clay and till may be difficult to homogenize; in these cases, it is recommended that ample soil material be collected and sent to the laboratory for homogenization prior to analysis.

Step 3
Transfer the homogenized soil into the appropriate sampling containers, ensuring that each aliquot of the composite sample is of approximately equal volume. Fill the containers in an alternating pattern. Using a spoon, jar or trowel, place a consistent volume of soil into in each container in sequence and repeat until the containers are filled, or until the composited soil is depleted. Fill the jar as completely as possible but do not overfill. Avoid including gravel and gravel size soil particles if possible/practical. If the material being sampled is hard, or very dense (e.g., till) it may not be possible to fill the sample container to achieve zero head space.

Step 4
Once the jar is filled, use a clean paper towel to remove excess soil. Using your fingertips (with nitrile gloves) and without touching the inside of the sample jar, ensure that all the threads on the jar are clean, and then fasten the lid securely.

Step 5
Clean all sampling tools and dispose of gloves before collecting new samples.

Step 6
Label the sample jar and lid separately using an appropriate sample nomenclature. Information included on the container label should include: Sampler's initials, sample collection date, company name, sample site identification and/or sample ID, desired analytical tests, and preservation method if any. Wrap the label and container with clear packing tape.

Step 7
Place the sample in a cooler chilled with freezer packs or ice (preferred). As a best practice, samples collected for chemical analyses should be kept cool while in the field and for the duration of their transport to the laboratory. Samples collected for physical analyses do not require cooling. If using ice, be aware that melted ice can result in damaged or destroyed labels and can also be a significant pathway for cross-contamination of samples. As such, if using ice, either the ice or the samples should be double-bagged and sealed.

Step 8
Complete the sample submission and chain-of-custody forms. Chain-of-custody forms should be filled out in their entirety and each cooler shipped should have its own chain-of-custody form listing only those samples contained in that cooler. Chain-of-custody forms should be enclosed in their own sealable bags to protect them from possible water damage during shipment. Be sure to specify to the laboratory the analytical detection limit desired. Samples should be delivered to the laboratory within 24-hours if possible.

Step 9
Dispose of all wastes (liquids, used gloves and materials) in an appropriate manner. Leave the site in a tidy condition.

8. References

ASTM D4547-15, 2015. Standard Guide for Sampling Waste and Soils for Volatile Organic Compounds, ASTM International, West Conshohocken, PA.

ASTM D4687-14, 2014. Standard Guide for General Planning of Waste Sampling, ASTM International, West Conshohocken, PA.

USEPA, 2014. Soil Sampling Operating Procedure, SESDPROC-300-R3, dated August 21, 2014.

Revision History: 0.0 (New document)

Approval

Sampling Method/Media: **Soil Gas Sampling/Soil Gas**	**Standard Operating Procedure for Soil Vapour / Gas Sampling**
Revision No: Original Revision Date: 17 July, 2020	**Reference No: SOP-D1-11 Parent Document: BC Field Sampling Manual – Part D1**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the sampling of soil gas/vapour sampling, including sub-slab sampling. Note that the term soil vapour usually implies volatile organic compounds in the subsurface, whereas soil gas is the total air in the subsurface which includes vapours such as VOCs and SVOCs and other gases such as oxygen and carbon dioxide. For the purpose of this SOP soil vapour and soil gas are considered interchangeable. This SOP includes procedures to complete pre-sample tests of the sample probe or well and sampling train. Pre-testing is carried out as a series of quality control (QC) checks comprised of flow, vacuum and leak tests. The flow and vacuum tests are conducted to verify that the vapour can be extracted from the subsurface without biasing a sample. The leak test (or shut-in test) is conducted to verify the sample train is free of leaks.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on soil gas sampling is provided in Part D1 – Soil Sampling and Investigations, which must be used in conjunction with the information provided in this SOP.

This SOP and the B.C. Field Sampling Manual are available at:

https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual.

Additional information regarding soil investigations is provided in guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Soil vapour sampling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D1 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Principle of the Sampling Method

Soil vapour sampling from the subsurface or sub-slab captures, where present, vapour phase contaminants of concern which can be used to determine the source and spatial distribution of the vapours or to estimate concentrations of indoor air contaminants from soil vapour intrusion.

Pre-testing of the sample apparatus is required prior to sampling. The objective of pre-testing is to ensure that unbiased representative soil vapour samples can be collected from the subsurface. If any of the pre-test components fail, the sample train is examined, adjusted and or reconfigured until the test results are satisfactory. If satisfactory test results cannot be achieved, a re-evaluation of site conditions such as soil type, depth to groundwater, surface cover and seasonal moisture should be conducted. When the pre-testing has been successfully completed, a soil vapour sample can be collected. Soil vapour samples can be collected from dedicated soil vapour probes, wells or from groundwater monitoring wells (if the monitoring well meets specific criteria).

4. Quality Control

- Ensure that all instruments are functioning and properly calibrated before starting and that all required information is recorded in the field.
- Use only clean purging/sampling equipment or equipment dedicated to the vapour probe/well.
- Only non-VOC emitting materials and equipment should be used.
- Never introduce foreign materials or liquids into a vapour probe/well.
- Purged vapour may contain contaminants at hazardous concentrations; field personnel should work up-wind of the purging and testing area.

5. Recommended Equipment and Materials

General field equipment:

1. Field notebook;
2. Soil Vapour Sampling Record Sheet;
3. Indelible VOC-free felt pen;
4. Site map; and
5. General tools.

Pre-testing field equipment:

6. 3 m to 5 m of flexible, non-VOC emitting tubing of sufficient diameter to ensure tight (snug) fit around all fittings;
7. Portable helium detector (e.g., Dielectric MGD-2002 Helium Leak Detector);
8. Vacuum chamber (“lung box”) with fittings and Tedlar™ bar;
9. Helium (balloon grade is adequate) with regulator and gauge;
10. Helium shroud (e.g., 20 L bucket, or equivalent, with fittings to attach equipment);
11. Flow meter (e.g., rotameter);
12. Vacuum gauge (e.g., magnehelic); and
13. Plastic sheeting if required (placed 24 hours prior to sampling/purging).

Soil vapour sampling field equipment:

14. Portable total vapour detector (e.g., combustible meter [Gastech®, RKI Eagle®] or photoionization detector, PID [MiniRae®]);
15. Water level meter;
16. Thermometer, barometer;
17. Stopwatch/timer;
18. Dedicated well caps with brass, ball-valve fittings; and
19. Sample submission/chain-of-custody forms.

Laboratory supplied field equipment:

20. Air flow restrictor attachment (for air pumps without a manual air flow control);
21. Air pump charging unit (optional);
22. Air sample pump(s) (calibrated), capable of operating in the range of 0.2 L/min (200 mL/min);
23. Air sample pump calibration unit (if field calibration of air pump maybe required);
24. Desiccant/drying tubes; and
25. Labels.

Field equipment that should NOT be used for soil vapour testing:

26. Sharpies or other VOC emitting pens;
27. Adhesive tapes (e.g., duct or electrical) or glue;
28. Any other product/object that emits VOCs that may interfere with sampling; and
29. No operating or idling of motor vehicles (or generators).

6. Purging and Sampling Considerations

- A minimum of three probe volumes including the air-filled pores of the filter pack should be purged prior to the collection of vapour samples.
- Purging and sampling flow rates should be between 20 mL/min and 200 mL/min; purge rates of up to 5 L/min are acceptable for large volume probes.

- Pre-testing can be conducted as part of the purging process which takes place prior to sampling; therefore, calculate the required purge volume prior to conducting these pre-tests and record the volumes purged.
- Neither pre-testing nor sampling should be conducted until an appropriate equilibration time has elapsed between the vapour probe or well installation and sampling (Table 1).

Table 1: Recommended Minimum Equilibrium Times Prior to Sample Collection

Drilling Method	Minimum Equilibrium Time (prior to sampling)	Comments
Direct push (from ground surface) Note: Equilibrium times have been increasing as more research has been done. From 20 minutes in 2003 to 2 hours in 2015 (IAVI, 2017)	2 hours	Rod is pushed >5 ft into undisturbed soil (up to 48 hours in fine-grained material)
	48 hours	Rod is pushed <5 ft into undisturbed soil
Direct push (in day-lighted pre-hole)	2 hours	Rod is pushed >5 ft into undisturbed soil
	48 hours	Rod is pushed <5 ft into undisturbed soil
Auger (hand, hollow stem, solid stem, etc.)	48 hours	
Sonic (rotosonic) Air rotary	Several weeks	Varies from a few days to a few weeks Empirically show equilibrium established by collecting time series data[1].
Sub-slab	2 hours	

[1] To verify equilibrium conduct time-series information. Oxygen and carbon dioxide shortly after installation, then frequency will depend on drill method. If in similar soil type, one installation can represent other locations.

- The laboratory that will be analyzing the samples must be contacted to select the most appropriate sample vessel and recommended flow rates. Analytical methods appropriate for analyzing soil vapour samples depend on risk assessment objectives, sampling method, and data quality objectives. The following tables provide general guidelines for common sampling vessels media and collection procedures.

Table 2: Types of Sampling Vessels

Sample Vessel	Comments
Polymer Bags (e.g., Tedlar™, FlexFilm, Kynar)	▪ Typically used for fixed gas analysis (O_2, CO_2, N_2, etc.). ▪ If vapour samples are collected they should be analyzed within six hours after collection. For fixed gases, analysis within 24 hours is acceptable. ▪ Sample collected using a vacuum chamber ("lung box").
Sorbent Tubes (e.g., charcoal, XAD and TD)	▪ A wide range of sorbent tubes are available. These tubes are selected based on the types and concentrations of SVOCs or VOCs that are expected in the soil vapour; ▪ Sorbent tube sampling rates are typically 0.2 L/min (200 mL/min) or less; the flow rate supplied by the sampling pump must be accurately determined; ▪ The sampling duration will depend on the expected concentration, flow rate, chemical type, sorbent and desired detection limits; and, ▪ For quality control purposes two tubes are placed in series to evaluate possible chemical breakthrough.
Stainless Steel Canisters (e.g., Silonite™, Summa™) or **Glass-lined Canisters** (e.g., SilcoSteel™)	▪ Canisters have a relatively inert, passive interior surface; ▪ Available volumes range from 400 ml to 6 L; ▪ Canisters are supplied under vacuum. The vacuum is measured prior to shipping by the laboratory, by the sampler immediately prior to and after sampling using a gauge supplied by the laboratory, and then again by the laboratory upon receipt. Significant differences in laboratory and field vacuums

	(beyond the range of accuracy of the gauge) indicate possible leakage during shipping; ▪ There should be residual vacuum left in the canister (review data quality objectives to determine desired residual vacuum); otherwise, the sample will not represent the entire planned sampling interval; and ▪ A flow regulator is typically used to control the sampling rate.

Table 3: Sampling vessel, COCs and other considerations

Sample Media	COCs (Parameters)	Flow Rate/Volume	Storage Requirements	Hold Times
Polymer Bag	Fixed gases and light hydrocarbons	0.5 L to 6 L (typically 1 L)	Placed in a cooler (ambient temperature). Sample should be shielded from sunlight to prevent degradation of the sample.	6 hours (light hydrocarbons) 24 hours (fixed gases)
Charcoal Tube	BTEX, VPHv, PHC (F1-F2), aliphatics and aromatics, napthtalene, n-hexane, methyl-cyclohexane, cumene, 1,2,3-trimethylbenzene (TMB), 1,2,4-TMB and 1,3,5-TMB	0.2 L/min (as per laboratory and project DQO)	In a dedicated clean and sealed container (bag) placed in a cooler at ambient temperature. Sample should be shielded from the sunlight to prevent degradation of the sample.	14 days
XAD Tube	PAHs and aromatics	0.2 L/min (as per laboratory and project DQO)	In a dedicated clean and sealed container (bag) placed in a cooler at ambient temperature. Sample should be shielded from sunlight to prevent degradation of the sample	14 days
TD Tube (thermal desorption)	BTEX, VPHv, PHC (F1-F2), naphthalene, n-hexane, methyl-cyclohexane, cumene, 1,2,3-trimethylbenzene (TMB), 1,2,4-TMB, 1,3,5-TMB, VOCs	0.2 L/min (as per laboratory and project DQO)	In a dedicated clean and sealed container (bag) placed in a cooler at ambient temperature.	30 days at 4^{o}C
Stainless Steel or **Glass Canister**	BTEX, VPHv, PHC (F1-F2), naphthalene, n-hexane, methyl-cyclohexane, cumene, 1,2,3-trimethylbenzene (TMB), 1,2,4-TMB, 1,3,5-TMB, VOCs	Project specific (grab sample to 24 hours). Volume 0.4 L to 6 L as per laboratory and project DQO)	In a cooler with no ice	30 days Recommend canisters be used within 15 days of preparation

Sampling Notes:

- All vapour samples must be collected between the probe/well and any pump (avoids cross-contamination and possible leakage).
- Total vapour samples should be collected from a polymer bag, using a vacuum chamber ("lung box").
- Groundwater monitoring wells can be used to obtain soil vapour data; however, prior to conducting any vapour sampling the following criteria must be met:
  - The well screen must extend above the tension-saturated zone (i.e., capillary fringe).
  - It is recommended that well screen lengths be 3 m or less and have an open screen section 0.5 m to 1 m above the water table.
  - Ensure there is a seal (e.g., bentonite or grout) in place to prevent leakage of ambient air or soil vapour from other depths from entering the sampling point.

- The “vented” well cap must be replaced with an air tight cap/fitting.
- Due to the larger casing diameters (e.g., 4” to 8”) of groundwater monitoring wells the purge volumes can be significant, requiring longer purge times and in some cases increased purging rates.

Table 4: Summary of Tubing (CARO, 2009)

Material	Acceptability	Comment
Tygon and **LDPE** (low density polyethylene)	Avoid	▪ Emits “appreciable” levels of VOCs
Silicone and **PVC tubing** (flexible)	Minimize lengths (use as connecting tube)	▪ Emits moderate concentrations of VOCs
Nylon (Nylaflow and Extra-Flex)	Good – Nylaflow Acceptable – Extra-Flex	▪ Nylaflow no emissions ▪ Extra-Flex emits acetaldehyde
Teflon (nylon material, not all nylons are the same)	Good	▪ No emissions
PVC Pipe (rigid)	Avoid scratched PVC	▪ Unscratched PVC emits acetaldehyde ▪ Freshly scratched PVC emits numerous VOCs

[1] Appreciable refers to VOCs greater than 20% of the numerical standard

7. Procedures

Preparations

1. Review any client specific requirements for soil vapour sampling. If client specific methodology deviates from that outlined in this SOP, contact the client to confirm the authorized methodology for the project. Confirm sampling technique based on the probe or well conditions (i.e., completion details, water level, depth of well, etc.) and potential contaminants of concern to be sampled for.

2. Scheduling of sampling: ensure that the event will be conducted prior to a rainfall event or at least up to approximately 24 hours after a rain event (1.0 cm) depending on the soil type. If required, discuss the effects of different soil types on sampling with project manager. In addition, samples should not be collected when there is active snow-melt or other soil-wetting activities. This is particularly important for sampling locations that are proximal to uncovered areas (e.g., no concrete or asphalt) since soil moisture content may affect the result.

3. It is recommended that a surface seal such as an inert plastic sheet be installed for samples collected within 1 m of ground surface. The surface seal should consist of an impermeable membrane with dimensions of approximately 1.5 m by 1.5 m. The surface seal should be installed 24 hours prior to purging and sampling. See Figure 1.

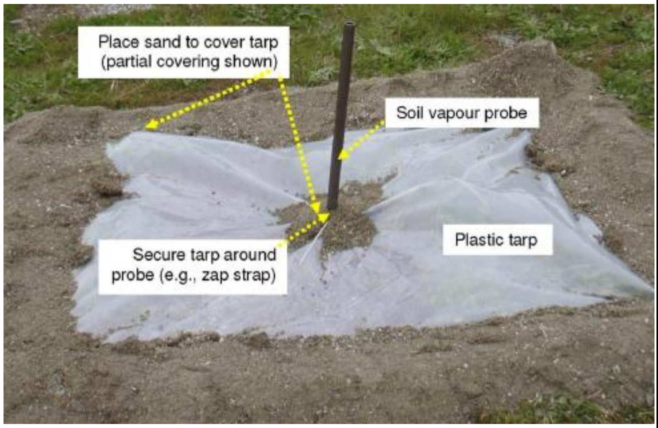

Figure 1. Secured surface seal around soil vapour probe.

Pre-Testing/Purging

4. If required and in conjunction with the DQO, determine if any probes or wells require flow, vacuum, and leak tests.

5. Record all information in a field book and sampling form, including the sampler's initials, equipment used, date and time of sampling, sample location(s), temperature, approximate wind speed, and direction, weather, humidity, etc. Note any unusual conditions that may have affected the measurements or sample collection such as vehicular exhaust.

6. Ensure the vapour probe/well is dry to bottom. For groundwater monitoring wells, measure the depth to groundwater and NAPL accumulation measurements. Note if LNAPL (e.g., petroleum hydrocarbon) is present or if the water level is above the well screen, do not collect a soil vapour sample.

7. Inspect the well cap to ensure that a proper soil vapour cap is being utilized. If not, replace it with a cap that contains a brass valve fitting and slip/tighten in place. Do not glue a cap onto the well (glues contain volatiles that may affect samples). If necessary, seal the cap or plug with Teflon tape.

8. Calculate three air volumes for purging.

$$P_v = 3 * \left(\pi * \frac{d_{w^2}}{4} * h_w * 1{,}000\ {}^{L}/_{m^3}\right)$$

where: P_v = three purge volumes (L)

d_w = diameter of well (probe and sand pack) (m)

h_w = height of exposed screen plus solid pipe (m)

9. Check the flow rate of the pump using the calibration unit provided by the supplier (omit if the pump has been calibrated by the laboratory). For purging, use the sample pump (check flow rate on the rotameter before proceeding if unsure about flow rate).

10. Determine the minimum time necessary to purge three air volumes from the well. If soil vapour probes were just installed, please refer to Table 1 for the time required between installation and sampling/purging.

11. For groundwater monitoring wells, attach a suitable length of flexible tubing to the brass fitting on the underside of the cap. Tubing should be 1/8” Teflon or equivalent; ensure the tubing is non-reactive and non-sorbing for the contaminant of interest. Re-secure the well cap leaving the tubing to hang inside the well. The tubing length, when hung in the well, should approximately coincide with the target depth of the well or probe screen. Record the tubing length installed in the well.

Flow and Vacuum Testing

12. Place a shroud (i.e., 20 L bucket or equivalent) over the vapour probe/well being tested and seal the system as shown in Figure 2. Use Teflon tape on all connections to ensure a tight seal.

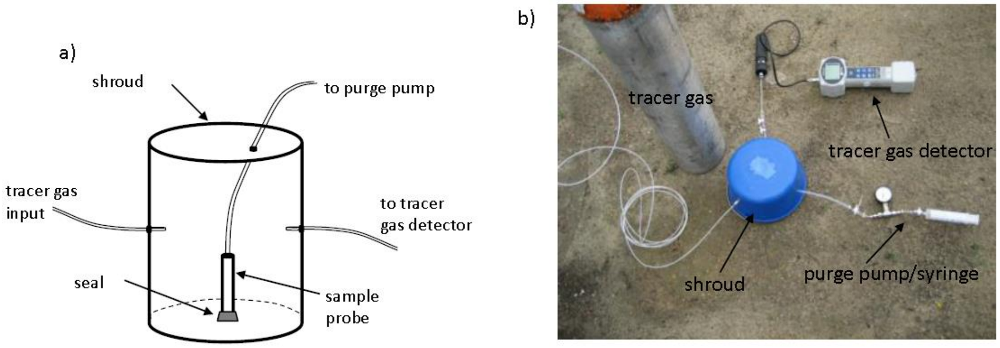

Figure 2. Typical pre-test set-ups: a) schematic and b) example of a shroud over a vapour probe (adapted from H&P Mobile Geochemistry. 2018).

13. Note that the flow and vacuum testing can be conducted at the same time as purging. The purpose of purging is to remove stagnant air from the probe; however, over-purging should be avoided, since the objective is generally to characterize soil vapour in the immediate vicinity of the probe. In addition, the purge rate should be in the same range as the subsequent sampling rate.

14. Attach tubing (see Table 4 for acceptable tubing material) to the air-tight cap on the probe/well and install an in-line “dummy” sample tube. This “dummy” tube will be provided by the laboratory to ensure that the friction losses through the tube are similar during purging and sampling (i.e., purging and sampling are at the same flow rate).

15. Attach a brass "T" connector (or equivalent inert connector) to the flow meter (e.g., rotameter), vacuum gauge (e.g., magnehelic) and the pump (e.g., SKC™). See Figure 3 below. Note: only the low flow connector on the vacuum gauge is connected and the high flow connector is left open to the atmosphere (there is no flow through the vacuum gauge).

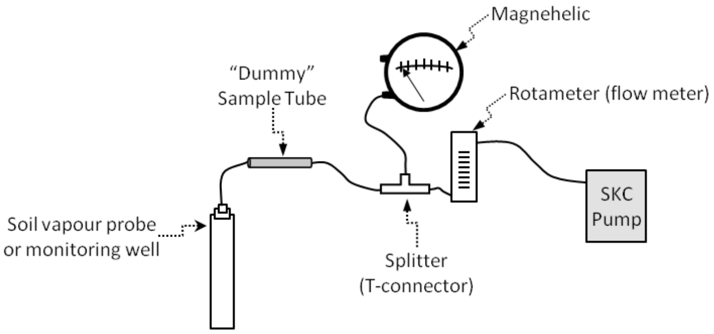

Figure 3. Configuration of a flow and vacuum test apparatus.

16. Note that the vacuum chamber can be attached between the flow meter (e.g., rotameter) and the pump. Place an empty polymer bag in the vacuum chamber and open the valve on the polymer bag. Close (seal) the vacuum chamber and connect the sample train tubing to the polymer bag in the vacuum chamber via the valve. Connect the air-sampling pump to the vacuum chamber such that air is drawn from the vacuum chamber into the pump. This will create a vacuum in the chamber, which in turn will fill the polymer bag with vapour from the probe/well.

17. Open the valve to the probe/well and the flow meter and start the sample pump. Purging should be conducted at the same flow rate as the sample collection flow rate; between 0.1 L/min and 0.2 L/min and should not exceed 0.2 L/min (200 mL/min). Record the time, flow rate and vacuum. Once the flow and vacuum readings stabilize, disconnect the polymer bag and measure the total vapours using the handheld vapour detector. Record total vapours.

18. NOTE: the induced vacuum should not exceed 10" H2O; if it does, reduce the flow rate using the flow adjuster. If reducing the flow rate does not reduce the vacuum then a biased sample may result due to VOCs partitioning from other phases (e.g., sorbed and dissolved) into the vapour phase. If reducing the flow rate results in an acceptable vacuum, adjust the subsequent sampling flow rate.

19. Once the flow and vacuum tests are completed, close the valve to the probe/well and disconnect the flow meter and vacuum gauge tubing. Record the completion time (or volume) of the purging vapour removed.

Leak Testing

20. To conduct the leak test, remove any vapour in the polymer bag and place it in the vacuum chamber ("lung box"). Close (seal) the vacuum chamber and connect the tubing from the well to the polymer bag in the vacuum chamber. Connect the sampling pump to the vacuum chamber

21. Open the air-tight valve on the vapour probe/well, but keep the sample train from the probe/well closed. Open the valve from the helium (or other tracer gas) tank to the shroud (Figure 2). Turn on the helium and adjust the flow rate using the flow adjuster on the regulator until the shroud is filled with helium. Ideally, the concentration should be between 80% and 100% (50% minimum). Record the concentration.

22. Open the valve from the well to the vacuum chamber, and the valve from the vacuum chamber to the air-sampling pump. Turn on the sampling pump, which will continue to purge the well, and record the time and flow rate. Continue to purge the vapour probe/well until the polymer bag is almost full (bags typically are 1 L).

23. Once the polymer bag is full, turn the pump off and close all the valves. Attach the helium detector to the polymer bag fitting and open the valve. Record the concentration of helium in the polymer bag. If the concentration of helium in the Tedlar bag is less than 1% of the concentration in the shroud, then there are no significant leaks in the system. If the concentration is greater than 1% then there is a leak. All fittings/connections should be checked and tightened (replaced if necessary) and the leak test repeated.

24. Once the system is adequately sealed, soil vapour sampling may commence.

Vacuum Check

25. After purging allow the vacuum inside the vapour probe/well to dissipate to equilibrium conditions. If the vacuum does not dissipate within a few minutes to an hour, sampling may not be practical. Typically, waiting two minutes for every litre purged is sufficient to re-establish equilibrium.

Sampling with sorbent tubes

26. Prepare the sorbent tubes for sampling by affixing a pre-made label to the container. Do not attach label directly to the sorbent tube. Do not use Sharpies or other felts, or tapes in or around any soil vapour sampling equipment.

27. Remove the end caps from the sorbent tube (for charcoal and XAD tubes break/cut both ends) and connect the tube between the vapour probe/well and the sample pump (with a low flow adapter, if necessary). The laboratory will have calibrated the pumps and added a low flow adaptor to the requested flow rate. DO NOT adjust the flow rate on the pump or low flow adaptor. It is recommended that flow rates be set within the range of 0.1 L/min to 0.2 L/min but should not exceed 0.2 L/min (200 mL/min).

28. It is imperative that the arrows marked on the sorbent tubes be aligned with the direction of the airflow through the system. The sorbent tube should be installed and kept in a near vertical position during sampling to minimize channeling through the tube.

29. Ensure that all connections within the system are tight and that the tubing is sealed over both ends of the sorbent tube.

30. Turn on the air sample pump and record the start time and flow rate. The total operating time and the flow rate are used to determine the actual concentrations present in the sample tube, thus, accurate measurements are critical. If the flow rate does change during the test, record the variation/s in flow rate and the time/s during which the changed rate was maintained. This additional information will allow an integrated volume to be calculated.

31. Let the air pump operate for a pre-determined time (as determined by the DQO) and record the stop time at the end of the sampling event.

32. If the site being investigated is expected to have high soil vapour concentrations then it is recommended that, if time and budget permits, two samples be obtained using two different intervals: a short sampling period (2 minutes) and a longer sampling period (i.e., depending on land use at the site). Or two sorbent tubes can be placed in series to detect potential breakthrough.

33. Once the sample collection time has passed, turn the air sample pump off and remove the sorbent tube from the system. Disconnect the tubing and cap both ends of the sorbent tube with the end caps. Place the sorbent in the pre-labelled container and store in a cooler (with NO ice).

34. Duplicate samples can be collected suing a T-splitter to divide the sample (Figure 4).

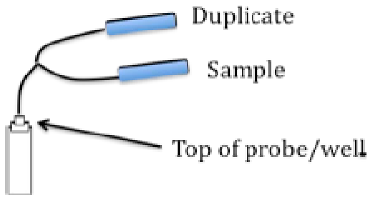

Figure 4: Schematic of duplicate sampling.

35. When collecting two samples simultaneously, the total flow rate at the probe should not exceed 0.2 L/min (200 mL/min). In this case, the sample and duplicate will be collected at 0.1 L/min (100 mL/min) each.

36. Field quality control samples should include equipment blanks, duplicate samples and trip blanks at a frequency of one in ten samples.

37. If multiple samples are required, allow the vapour probe/well to equilibrate before collecting the next sample.

38. Submit the sample to the laboratory with proper sample transmittal documentation.

Sampling with canisters

39. Prepare the Canister for sampling by affixing a pre-made label to the canister. Do not use Sharpies or other felts, or tapes in or around any soil vapour sampling equipment.

40. Using an air-sampling pump purge the vapour probe/well in a similar manner to that described above. The canister CANNOT be used for purging.

41. Prior to sampling, check the canister vacuum and record the reading.

42. If samples were collected prior to the collection of the soil vapour into a canister, allow the probe/well to equilibrate before collecting the next sample.

43. Connect the flow regulator and gauge to the canister.

44. Connect a small section of tubing to the brass fitting at the top of the vapour probe/well cap then connect to the flow regulator attached to the canister.

45. Ensure that all connections within the sample train are tight and that the tubing is sealed at the flow regulator attached to the canister.

46. Open the regulator and record the start time and vacuum pressure. Collect the sample over the required interval (as determined by the DQOs). At the end of the sample interval record the stop time and the end vacuum pressure. There should be a residual vacuum left in the canister at the end of the sampling interval; otherwise, the sample will not represent the entire planned sampling interval (residual vacuum is based on DQOs).

47. Field quality control samples should include field duplicates and field blanks. Field duplicate samples can be obtained using a “T” splitter provided by the laboratory and certified by the laboratory that it is clean. A similar setup to the schematic above is used to collect duplicates. Consideration should be given to filling a canister with ultra pure nitrogen supplied by the laboratory in a separate canister and designating this as the field blank. Field duplicates are recommended at a frequency of one in ten samples.

8. Technical Notes

1. Water mist and water vapour can interfere with the collection of organic compound vapours. Humidity greater than 60% can reduce the adsorptive capacity of sorbent material by 50% for some chemicals. The presence of condensed water droplets in the sample tube will indicate a suspect sample. A desiccant in the sampling stream, a cold-water bath or a laboratory supplied drying tube may be used to condense the moisture in the sample stream. Selection of the right sorbent media and desiccant is required and should be discussed with the laboratory to minimize the effect of moisture on the analysis.
2. If there is high humidity (>90%) or relatively high concentrations of other organic vapours present the air pump flow rate may need to be lowered or the air volume collected reduced (to about half of the projected volume).
3. Barometric pressure has an influence on observed vapour concentrations collected from the subsurface. Changes in barometric pressure can lead to a pressure gradient between the soil vapour and atmosphere creating a flow of soil vapours out of the unsaturated zone during barometric lows and into the unsaturated zone during barometric highs. Barometric pressure data can be found on the Environment Canada weather website.
4. It is recommended to wait at least 24 hours after a rain event (>1.0 cm). However, sampling time depends on soil type, rainfall intensity and duration, ground cover, and other factors.
5. Soil vapour samples are collected under vacuum. In order to avoid or minimize partitioning from the sorbed and dissolved phase into soil gas, the vacuum applied to the probe should be kept to a minimum. That is, if the air sample pump is labouring then the soil is under too much vacuum. Therefore, the flow rate of the air sample pump should be reduced to maintain a vacuum less than 10” H2O or the soil vapour sampling should be discontinued (some jurisdictions allow up to 100” H2O vacuum, this should be verified in the DQOs). Note that reducing the flow rate of the sample pump will increase the sampling time in order to obtain the required sample volume to ensure that the appropriate detection limits can be met.

9. References

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Revision History: 0.0 (New document)

Approval

The British Columbia Field Sampling Manual

Part D2

Sediment Sampling

Table of Contents

1 Introduction 1

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Tables

Appendices

1 Introduction

Part D2 of the British Columbia Field Sampling Manual (BCFSM) provides foundational information and guidance on sediment sampling and monitoring. The information presented in this part of the BCFSM provides essential components of sample plans and field work procedures. The information and guidance are based on a wide variety of sources including industry best practices, technology, Provincial and peer-reviewed literature. Part D2 of the BCFSM focuses on methods for sediment sampling in freshwater aquatic environments (i.e., stream, river and lake), with methods that are also applicable to sediments in shallow and near-shore marine environments. Sediment collected using the techniques outlined herein provides samples that are suitable for sediment chemistry analysis and physical characteristics such as particle size distribution. Some of the information provided in this section of the BCFSM may also be helpful in the collection of samples for benthic invertebrate monitoring.

The primary objective of a sediment sampling program or plan is to produce samples that are representative of their parent material and to deliver those samples to a qualified laboratory without contamination or deterioration. **The procedures outlined in this manual standardize sampling protocols and methods which may be required by permit, approval, regulation or bylaw. These procedures also serve as a guideline for regulatory staff, permittees, and consultants.** The BC Field Sampling Manual is a living document that will be updated periodically to reflect technological advancements and improvements to sampling methodologies.

This *part* of the BCFSM takes into account BC acts, regulations, protocols and technical guidance. The primary acts and regulations that apply to the information contained in this *part* of the BCFSM include:

The **Environmental Management Act (EMA)** regulates industrial and municipal waste discharge, pollution, hazardous waste and contaminated site remediation. The EMA provides the authority for introducing wastes into the environment, while protecting public health and the environment. The Act enables the use of permits, regulations and codes of practice to authorize discharges to the environment and enforcement options, such as administrative penalties, orders and fines to encourage compliance. The EMA is the enabling statute for both the Contaminated Sites Regulation and the Hazardous Waste Regulation.

The **Contaminated Sites Regulation (CSR)**[8] provides numerical and risk-based standards for soil, sediment, water and vapour which are used to determine a site's compliance with the regulation.

Additional guidance regarding contaminant related investigations is provided in protocols, fact sheets, and technical and administrative guidance documents provided on the Provinces Contaminated Sites Guidance & Resources web page which can be found at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/guidance-resources

The **Hazardous Waste Regulation (HWR)**[9] addresses the proper handling and disposal of hazardous wastes; materials which could represent a risk to soil, sediment, surface water and groundwater.

Note: The BCFSM does not address the collection of samples for the purpose of providing legal evidence. For information regarding legal sampling contact the Laboratory Standards and Quality Assurance unit of ENV.

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[8] *Contaminated Sites Regulation (CSR), B. C. Reg. 375/96, incl. amendments up to B. C. Reg. 196/2017, November 1, 2017.*

[9] *Hazardous Waste Regulation* (HWR), B. C. Reg. 63/88, incl. amendments up to B. C. Reg. 243/2016, November 1, 2017.

1.1 General Considerations

Many factors need to be considered when designing and planning a sediment sampling program. Sediment sampling programs can be used to evaluate the distribution of sediment types within a water body, for geological or geotechnical surveys, to identify and quantify contamination in sediments, and to evaluate of the effects of sediment contamination on a water body and/or aquatic life (e.g., through benthic invertebrate sampling). The objectives for sediment sampling must be defined within the objectives and scope of the sampling program, which in turn will inform the planning process. Sediment monitoring and or sampling plans include identifying strategic sampling locations, appropriate methods for sample collection, analyses to be completed and commensurate quality control measures. Depending on the sampling program's scope and objectives, programs can range from highly localized gridded sampling to regional scale sampling.

The scope and objectives of a sampling program should be well defined before the sample program is designed, and the sampling methods selected. As part of determining the program scope, considerations defining the intended outcome and purpose for the sediment sample results should be used as a guiding framework. Considerations include the purpose for sampling, regulatory requirements if applicable, how the sediment analytical (or other) data will be used, the number and locations of samples to be collected (for statistical analyses, if applicable), and whether or not reference/background samples are required. An effective way to communicate the scope and goals of a proposed sediment sampling program is through the creation of a detailed sampling plan, which should include a site plan with proposed sampling locations.

Once the objectives and scope of the sediment sampling program are well understood and defined, the next step is to decide on the sample layout and design. Considerations for the sampling program design include defining the spatial coverage of the targeted areas of investigation, sample density required to obtain samples representative of the site's conditions, the sample size required to accommodate planned or future statistical analyses and monitoring for temporal changes in sediment conditions if applicable. In addition to these considerations the sampling design must accommodate the site's field conditions. Aspects such as access to sampling locations (e.g. shoreline or boat access), tides, high/low flow conditions, potential seasonal fluctuations in parameters, substrate type (e.g., fine- or coarse-grained sediments), overlying water depth, and potential hazards such as underwater utilities must be considered and planned for.

1.1.1 Sample Layout and Design

Sediment parameters across a given area are inherently variable, and so the sample layout and design should consider the objectives of the sampling program to determine the most appropriate approach to obtain representative samples for the area under investigation. This includes consideration of the potential need for comparison of site-specific sediment results to background (or "reference") samples, and selection of an appropriate sampling program design for the area of investigation.

1.1.1.1 Sampling to Evaluate Background Conditions

A sampling program may require a comparison of site-specific sediment results or analytical data to those of sediments collected from outside of the investigation area; an area considered to be representative of local background conditions. Site-specific background sediment quality may be established by comparison to sediment from a local reference location with similar characteristics to those of the site. Careful selection of an appropriate background site (or "reference site") will ensure that the material and/or the concentrations of parameters within the material, are attributable solely to natural conditions, and that the background site itself is not contaminated. The background site should be proximal to and adequately representative of the investigation site's conditions. Optimal background sites include locations along the same stream, or an area with similar sediment depositional mechanisms. Additionally, the sediment substrate type at the background site should, as closely as possible, reflect the substrate type at the investigation site. Whenever possible, the sediment sampling method used at the investigation site should be the same as that used at the background site.

Background conditions can be established through statistical evaluations of background sediment data provided in *Technical Guidance 16; Soil Sampling Guide for Local Background Reference Sites* (ENV, 2017).

1.1.1.2 Discrete Sampling

Traditional sediment sampling plans are often based on discrete sampling for sediment characterization. Discrete sampling involves the collection of one or more ‘discrete sample/s’ from each sampling location. This sampling design is effective when many sediment samples are being collected from the same general area, where larger-scale evaluation of sediment heterogeneity is not necessary. Advantages of this technique are that sampling is easy to implement, is relatively cost effective, and can be efficient when knowledge of the site, including areas of potential concern, are well understood. A disadvantage of discrete sample collection is that it generally cannot be reliably replicated, as the sample design relies on professional judgement, which can introduce bias in the selection of sampling locations.

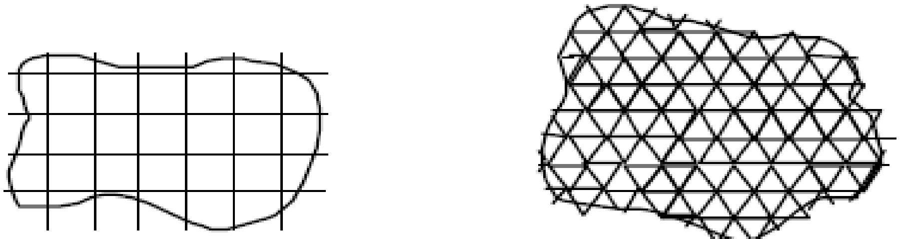
1.1.1.3 Probability-Based Sampling

The alternative to discrete sampling is probability-based sampling, which includes gridded, incremental and composite sampling. These approaches are better suited for sediment sampling plans that require sediment characterization components such as heterogeneity which is commonly required for regional-scale sampling programs. Probability-based sampling is also deployed for detailed investigations of a given site and projects that require reduced uncertainty in reproducible results. Statistical inferences can be made from probability-based sample collection and estimates of uncertainty can be calculated. Disadvantages of this sampling methodology include an increase in the time required to design the sample plan and an increase in the time required to collect the samples. Additionally, random sample locations may be difficult to locate, and the design may be impeded by site conditions such as built structures, physical barriers, or unsuitable substrates.

1.1.1.3.1 Gridded Sampling

Gridded sampling is a systematic approach to sampling, in which samples are collected at regularly spaced intervals, often at the intersection of the grid lines overlaid on a site plan. The first sample location is chosen, and then all remaining sample locations are arranged systematically at regular intervals over a given area defined by the projects’ sampling objectives.

Examples of grid sampling are shown in Figure 1.1 below. Grid designs can include square, rectangular, triangular, or radial. Grid sampling applications can include sampling to identify contamination gradients or hot spots; for statistical approaches to infer means or percentiles; and for estimating spatial patterns or trends with time.



Systematic Grid Sampling – Square Grid

Systematic Grid Sampling – Triangular Grid

Figure 1.1: Examples of Grid Sampling Designs

1.1.1.3.2 Incremental Sampling Method

The incremental sampling method (ISM) is a structured composite sampling and processing protocol, designed to reduce data variability and increase the representativeness of the sample, yielding a more reproducible sample. The incremental sampling method produces a single sample that is representative of a given area within a site referred to as the decision unit or DU.

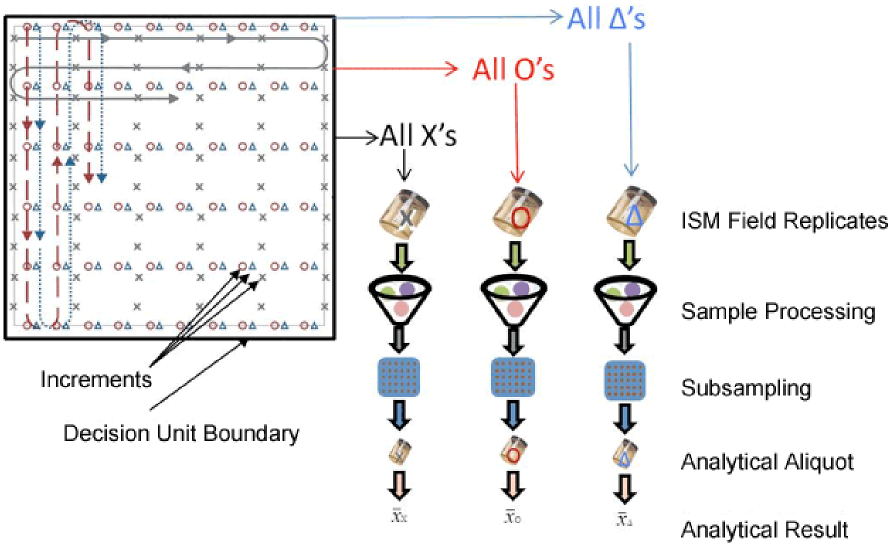


Figure 1.2: ISM Sampling Design Overview

In the ISM method, the sample area is a subset of the site, referred to as the decision unit (DU), which should be of limited size to prevent sample dilution. As illustrated in Figure 1.2 the DU is divided into increments, typically between 30-50 divisions for sufficient spatial representation. Starting at a random point in the first grid cell, one sample is collected from each increment per grid cell.

All increments are collected from the same relative location within the grid cell and the same volume of sediment is collected at each increment. Each aliquot of sediment is combined in an intermediate container. The sample is then subdivided based on a grid, with between 30 and 50 sections. Equal volumes of sediment are collected from each grid section. The combined sample material is further subdivided into equal portions that are placed in sample jars.

One specific application of the ISM, as indicated by the US EPA, is utilization for risk assessments, to identify maximum concentrations or to determine upper confidence levels for sediment concentrations at a given site. Additional applications include meeting specific data requirements for statistical evaluations and obtaining representative samples with adequate coverage when sampling heterogeneous sites. This method may not be suitable for sites where a grid design cannot be established, or where fewer than 30 increments can be collected.

1.1.1.3.3 Composite Sampling

Composite sampling is a form of systematic sampling in which sediment from several sampling units within a sampling area are mixed to form a single homogeneous sample for analysis. The approach is dependent on sampling objectives. Examples of sampling plans which incorporate composite sampling are shown in Figure 1.3. Composite sampling is often combined with other sample designs (e.g., as part of a gridded sample) when the objective is to estimate statistical characteristics, or when evaluation of data pertaining to spatial or temporal variability is not an objective. Composite sampling is not suitable if there are potential biases, such as the potential loss of volatiles during the necessary homogenization of composite samples, or sediment dilution which would occur if contaminated sediment is mixed with non-contaminated sediment.

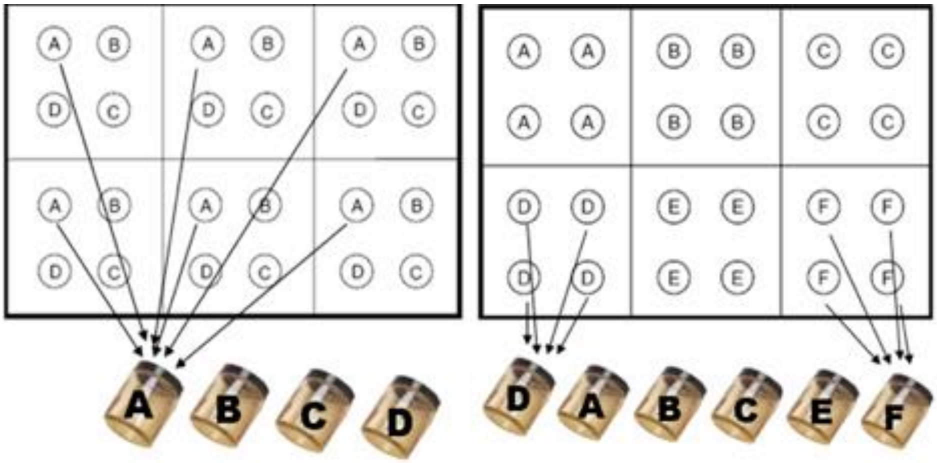


Figure 1.3: Examples of Composite Sampling Designs

1.2 Preparing to go to the Field

Dependable preparation protocols will save time, money and resources as oversights are usually not noticed until the field crew have arrived at their first sampling location. The most effective way to prepare for a sampling trip is with a checklist designed specifically to meet the requirements of the project. In addition to site-specific instructions, a project-specific pre-trip checklist should be generated to prompt the field team to ensure that all required equipment, materials and logistics are ready in advance of the scheduled sampling event.

The following items should be included in a pre-trip checklist:

- Permission to enter the site, gate keys and maps as necessary to access the site;
- Field equipment:
  - field screening instruments such as meters (with spare batteries, calibration equipment and adequate trouble-shooting equipment for small repairs);
  - sampling tools (i.e. grab sampler, core sampler) and equipment for homogenizing the sediment samples (mixing bowl, spoon);
  - decontamination supplies;
  - nitrile gloves;
  - tools for measuring/locating sample locations (GPS, tape measure, surveyor’s wheel), etc.;
- Sample containers (pre-labeled) and preservatives – include types and quantities (include extras);
- Appropriate quantity of ice packs and coolers;
- Field notebooks and/or log books;
- Personal gear for all possible weather conditions (e.g., raincoats, protective footwear, etc.);
- Health and safety documentation, first aid kit and appropriate safety equipment for working in/around water (e.g., cell/satellite phones, survival suit, life jacket);
- Camera or video equipment as required (waterproof equipment is preferable); and,
- Laboratory requisition forms (partially filled out).

A prudent approach to field trip preparation is to have the key equipment in a clean lidded box or plastic "tote" dedicated to sampling events. See Appendix 1 of this chapter for an example of a generic field preparation checklist specific to sediment sampling.

1.3 Locating Sampling Stations in the Field

It is the responsibility of field staff to locate all sampling stations accurately. To generate the data necessary to interpret temporal changes in sediment quality, samples must be consistently collected from an established sampling station or from a series of established sampling stations. To achieve this goal, articulate and effective descriptions must be prepared for each sampling station. Descriptions should include key site features, permanent structures, effective photographic documentation and GPS coordinates. Where possible visible markings should be installed to help ensure that sample stations are accurately located. A map depicting the sample stations and landmarks should accompany the site identification log book. For streams and small rivers sampling sites can be marked by attaching flagging tape to shoreline vegetation.

Basic site location data such as latitude, longitude, map sheet number, site identification number, should be incorporated into the database (EMS in the case of ENV). Handheld Global Positioning System (GPS) devices should also be used where possible to for navigation back to the sampling locations.

1.4 Field Notes and Observations

Good sampling practice includes the creation and use of detailed field notes. Specific information regarding ambient conditions such as time of day, weather conditions, and activities taking place in the area surrounding the sample site provide important information when reviewing and interpreting the analytical results of sediment samples. A field log book containing water-proof paper should be dedicated for each project. In addition to daily recordings of ambient conditions, field measurements, sample ID and matrix characteristics should be recorded and entered by date, directly into the field log book.

The following list emphasizes the information and observations that should be recorded in a field log book:

- Site name and EMS code;
- Date, time, and weather conditions;
- Station depth;
- Names of all personnel on the sampling crew;
- Gross characteristics of the sediment;
    - Texture / grain size;
    - Colour;
    - Biological structure (e.g., shells, tubes, macrophytes);
    - Debris (e.g., wood chips, plant fibers);
    - Presence of oily sheen;
- Obvious odour;
- Gross characteristics of vertical profile (distinct layers, depth of layer changes; especially important for processing of sediment cores);
- Penetration depth of sediment sampler;

- Sampling protocol deviations and or difficulties encountered during sampling; and,
- Any activities such as construction being conducted nearby.

All information recorded in the log book should be entered into the database as soon as possible upon return from the field.

2 Quality Assurance/Quality Control

2.1 Field Quality Assurance

The field quality assurance program is a systematic process which, together with the quality assurance programs of the laboratory and data storage unit, ensures a specified degree of confidence in the data collected for an environmental investigation, sampling program or survey. The field quality assurance program involves a series of steps, procedures, and practices which are described below.

The quality of data generated in a laboratory depends, to a large degree, on the integrity of the samples that arrive at the laboratory. Consequently, the field investigator must take the necessary precautions to protect samples from contamination and deterioration.

There are many opportunities for and sources of contamination that must be considered during the complete process of sampling and sample handling. The following basic precautions must be included in field quality assurance programs:

- Sample volumes and sample containers vary by analytical method and laboratory. For this reason, it is strongly recommended that the requirements of any sampling event be established in consultation with the testing laboratory. Ensure that the sample container, the volume of sample material required, and the preservation requirements for each analysis included in the planned sediment sampling program are understood.
- With few exceptions only sample containers that have been provided by an analytical laboratory should be used. The containers should be certified as ‘contaminant free’ by the laboratory or their supplier.
- During field preparations ensure that the lids of all sample containers are securely fastened prior to transport to the field. If preservatives are required ensure they have not exceeded their expiry dates. Pack all sampling supplies in clean sealed totes or coolers for transport to and from the site.
- Vehicle cleanliness is an important factor in eliminating potential sources of contamination.
- Ensure you have enough ice and or ice packs to keep your samples adequately cooled from the time the samples are collected until they arrive at the laboratory.
- Samples must never be permitted to get warm. It is recommended that samples be placed in coolers packed with ice packs or double-bagged ice cubes as soon as they are collected and processed. Samples for most analyses are required to be stored at a temperature less than 10°C from the time they are collected until their arrival at the laboratory. Conversely, samples must not be permitted to freeze unless freezing is part of the preservation protocol. In warmer ambient temperatures it is prudent to repack the cooler with fresh ice for transport to the laboratory.
- While sampling, the inner portion of sample containers and lids/caps must never be touched with anything including gloved hands.
- Petroleum products such as gasoline, oil, and exhaust fumes are prime sources of contamination. Spills or drippings which are apt to occur in boats must be controlled and or removed immediately. Exhaust fumes, which are of particular consideration when sampling from a boat must be downwind from the sampler during sample collection. Cigarette smoke can contaminate samples with lead and other heavy metals. Air conditioning units are also a source of trace metal contamination.
- Sample collectors should keep their hands clean, gloved and refrain from smoking or eating while working with samples.

2.2 Decontamination Techniques

Standard decontamination techniques are required for sampling and field equipment to avoid contamination of sediment samples between sample locations. To decontaminate sampling equipment between each sample collection, wipe away visible sediment with clean paper towel, and or rinse the equipment with clean or deionized water. Detergents should be avoided unless the sampling equipment has come into contact with oil, grease or hydrocarbon compounds. This is especially important for samples that will be tested for phosphorous or phosphorous-containing analytes. Equipment which has been used for or has come into contact with oil, grease or hydrocarbon components should be washed in a dilute solution containing a mild detergent (e.g., Alconox^{TM} or Liquinox^{TM}). Any equipment cleaned with detergent must be thoroughly rinsed with potable or preferably distilled/deionized water and dried with clean paper towelling. Dispose of all gloves, paper towel, and contaminated cleaning materials in an appropriate manner. To prevent cross contamination gloves must be changed between samples and after equipment decontamination.

2.3 Field Quality Control

Quality control is an essential element of a field quality assurance program. In addition to standardized field procedures, field quality control requires the submission of replicate, blank and in some cases, reference samples. The number and type of replicate, blank and reference sample submissions will depend in large part on the objectives of the sampling program.

Replicate samples detect heterogeneity within the sample material, allow the precision of the measurement process to be estimated, and provide an opportunity to demonstrate that a sample is reproducible. Blank samples are used to identify, where present, the inclusion of contaminants in or on equipment (equipment blank), the ambient environment (field blank), or the laboratory (travel blank). Blank samples can be prepared to capture any aspect of the sampling process. Reference samples are made up of prepared matrix materials with established analytical parameters. Reference samples are used primarily to document potential biases of the analytical (laboratory) process. The timing and the frequency of replicate, blank and reference samples are established during the project design and will vary with each project.

2.3.1 Replicate Samples

To determine the degree of heterogeneity within the sediment being tested as well as the precision of the analytical process, it is necessary to take replicate samples. These replicates can consist of multiple grab samples from the same general area to measure site heterogeneity, or portions of a single grab to measure more localized heterogeneity. Grab samples that are homogenized in the field by physical stirring and then sub-sampled into replicates serve as a tool to estimate the analytical precision of the testing process. Replicates from a sediment core sample would be collected from the same depth range of the same core sample. Sections 4.1 to 4.3 provide protocols for the collection of replicate samples.

2.3.2 Reference Samples

Reference samples are prepared using sediment that has been tested by a statistically significant number of laboratories and then preserved to maintain the stability of the matrix. Reference materials are certified by national or international agencies or standards agencies such as the National Research Council of Canada. Reference materials are subjected to a large number of analyses performed by independent laboratories using several different analytical techniques. Data produced during this testing process provides mean values and confidence intervals for these substances.

Reference samples should be submitted to the analyzing laboratory along with the samples collected in field. Reference sediment samples are distributed as a dry dust, therefore, the analyzing laboratory will be aware that they are reference samples. Nevertheless, the reference material should be transferred into an appropriate laboratory-supplied sample container for submission. The sample container should be labelled in a manner that does not indicate the identification of the reference material.

3 Sampling Equipment

In general, there are three established sediment sampling methods and each method deploys specific equipment. Surface sediments in shallow water is typically sampled by hand using a spoon, scoop or trowel. Grab samplers are deployed from a barge or boat to collect surface sediments in water that is too deep to stand in or wade into. Grab samplers, due to their ease of use and the large volume of sediment they capture, are ideal for assessing the quality of relatively shallow sediment and to evaluate the horizontal distribution of parameters. Core samplers are used to collect a sediment depth profile and are better suited for assessing historical depositions and the vertical distribution of parameters. Table 3.1 provides a summary of the equipment used to collect surface sediment samples. Table 3.2 provides a summary of the equipment used to collect sediment core samples. The selection of an appropriate sampling method is constrained by site conditions and sample analytical requirements and will ultimately be dictated by the purpose of the study and the resulting sampling program design.

3.1 Sampling by Hand: Scoop, Spoon or Trowel

Sampling by hand using a scoop, spoon or trowel is the simplest and most efficient way to obtain a sample of exposed sediments or of sediments in shallow water, under minimal current conditions. Typically, this type of sampling is most effective for small streams, stream or river banks or sandbars, or intertidal zone sediments under low tide conditions. Sediments located below shallow water can be sampled from shore or by wading if care is taken to minimize the loss of fine-grained sediments during retrieval. Sampling equipment required for this method of sample collection includes a scoop, spoon or trowel and a bowl or pail.

In water that is too deep to wade into scoops or spoons may be attached to a piece of conduit to collect the sample providing the water body does not exhibit a current. This method is typically not recommended as sediment retrieval is difficult and not reliable under less than ideal conditions. Instead, for surface sediment sampling in aquatic environments where sediments are submerged beyond a wadeable depth, grab sampling is recommended.

3.2 Grab Samplers

Due to their ease of deployment and capture capacity, grab samplers are widely used to collect sediment samples. Most designs incorporate a set of jaws which bite into the sediment when activated and shut to contain the captured material. Certain designs, like the Ekman and Ponar grab samplers, include vented or hinged tops that allow water to flow freely through the device during descent. This free-flow feature reduces sediment disturbance that would otherwise be created by a shock wave inherent in grab samplers which don’t provide this feature.

Two advantages of grab samplers are that they are easy to use and that they obtain relatively large volumes of sediment per grab. A disadvantage is that during retrieval fine surface particulates can be carried away by outflowing water during ascent. Additionally, sediments must be relatively soft/fine-grained for grab sampling as gravel and other debris can prevent the jaws from fully closing which would result in sample loss during retrieval. Several designs of grab samplers are available, varying by size, weight and sediment penetration depth. Brief descriptions of select available grab samplers are provided in the following sub-sections. Summaries of equipment specifications, including advantages and disadvantages for these samplers, are provided in Table 3.1.

3.2.1 Ekman Grab

Ekman grabs (Figure 3.1) are variable in size with larger models requiring the use of a winch or crane hoist for operation. The dimensions of a common size deployed are 15 cm x 15 cm. These grab samplers have historically been fabricated in brass, but stainless steel is now used and is more desirable as they present fewer problems with corrosion and they are less likely to affect metal concentrations in sediment samples. The spring-tensioned, scoop-like jaws are mounted on pivot points and are set with a trigger assembly which is activated from the surface by a messenger. Flaps on the top of the grab sampler open during descent, allowing water to flow freely through it. The flaps close during ascent to reduce the loss of sample material during retrieval. The sediment collected in the sampler can either be sub-sampled through the top flaps or the contents of the sampler can be dumped into a tray and treated as a bulk sample. The Ekman sampler is suitable for collecting soft, fine-grained sediments (silt and sand). Larger substrate particles such as gravel and objects such as shells and wood tend to prevent the jaws from fully closing which results in a loss of sample material. If the jaws are not fully closed upon retrieval, then the sample is not considered to be representative of the sampling location and must be discarded.

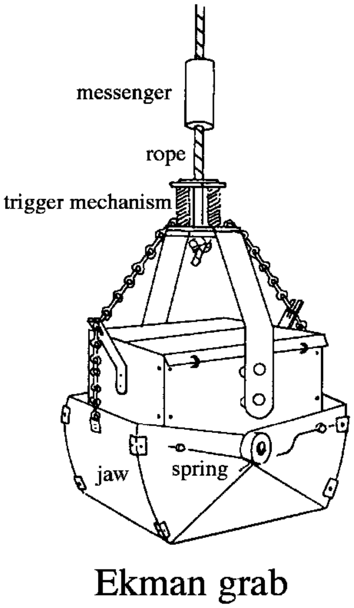


Figure 3.1: Schematic diagram of an Ekman Grab Sampler

3.2.2 Petersen Grab

The Petersen grab sampler (Figure 3.2) consists of a pair of weighted semi-cylindrical jaws which are held open by a catch bar. Upon impact with the sediment (slackening of the rope), the tension on the catch bar is reduced allowing the jaws to close. Auxiliary weights can be added to the jaws to improve penetration into harder, more compacted sediments. There is no access to the sample through the top of the grab sampler and consequently the sediments must be dumped into a tray and treated as a bulk sample. The Petersen grab is suited to the collection of hard bottom material such as sand, marl, gravel and firm clay.

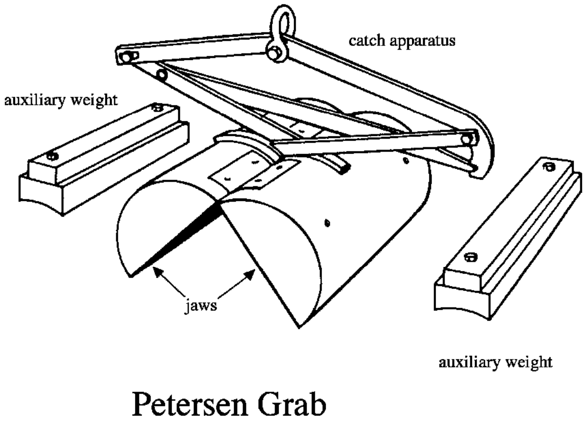


Figure 3.2: Schematic Diagram of a Peterson Grab Sampler

3.2.3 Ponar Grab

The Ponar grab sampler (Figure 3.3) consists of a pair of weighted, tapered jaws which are held open by a catch bar. It is triggered to close in much the same fashion as the Petersen grab. The upper portion of the jaws is covered with a mesh screen which allows water to flow freely during descent, significantly reducing the shock wave that precedes the sampler. Upon recovery, the mesh can be removed to allow access to the sediment for sub-sampling purposes. The Ponar grab is suitable for collecting fine-grained to coarse material and comes in 2 sizes: a smaller, hand-held design referred to as a mini or petite Ponar, and a standard design, which due to its weight will often require a winch or crane to operate.

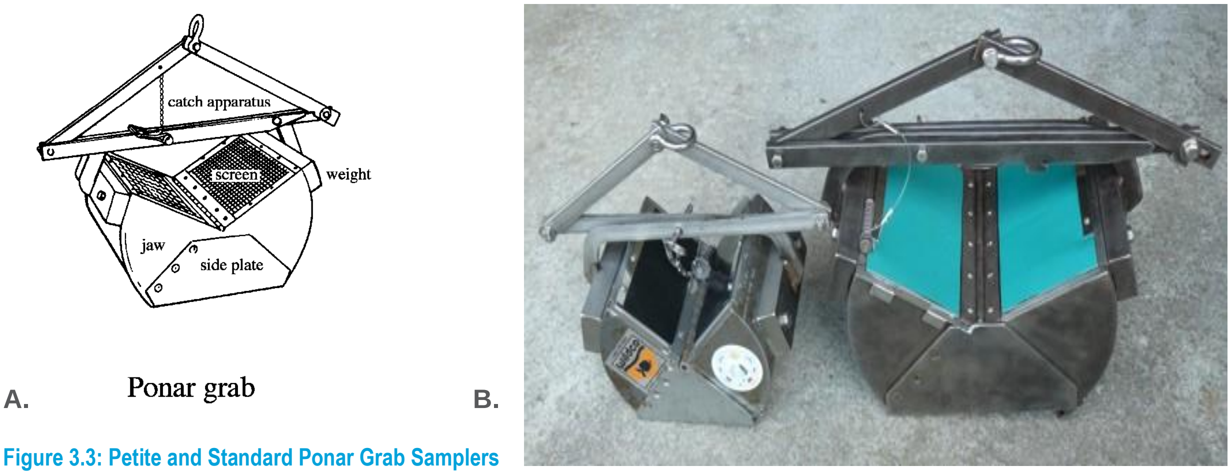


Figure 3.3: Petite and Standard Ponar Grab Samplers
A. Schematic Diagram of a Ponar Grab Sampler; and, B. The two sizes of the Ponar Grab; the Petite (left) and the Standard (right).

3.2.4 Van Veen Grab

The Van Veen grab sampler (Figure 3.4) consists of a pair of weighted jaws which are held open by suspension chains. The Van Veen is a large grab sampler which requires the use of a winch or crane and is typically deployed from a boat or other sampling platform. When the sampler contacts the sediment, the lowering wire slackens and a hook on the release device rotates allowing the suspension chains to fall free. When the lowering wire becomes taut, the chains attached at the top of the release device exert tension on the arms, which cause the jaws to dip deeper into the sediment and close tightly. The upper portion of each jaw is covered by a mesh screen, which allows water to flow freely through the sampler during descent; rubber flaps on the mesh screens prevent loss of sediment during retrieval. The Van Veen grab is suitable for collecting sediments ranging from soft, fine-grained to sandy material.

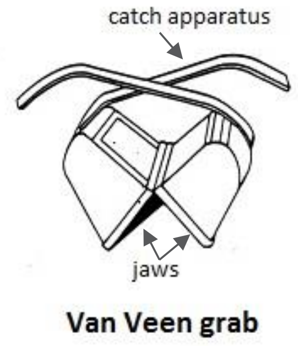


Figure 3.4: Schematic Diagram of a Van Veen Grab Sampler

Table 3.1: Sediment Grab Sampler Comparison Chart

General Sampler Type	Specific Sampler Type	Equipment Information[a]			Sediment Sample Specifics[a]			Appropriate Site Conditions		Advantages	Disadvantages
		Weight Empty (kg)	Weight with Sediment (kg)	Winch/ Crane Required?	Sediment Depth Sampled (cm)	Sampled Area (cm x cm)	Sample Volume (L)	Substrate Types	Current		
Ekman	Standard	3 to 10	10 to 16	No	0 to 10	15 x 15	3 to 3.5	Clay and Silt	Zero to slight	› Easy handling and light weight › Under good (low current, soft sediment) conditions, can obtain a relatively undisturbed sample › Sediment can be sub-sampled through flaps on top of sampler	› Larger objects (e.g., gravel, wood debris) can prevent jaw closure and result in sample loss › Not recommended for high current or high wave conditions › In very soft sediments with high water content, sampler tends to advance too deeply
	Tall	5	21	No	0 to 23	15 x 15	5 to 5.3				
	Large	13	35 to 40	Likely	0 to 10	23 x 23	12 to 14				
Petersen	n/a	34	40 to 60	Yes	0 to 30	30 x 30	9 to 10	Clay to fine gravel	Zero to slight	› Suitable for collection of hard bottom material › Collects large sample volumes	› Sediment cannot be sub-sampled; no access to retrieved sediment from top of the sampler. › Large sampler; requires a winch › Not recommended for high current or high wave conditions
Ponar	Petite	6 to 11	10 to 15	No	0 to 10	15 x 15	1 to 2.5	Fine-grained, soft to firm, sandy	Zero to medium	› Excellent general purpose sampler, capable of collecting most types of surface sediments › Petite ponar is easy to handle and light weight › Jaws of the sampler overlap, reducing washout during retrieval › Design reduces disturbance of sediment upon retrieval › Sediment can be sub-sampled through flaps on top of sampler	› Sampler must be lowered at a steady, slow speed with consistent cable/rope tension, to prevent premature closure › Petite Ponar not recommended for high current or high wave conditions
	Standard	23	30 to 35	Likely	0 to 10	23 x 23	7 to 8.5				
Van Veen	Standard	30	40	Yes	0 to 30	35 x 70	18	Fine-grained to sandy	Zero to strong	› Works well in marine environment and in deeper waters, due to size and weight › Collects large sample volumes › Sediment can be sub-sampled through top of sampler	› Very large samplers; require winch/crane with lifting capacity of 150 to 400 kg
	Large	65	85	Yes	0 to 30	50 x 100	75				

Notes:

[a] Equipment weights, sampling depths and sampled areas vary by commercial product and/or can be customized; these values/ranges are provided as estimates for comparison purposes only.

3.3 Core Samplers

Core samplers penetrate the sediment more deeply than grab samplers; consequently, they provide a cross-sectional slice of sediment layers and information about sediment deposition. The information provided by a core sample enables a vertical evaluation of sediment characteristics as well as the vertical distribution of contaminants. Generally, core samplers consist of a hollow pipe (the core barrel), which varies in length and diameter; a core cutter or cutting head is located at the advancing end of the core barrel to facilitate the sampler's advancement into the sediment. Core samplers are typically lined with replaceable internal liners to prevent contamination between samples. Selection of the liner type is dependent on the sampler type and the type of contaminants being evaluated. Available liner materials include stainless steel, glass, Teflon®, polyvinyl chloride (PVC) or carbon steel. A valve or piston mounted on the top of the core barrel allows water to flow through the barrel during the sampler's descent. The valve shuts following advancement into the sediment to prevent the sediment from flowing out through the valve as the sampler is retrieved. Core catchers are commonly inserted into the cutting head to prevent sample loss during retrieval and can vary in dimensions depending on the sediment type being sampled. Additional features available for core samplers include weights to increase penetration depth and stabilizing fins.

Core samplers typically fall into one of four categories: hand core samplers, gravity core samplers, piston core samplers and vibracore samplers. The coring method selected will depend on a number of site-specific factors including overlying water depth, sediment characteristics and the length of the core desired. Two inherent effects of core sampling that can alter the physical integrity of the core sample are spreading and compaction. Spreading occurs when sediment is pushed to the side as the core barrel advances into the sediment. Compaction occurs when the sediment is pushed downward as the core barrel advances. Both of these factors require consideration when selecting an appropriate coring method for a given site.

3.3.1 Hand Core Samplers

Most hand core samplers are suitable for collecting sediments of soft or medium firmness which are typically encountered in shallow marshes, tidal flats and rivers. In special circumstances hand corers are used in deep waters by a diver. Most core barrels are relatively short, ranging in length from 50 cm to 120 cm and weigh between 5 kg and 17 kg. An example of a hand core sampler is a multi-stage sludge sampler. The sludge sampler collects a 5 cm diameter by 30 cm long sludge/sediment core sample. Additional 30 cm sections can be added to extend the core to a maximum length of 1.2 m. Another example is a Russian peat borer (Figure 3.5), which is a side filling corer designed to collect un-compacted sediment samples. Following insertion, the core tube is rotated to fill the core tube. The Russian peat borer can be used to obtain core samples to a depth of 3 m with little core loss.

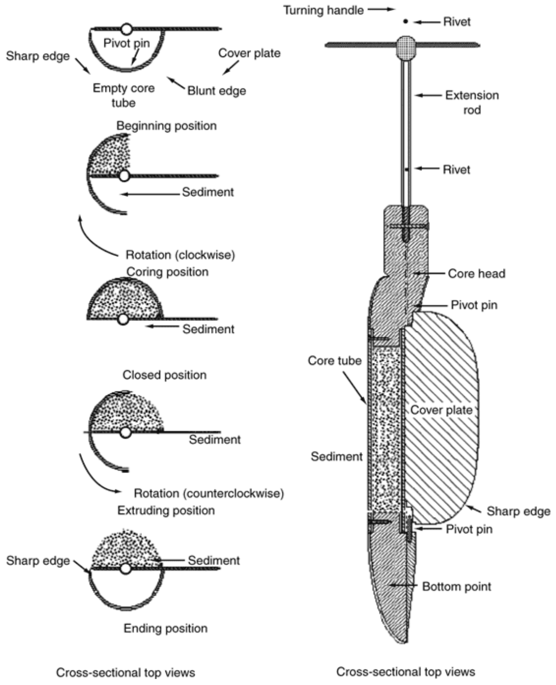


Figure 3.5: Schematic Diagram of a Russian Peat Borer

3.3.2 Gravity Core Samplers

Gravity core samplers rely on the weight of the device and the force of gravity to penetrate sediments. For these samplers to be most effective, the water depth must be sufficient to obtain adequate velocity for the sampler to penetrate the sediment. In soft, fine-grained sediments, gravity core samplers can penetrate up to 3 m. An example of a commonly used sampler for this purpose is the Kajak-Brinkhurst sampler shown in Figure 3.6. Gravity check valves are used in gravity core samplers to allow air and water to pass through the tube as it descends; this mechanism creates a vacuum pressure, which minimizes sample loss. A core catcher at the end of the core sampler will help retain the core inside the sampler upon retrieval. Gravity core samplers can be modified to consist of several core barrels mounted on a single fin/weight system. These multiple-gravity corers have been developed to collect multiple samples from a single location, for evaluation of sediment sampling precision and/or sediment heterogeneity over a small area. Descriptions of select gravity core samplers, including equipment specifications and the advantages and disadvantages of their use are included in Table 3.2.

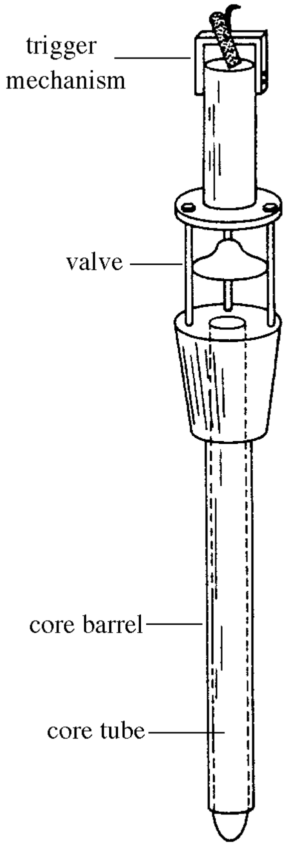


Figure 3.6: Schematic Diagram of a Kajak-Brinkhurst Core Sampler

3.3.3 Box Core Samplers

Box corers are also considered gravity core samplers, but instead of a cylindrical core barrel, the sampler is shaped like a rectangular box. These samplers are used to collect large, relatively undisturbed, rectangular sediment cores for biological and geological studies at various water depths and in different sediment types.

There are two typical box-core designs; the Ekman design, in which there are two bottom flaps that can be triggered and closed like the Ekman grab sampler; and the Reineck design (Figure 3.7), in which a large, shovel-like device slides across the bottom of the box corer to cut off the sample. Many box corers of different designs and sizes are available; Table 3.2 describes box corers, including equipment specifications and advantages and disadvantages.

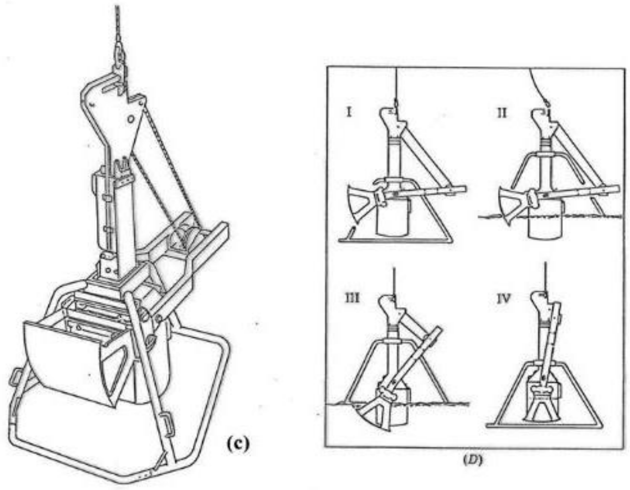


Figure 3.7: Schematic Diagram of a Reineck designed Box Core Sampler

3.3.4 Piston Core Samplers

Similar to gravity core samplers, piston core samplers are lowered to the streambed using gravity; however, when the piston core sampler reaches the sediment surface a piston located inside the core barrel stops and the core barrel continues to advance and penetrate the sediment. This creates a vacuum within the core barrel, reducing resistance and enabling a deeper penetration of the core barrel into the sediment. The vacuum in the core barrel also reduces sample disturbance and sample loss. In soft-sediment, piston core samplers can penetrate up to 30 m. Due to their large size and required retrieval mechanisms, these samplers are typically deployed from large boats or platforms.

3.3.5 Vibracore Samplers

Figure 3.8: Vibracore Sampler
(www-udc.ig.utexas.edu)

Vibracore samplers are equipped in a variety of configurations. The penetration and advancement of a core barrel into sediment is facilitated through vibration. An electric motor creates a vibration frequency range that enables the corer to displace sediment and advance the corer with limited sediment compaction or spreading, making it an ideal method of sampling for soft or loosely consolidated sediments. Vibracore samplers can collect cores of over 10 m in length. Due to their large size, required deployment with an electric motor and retrieval mechanisms, these samplers are typically deployed from large vessels or platforms as shown in Figures 3.8 and 4.3.

Table 3.2: Sediment Core Sampler Comparison Chart

General Sampler Type	Specific Sampler Type	Equipment Information[a]		Sediment Sample Specifics[a]		Appropriate Site Conditions	Advantages	Disadvantages
		Weight Empty (kg)	Winch/ Crane Required?	Sediment Core Length	Core Barrel Inner Diameter (cm)	Substrate Types		
Hand Corer	Multi-stage sludge/sediment sampler	5 to 17 kg	No	50 to 120 cm	3.5 to 7.5	Fine to medium-grained, soft to semi-compacted	› Easy handling and light weight › Can be operated manually in shallow environments	› Only to be used in shallow water or by divers in deep water › Small core diameter; limited sediment available for analysis
Gravity Corer	Kajak-Brinkhurst (K-B) Corer	9	No	50 to 75 cm	5	Fine-grained, soft	› Easy handling and light weight › Operated manually	› Messenger system to tigger sampler closure can be unreliable (however, on some models an automatic closure system is available)
	Phleger Corer	8	No	50 cm	3.5	Fine to coarse-grained, soft to semi-compacted, peat and vegetation roots	› Can be used in marshes and areas of peat/vegetation root matting	› Small core diameter; limited sediment available for analysis
	Benthos Gravity Corer	25	Yes	Up to 6 m	5 to 7	Fine-grained, soft	› Simple and reiable in low current, relatively shallow conditions › Cost effective to operate	› Requires fine-grained/soft sediments and consistently calm site conditions
Box Corer		Up to 800	Yes	Up to 1 m	Up to 2 m x 2m	Fine-grained, soft	› Recovers large, rectangular sediment sample of excellent quality › Limited disturbance at the sediment/water interface	› Due to the heavy weight and required lifting capacity (on the order of 2,000 to 3,000 kg), this equipment requires a large vessel with sufficient lifting capacity and deck space › Recommended for use in areas > 1 m soft sediment available
Piston Corer		Up to 1,500	Yes	3 to 30 m	9 to 10	Most sediment types	› Recovers longer, less disturbed and more complete cores (compared to gravity corers) › Can be used in oceans and deep, large lakes	› Due to the heavy weight and required lifting capacity (on the order of more than 2,000 kg), this equipment requires a large vessel with sufficient lifting capacity and deck space and an experienced crew
Vibracorer		Up to 4,000	Yes	Up to 10 m	7 to 11	All sediment types	› Vibration enables penetration of sediments with higher resistance (e.g., sandy, unconsolidated sediments)	› Due to the heavy weight and required lifting capacity (on the order of more than 2,000 kg), this equipment requires a large vessel with sufficient lifting capacity and deck space and an experienced crew › Motor required to generate vibration for core barrel

Notes:

[a] Equipment weights, barrel lengths and diameters vary by commercial product and/or can be customized; these values/ranges are provided as estimates for comparison purposes only.

3.4 Other Sediment Sampling Equipment

3.4.1 Bilge Pump: The "Guzzler" Method

The Guzzler method employs a hand-held, piston-type bilge pump to assist in sampling sediments in shallow freshwater environments, including streams, lakes and rivers. Typically, the Guzzler method is used when fine-grained sediments are patchy or limited in thickness (i.e., deposition is limited to a few millimetres), making surficial grab sampling or scooping difficult and/or ineffective. The guzzler method is typically employed in waters that are less than 1.5 m deep but can be used in waters up to 3 m deep if there is minimal current and the equipment is modified.

Prior to sampling the target area (e.g., 1 m^2) is defined and marked. A hand-operated bilge pump is then used to "vacuum" sediments from the defined area into a bucket. Bucket contents are mixed well, and the bucket is then left undisturbed to allow suspended sediments to settle out. Overlying water in the bucket is slowly decanted and discarded allowing the remaining sediments to be sampled.

3.5 Sediment Particle Size Samplers

Although sediment samplers can be used for the purpose of determining the distribution of streambed particle sizes, they are not ideal. Much of the very fine sediments are lost as a result of the pressure wave that precedes these samplers and the washout that occurs as the samplers are retrieved. Better estimates of particle size distribution can be obtained through the use of sediment traps which are deployed over a prescribed time frame, or samplers that collect an entire portion of the streambed such as the McNeil sampler and the Freeze core sampler. The Freeze core technique is elaborate and cumbersome and consequently will not be discussed here. Detailed descriptions can however be obtained from Ryan (1970) and Sookachoff (1974).

Sediment traps are simply open buckets of a given volume that are filled with cleaned gravel and immersed in the streambed. They are collected at a later date and submitted for mechanical analysis of sediment particle size.

The McNeil sampler shown in Figure 3.9 consists of a cylinder that defines the portion of the streambed to be sampled and an attached basin that is used to store the collected sediments and trap the suspended fines.

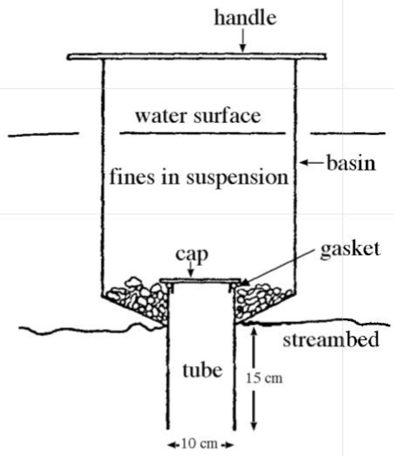


Figure 3.9: McNeil Particle Size Sampler

4 Sediment Sampling Methods

Sediment samples are collected for analysis of chemical and physical properties, or to assess the benthic biotic community structure (biomass and/or taxonomy). For either analysis a number of basic requirements must be met to ensure that the sediment samples are representative of the sampled body:

- The sampling device must penetrate the sediment to a sufficient depth to accurately measure the variables of concern.
- The sampling device must enclose the same volume of sediment each time a sample is collected.
- The sampling device must close completely each time.
- Care should be taken not to mitigate sediment disturbance prior to deployment of the sampling device. Note that since sediment samplers disturb overlying waters, they should be used only after any ambient water sampling has been completed at the site.

The sediment sampling methods described below are presented in one of three groups which are defined by the techniques and associated equipment used to obtain sediment samples. The three groups are:

1. Sampling by hand, using a scoop, spoon or trowel (Section 4.1);
2. Grab sampling (Section 4.2); and
3. Core sampling (Section 4.3).

Appropriate sampling methods are determined during the sampling program design and planning stages. Upon arrival at the sampling site, it is important to confirm that the site’s current conditions satisfactorily concur with the assumptions made during the planning stage such as water depth, current speed, sediment grain size, etc. This is important because it is these assumptions upon which the equipment and methods for sampling were selected. If the site’s conditions differ significantly, modifications and or changes may be required to ensure the safety of field staff and or the effectiveness of the equipment and methods deployed.

Additionally, before employing any of these techniques in the field, samplers must be confident that they have all the information and training required to effectively and safely collect sediment samples. This is especially important when operating grab and core sampling devices. The jaws of grab samplers are often spring-loaded when set and great care and experience is required to ensure that the sampler is safely deployed and retrieved. Large core samplers deployed from vessels or platforms should be operated by trained personnel. While samplers have been grouped by type, specific devices will differ by manufacturer. Operating instructions provided by the manufacturer should be carefully reviewed prior to deployment of the selected sampling device.

Prior to deployment, sampling equipment should be decontaminated using the methods described in Section 2.2. If relevant and/or applicable, sampling should begin in the suspected “cleanest” area of the site and proceed to the more contaminated area/s of the site. The physical locations selected for sampling should contain sufficient sediment and not be located in rocky areas or areas of bedrock. If possible, each sampling location should be physically marked for easy reference and to enable efficient relocation of the sampling location if the site is to be sampled again at a later date. For example, sampling stations in streams and small rivers are typically marked with flagging tape fixed to shoreline vegetation. Ensure that GPS coordinates are collected and recorded in real time at each sampling station.

4.1 Sampling by Hand

Procedure for Sampling by Hand

1. Using a scoop, spoon or trowel, scoop sediment to a predetermined sampling depth (e.g., 0-5 cm, as outlined in the sediment sampling program plan).
2. If the sediments being sampled are submerged, slowly and with control retrieve the scoop, spoon or trowel through the water column to minimize turbulence and the loss of fine-grained surface sediments.
3. A consistent and predetermined sediment volume should be retrieved from each sampling location. Sample from downstream to upstream locations.
4. Collect sediment samples from a consistent sampling depth and ensure that sufficient sediment is obtained for the selected laboratory analyses. If the sample will be screened 63 µm for metals testing, ensure that enough sediment is collected to satisfy the volume required for the analytical test by increasing the sample volume to compensate for any potential loss of material during screening.
5. Place the retrieved sediments into a container such as a shallow pan, a pail or bowl. Allow suspended sediments to settle out and carefully decant excess water.
6. Immediately record observations of the sediment such as texture, colour, odour, presence of biota, presence of detritus, and the depth of sediment sampled in the field log book (as outlined in Section 1.4).
7. With the exception of samples collected for analysis of volatile organic compounds, use a clean spatula or spoon to thoroughly mix the sediment to a homogeneous state. Place an aliquot of the sediment into a pre-labeled laboratory supplied sediment sample container.

   Note: *For samples that are to be analyzed for organics, the spatula/spoon and container must not be plastic and the sample container must be a laboratory-supplied glass jar. For samples that are to be analyzed for metals, the spatula/spoon must not be metallic.*
8. Place the collected samples directly into a cooler containing ice or ice packs.

   Tip: Second hand stainless steel spoons can be purchased for this type of sampling. Prior to use decontaminate the spoons using nitric acid. Decontaminated spoons can be placed into sealable bags in preparation for the sampling event. If enough spoons are prepared, decontamination in the field can be avoided.

Sample Homogenization

Sediment samples must be thoroughly mixed to ensure that any given sub-sample is representative of the sampled sediment at that particular location and depth. Note that samples collected for volatile organic compound analysis should not be homogenized. If homogenization is occurring in a mixing bowl, adequate mixing can be achieved by stirring the material in a circular fashion, reversing direction and occasionally turning the material over. Repeat several times until the sample is well-mixed.

(a)

Figure 4.1: Sample Homogenization

4.2 Grab Sampling

Procedure for Grab Sampling

1. Review the manufacturer's operating instructions prior to device use.
2. Set the grab sampling device with the jaws cocked open. Great care should be taken while dealing with the device while it is set; accidental closure could cause serious injuries.
3. Ensure that the rope is securely fastened to the sampler and that the other end of the rope is tied off to the sampling platform (e.g., to bridge, boat or barge) to prevent device loss.
4. Slowly lower the sampler over the upstream side of the bridge or boat until it is resting on the sediment; the weight of the sampler is adequate to penetrate soft sediments. At this point, the slackened line will activate the mechanism that releases the jaws of Ponar and Petersen grab samplers.
5. If using the Ekman grab sampler, send the messenger down to 'trip' the release mechanism.
6. Retrieve the sampler slowly to minimize the turbulence effect which may otherwise result in the loss of surface sediments.
7. Place a container such as a shallow pan or a mixing bowl beneath the sampler as soon as it reaches the sampling platform. Inspect the sediment sample through the screen or flaps of the sampler to confirm that a complete sample has been obtained.

   It is important to note that if the jaws of the device were not completely closed, the process will have to be repeated and the incomplete sample must be discarded.

   After a sample has been successfully collected dump the unwanted sediment over the downstream side of the bridge or boat, or at shore if sensitive water uses exist.
8. If a target depth is to be sampled use a clean spatula or spoon to select that layer of sediment from the top flaps of the grab sampler. A depth selection can be made of the surface sediments (1 – 2 cm) by carefully scooping off the top undisturbed layers. In some lakes, for example, a grab sample to a depth of 10 cm to 15 cm is typical and the vertical heterogeneity may represent many years of lake or watershed changes. If a bulk sample is required gently open the jaws and allow the sediments to empty into the container.
9. Immediately record in a field log book, observations of the sediment such as texture, colour, odour, presence of biota, presence of detritus, and the depth of sediment sampled (as outlined in Section 1.4).
10. With a clean spatula or spoon, either remove the top portion of the sediment (when this is outlined by the study design), or thoroughly stir the sediment to homogenize. Place aliquots of the homogenized sediment into pre-labelled sediment sample bottle/s as needed. Replicate samples can be collected from the homogenized mixture.
11. Place the samples in a cooler with ice or ice packs without delay.

    Note 1: *Many lake and marine sediment samples are anoxic and a number of chemical changes will take place if the samples are exposed to atmospheric oxygen. If samples are to be retained with as low an oxygen content as possible, they will need to be packed inside multiple airtight containers and frozen to minimize the chemical and microbial transformations. Be warned that it may still have a strong odour even if sealed and frozen! If samples are frozen, allow sufficient head space for expansion of the sample. Otherwise, the container will split or break when the sample freezes.*

    Note 2: *For samples that are to be analyzed for organics, the spatula/spoon and container must not be plastic (the sample container must be a glass jar provided by the laboratory). For samples that are to be analyzed for metals, the spatula/spoon must not be metallic.*

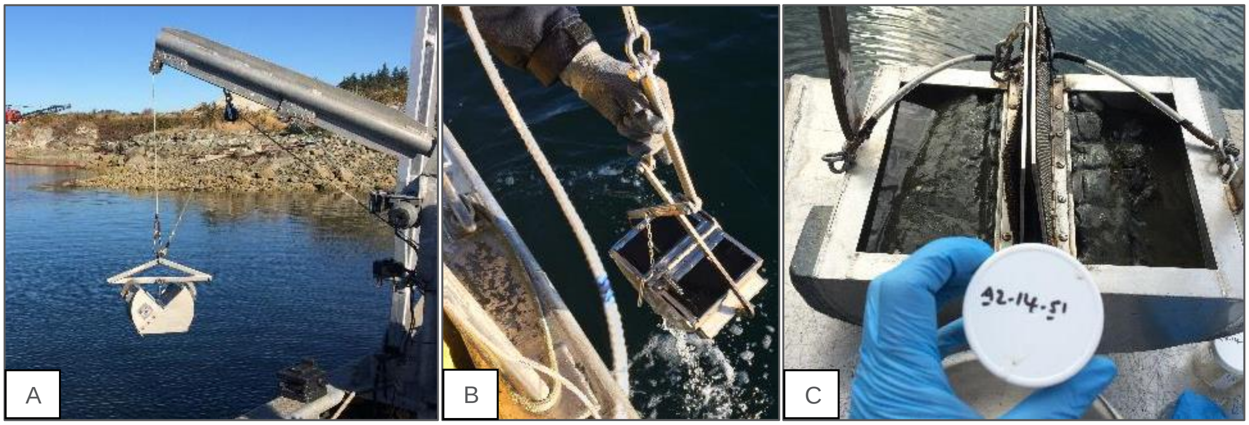


Figure 4.2: Ponar Grab Sampler Configurations (A) Standard Ponar grab sampler attached to winch/crane secured to a boat; (B) Petite Ponar grab sampler retrieval by hand; and, (C) Inspecting sediment through top flaps of a Ponar grab sampler.

4.3 Core Sampling

The following core sampling procedures provide general instructions for gravity core sampling. This protocol assumes that large coring equipment such as gravity corers, piston corers and vibracorers will be deployed from a large vessel or barge and that both the corer and the vessel will be operated by trained professionals. For this reason, a description of core processing techniques and considerations is provided however specific instructions on core sampler deployment is not included.

Procedure for Core Sampling

1. Open the valve and set the trigger mechanism. Ensure the rope is securely fastened to the corer and attach the other end of the rope to the sampling platform (e.g., barge or boat).
2. Lower the corer to approximately 5 m above an area of undisturbed sediment (drop depth may vary with sampler size, weight, and sediment type). Allow the corer to fall freely into the sediment. Sufficiently heavy corers can simply be lowered into the sediments to avoid disturbance caused by impact.
3. Send the messenger down to release the trigger mechanism.
4. Carefully retrieve the sampler stopping its ascent before breaching the water's surface. Prior to removing the corer from the water place a stopper into the bottom opening to prevent the loss of sample material.
5. Remove the liner from the corer and stopper the upper end. Store erect. Repeat this procedure to obtain replicate cores of at least 0.5 m in length.
6. Carefully siphon off most of the water overlying the sediment in the core tube but leave a small amount at the sediment-water interface. Take care to avoid disturbing the sediment-water interface. Processing is typically completed onshore however this can be done on the sampling platform if space and time permit.
7. Make careful measurements of the total length of the core and precise points (nearest mm) of any layers of sediment that appear to be different. Note any changes in stratigraphy, such as colour and texture.
8. Insert a rubber stopper into the lower end of the liner tube to form a watertight seal. The core is then gently and slowly forced upward to the top of the tube. Some advanced corers come equipped with a stopper which allows the increment of each sediment slice to be adjusted.

9. As the sediment core is extruded, carefully cut slices (one cm or more thick) with clean spatulas and place the slices into labeled sample jars. A core slicer greatly assists in this operation, however good samples can be obtained without a core slicer when processed carefully.

   Note: For samples that are to be analyzed for organics, the spatula and container must not be made of plastic and the sample container must be a laboratory supplied glass jar. For samples that are to be analyzed for metals, the spatula must not be metallic.

10. Place the samples directly into a cooler filled with ice (preferred) or ice packs without delay.

11. Large gravity corers, piston corers, or vibracorers, will be operated by trained personnel who will remove the sediment core from the equipment; typically, the sediment core will be in a liner. Core sample recovery is highly dependent on the operators' technique and experience, and the sediment conditions of the site. After the core barrel is advanced to the limit of the run, the core barrel and extensions are withdrawn from the hole. Typically, the recovered sediment core is then collected from the core barrel in the liner material. Cores may be processed on the sampling platform or vessel, if space and time permit, or retained for evaluation on shore.

    - As a result of the deployment technique, the outer surface of the core may be smeared or disturbed obscuring stratigraphic detail. To reveal these details the core should be split longitudinally to expose a fresh surface for logging.
    - Sediment cores should be logged in accordance with SOP D3-1. The exposed core should be flanked with markers to identify the depth at the top and bottom of the core run, and a placard identifying the borehole number, the project number and date. Once configured a photograph should be taken to produce a permanent record of the core's details.
    - Consideration should be given to collecting samples at changes in stratigraphy as inferred from changes in deployment action, observed changes in sediment characteristics, or at predetermined depths (e.g., continuous, every 0.75 m or 1.5 m).
    - Samples collected for laboratory or headspace analysis (screening) may be collected directly from the recovered core. Laboratory and headspace samples should be collected from the inner portion of the core where possible to minimize the possibility of including contamination which may be present on the outer surface of the core sample from shallower soils or liquids co-recovered in the core run.
    - Information specific to the method of the coring devices deployment should be recorded along with the length of run and the length of core recovered. During extrusion, the core will have a tendency to compress or lengthen which should be described and accounted for when logging the details of the core.
    - If possible, an opinion should be made regarding the depth interval of missing core material when core recovery less than 100%. Core recovery should be recorded on the sediment core log. In some cases, this may be obvious, for instance drilling from a dense material into a softer material may result in spreading or compaction, rather than recovery.

Figure 4.3: Photos of Vibracore Sampling and resultant Core.

4.4 Sampling Methods for Special Conditions

4.4.1 Stream and River Sediment Sampling

Sediment sampling in deep sections of rivers and streams rarely involves the use of core samplers as these devices require that flow be minimal (very few rivers world-wide have sufficiently low flow). Alternatively, core samples can be collected in shallow, flowing waters by physically pushing the corer into the sediment by hand.

It is useful to have some understanding of the currents at the sampling site. Strong near-bottom currents can lead to poor equipment deployment, deflect a grab sampler, or require a long cable/wire to be deployed. Care should be taken to ensure that the weight of the sampler is adequate for the particular current conditions and that the sampler collects sediment at or very near the desired sampling site. Strong current conditions can pose a safety risk to sampling personnel wading into these waters or sampling from a platform/shoreline. For sampling programs that include locations with strong currents and or other potentially dangerous conditions extra safety precautions should be included in the sampling plan. These precautions may include special training such as swift water training and equipment such as lifejackets and safety harnesses.

4.4.2 Lake Sediment Sampling

Regardless of the equipment chosen for sample collection, it is necessary to know the water depth at each station before starting. If water depth information is unavailable, it is recommended that it first be measured. Measurement equipment can range from a weighted rope to an electronic depth sounder. The purpose is to ensure adequate cable (rope) length for operation of the equipment and to control the speed of entry of the sampler into the sediment. The speed of deployment of the sampler can be critical to effective operation and sample recovery. A deployment that is too rapid will generate an increased shock wave advancing in front of the equipment. This shock wave can displace the soft unconsolidated surface sediments that may be desired for the sample. Rapid deployment may also cause equipment malfunction, such as activating the trigger mechanism before the device reaches the sediment. In the case of core samplers, if the deployment is too slow an insufficient quantity of sediment will likely result. Since site-specific conditions will dictate the speed of sampler deployment, the specifics should be recorded in the field log book (i.e., the height from which the corer was allowed to free fall).

4.4.3 Marine Sediment Sampling

Sediment sampling can be planned for the intertidal or subtidal zone of marine environments. It is generally recommended that surficial sediment sampling in the intertidal zone be completed by hand in low tide conditions. Subtidal sampling or sampling of the intertidal zone at high tides will need to be completed from a boat (Section 4.4.4) or a barge/platform. The success of these sampling programs is highly weather dependent, as weather, particularly wind, can create wave activity that can disrupt sediment sampling operations by affecting the efficacy of the sampling equipment's deployment and retrieval.

Currents, typically associated with tides, are important to consider when sediment sampling in the marine environment. Additionally, water depths to sediment can change significantly in nearshore areas due to tidal fluctuations and should be considered when planning sampling programs and determining the appropriate sampling equipment to be deployed. Care should be taken to ensure that the weight of the sampler is adequate for working in the particular current conditions and that the sampler collects sediment at or very near the desired sampling site.

4.4.4 Sediment Sampling from a Boat

The collection of deep water samples requires that at least one member of the sampling group be very familiar with boat operation and safety. If the sampling trip involves the use of a boat one member of the group must be designated as the vessel operator. The vessel operator must possess 'proof of competency' to operate the vessel. It is the vessel operator's responsibility to ensure that the weather forecast and/or marine conditions for the sampling period do not exceed the vessels ability. If conditions are poor, then the sampling trip should be postponed. Establish a trip contact and advise the contact of your departure and expected return times. Check in with the contact before you set off in the boat and upon your return to shore.

Fast flowing river water requires specific training and or experience. If the boat is being used for river sampling it is essential that the vessel operator be very experienced with river boating. Ideally, there should be three people involved in the sampling trip when it involves boating on a river. Two people are responsible for collecting the samples, taking field measurements and recording field notes. The remaining person is responsible for boat operation only.

If sampling for hydrocarbons, be aware of boat exhaust as a potential source of contamination. Do not retrieve sediment samples next to the engines exhaust outflow and be mindful of wind direction while processing samples on the boat.

Sampling should begin downstream and work upstream. This proactive measure will allow the current to return your vessel to your starting point if mechanical problems are encountered.

Procedure for Sediment Sampling from a Boat

1. When a sample site is reached, the boat operator will idle into the current to maintain the boat's position. Use reference points on shore to do this.
2. Water column samples must be obtained before sediment samples.
3. Collect sediment samples with the relevant sampler, as outlined in Sections 4.2 or 4.3, above.

4.4.5 Winter Sampling and Sampling Through Ice

Sampling in winter weather conditions present additional elements of danger and as such a safety assessment should always be conducted once on site. If conditions present unreasonable safety risks abandon the sampling event. Always proceed with caution over ice and do not jeopardize your safety in pursuit of sample collection.

Check the ice for thickness with a rod or ice chisel every few steps and do not proceed if the ice thickness is less than 8 cm. Wear a harness and life-line and always have a team member on shore.

For lake sampling, it is important to consider that ice near the outlet of a lake is often thin; therefore, caution should be used when sampling this area of a lake. Ice may also be thin where a stream enters a lake or where groundwater enters a lake.

As flow patterns in rivers and streams are generally more complex than in lakes, there are additional safety factors to consider. Honeycombed ice and areas over rapids should always be avoided. Be aware that ice downstream from bridge supports may be thin as a result of modified flow patterns and de-icing agents.

Generally, winter sampling on rivers follows a similar protocol to sampling lakes in winter. The primary exception occurs when the ice is unsafe; when this is the case, sample stations that are accessible from a bridge are the only option.

Procedure for Sampling in Winter & Ice Conditions

1. With safety considerations in mind, winter sampling locations should be as close as possible to the summer locations. The sites should be chosen where the water is known to be deep enough to avoid stirring up bottom sediments while drilling the hole and to ensure that there is water movement under the ice at the selected spot (in a river/stream environment).
2. Clear loose ice and snow from the sampling location, and drill through the ice with a hand or motorized auger. Keep the area around the hole clear of potential contamination (e.g., dirt, fuel, oil, etc.). At least one member of the sampling team should be familiar with the operation and safety of both motorized and hand operated augers.
3. Collect sediment samples with the relevant sampler, as outlined in Sections 4.2 or 4.3, above.

4.5 Other Sediment Sampling Methods

4.5.1 The Guzzler Method

Procedure for the Guzzler Method

1. Identify the sampling area by placing a frame (e.g., 1 m^2) on the sediment bed to define the sampling area.
2. Use a hand-operated bilge pump to “vacuum” sediments from the defined sampling area and transfer the collected sediments into a clean bucket. As sediments are highly disturbed through this sampling process, this collection method is not suitable for the analysis of volatile organic compounds (VOCs), or any sampling that requires minimally disturbed sediment.
3. Mix the contents of the bucket well and leave to sit undisturbed allowing suspended sediments to settle out. When the coarse-grained sediments have settled out, excess water should be carefully decanted from the bucket, and the bucket should again be left to sit undisturbed allowing the finer-grained sediments to settle out. When the sediments have satisfactorily settled out, carefully decant the remaining water from the bucket, leaving behind the collected sediment.
4. Estimate and record the quantity (volume/weight) of sediment recovered and record observations of the sediment such as texture, colour, odour, presence of biota, presence of detritus, and the depth of sediment sampled (as outlined in Section 1.4).
5. With a clean spatula or spoon, thoroughly stir the sediment in the bucket to homogenize. Place aliquots of the homogenized material into pre-labeled sediment sample jars.

   ***Note**: Samples collected for the analysis of organic compounds, the spatula/spoon and container must not be plastic, and the sample container must be a laboratory supplied glass jar. For samples that are to be analyzed for metals, the spatula/spoon must not be metallic.*

6. Place the samples into a cooler with ice or ice packs without delay

4.6 Sampling for Sediment Particle Size

4.6.1 McNeil Sampler

Procedure for the McNeil Sampler

1. Wade into the water downstream of the intended sample collection site.
2. Remove the cap from the sampling tube. Ensure that you are in water that is sufficiently shallow so the sampler will not be swamped when the tube portion is inserted into the sediment.
3. Thrust the sampler through the water column and force the tube into the sediment until the bottom of the collecting cylinder is on the streambed.
4. Reach in and remove all the streambed material that is in the tube.
5. Recap the tube and carefully withdraw the sampler from the sediment. Return to shore and pour the contents of the sampler through a fine mesh sieve into a collecting pan.
6. Transfer the water from the pan to a pre-labeled bottle. This bottle can either be submitted for total suspended sediment analysis (non-filterable residue), or to a pre-determined lab for hydrometric particle size analysis. The larger materials that were trapped in the sieve must be submitted to one of the facilities capable of mechanical analysis for size. These can be transported in well labeled heavy duty plastic bags.

4.6.2 Sediment Traps

Procedure for Sediment Traps

1. In preparation for the sampling trip, gravel of fairly uniform size should be collected and cleaned. Place the cleaned gravel in four litre buckets (fill each bucket to the rim). Replace the lids.
2. Once in the field, dig a hole in the streambed large enough that the bucket will be immersed in the sediment to the point that the top will be flush with the streambed. Wait until the disturbed fine sediments have cleared before you place the bucket in the hole.
3. While the lid is still on, gently place the bucket in the hole and surround it with streambed material until it is secure. Once again, wait until disturbed materials have cleared before removing the lid.

   ***Note**: Never walk upstream of the buckets as this will disturb sediments that will be captured in the sediment trap.*
4. After a predetermined sampling period as outlined by the project design (usually 2 - 4 weeks), gently replace the lid and remove the bucket from the streambed.
5. Submit the bucket(s) to a qualified laboratory for mechanical (particle size) analysis.

4.7 Sampling for Parameters Requiring Special Handling

4.7.1 Volatile Organic Compounds

Collecting sediment samples for VOC analysis requires careful selection of sampling methodologies and handling procedures to minimize the loss of VOCs through volatilization and biodegradation. Careful handling and transfer are critical to minimize losses due to volatility. The sample must be collected in a manner that minimizes the disturbance of the sample material. The sample should be collected directly from the sample device if possible. If that is not possible, such as with grab samples, then the sample should be collected from the sampler’s contents immediately upon retrieval and prior to any sample mixing that may be required for other analytical tests.

Additionally, the VOC sample should be collected prior to any other procedures, such as logging sediment characteristics etc. Samples for VOCs can be collected using methanol preservation or hermetically sealed field sample methods. Refer to SOP D3-1 for a detailed sampling methodology specific to VOCs.

5 Packaging & Shipping

Sampling events that require shipping should be scheduled to ensure that samples do not sit in a courier's warehouse during weekends or holidays. Always consult with the shipping company and the laboratory to ensure that the samples will be received by the laboratory without undue delay, within the shortest hold time prescribed for all of the analytical tests requested and at a temperature that ensures they are fit for those tests.

The following products should be brought to the field to package and prepare environmental samples for transport to a laboratory:

- Shipping containers capable of holding water (melted ice) and capable of providing protection against normal abrasive actions encountered during shipping. Select a cooler size that accommodates the upright storage of sample containers plus the volume of ice required to maintain a temperature at or below 10º C. Sampling events that generate more than a few samples commonly deploy 45 litre hard-bodied coolers.
- Chilled containers. These can be the same containers that will later be used for shipping however these containers are used specifically to provide a chilled receptacle for storage as the samples are collected and as such should be chilled with ice or ice packs prior to sample collection.
- Extra ice (stored in a cooler); this is especially important during warm weather periods. The cooler containing the extra ice should remain closed until the samples are ready to be packaged for shipping to maintain the integrity of the ice.
- Packing materials such as bubble wrap and sealable bags made of bubble wrap. Never use paper or other water absorbing materials for packing.
- Large sealable plastic bags for ice and documentation.
- Wide durable tape to seal the shipping container.
- Chain of custody forms and Ministry requisition forms. Pens and indelible, VOC-free markers.

Packaging and Shipping Procedure

The following procedure must be followed to maintain the integrity of the samples during transit.

1. Place each sample in a pre-chilled cooler as soon as they are processed. Ensure the lids of each sample container are firmly closed. Individual glass sample containers should be placed in bubble wrap bags or otherwise adequately protected with bubble-wrap or an equally protective product.
2. To ensure the samples are maintained at a temperature at or below 10º C during transport, repack the shipping container (cooler) in preparation for transport and replace the ice with fresh ice using the extra ice brought to the field.
3. Place the ice in a plastic sealable bag. Place this bag of ice into a second sealable plastic bag and ensure each bag is fully sealed. Fill as many bags as needed based on the total volume of sample material in the cooler, the ambient temperature and the duration of travel to the laboratory. In cold to mild weather conditions the ratio of ice to sample material should at a minimum, be 1:1 by volume.
4. Ensure the bags of ice are placed on the bottom of the shipping container.
5. Place the samples upright in the shipping container. Do not overfill the container with samples.
6. Intersperse/alternate the glass sample containers with the plastic sample containers and bags of ice.
7. Arrange the sample containers and ice in a manner that provides a measure of physical protection for the glass sample containers.

8. Use packing material to provide further protection by filling any voids left in the shipping container. This will reduce shifting during transport. It is important to keep in mind that as the ice melts space will result which in turn will provide opportunity for the samples to shift and move about during transport. Densely packed bubble-wrap will provide a partial compensation as this occurs.
9. Complete the chain of custody and or Ministry requisition form/s and enclose it/them in a sealed plastic bag. Place the bag in the cooler on top of the samples. The recommended minimum information that should be included in each requisition form is listed below:
   - Site name;
   - EMS site number/s;
   - Date and time of sample collection;
   - Name of sampler/collector;
   - Field measurements;
   - Comments on sample appearance;
   - Weather conditions; and,
   - Any other observations that may assist in interpreting data.
10. Seal the cooler with heavy duty packing tape to reduce the possibility of it accidentally opening and to prevent tampering. Coolers arriving at the laboratory with torn or absent tape should be noted by lab staff with notification sent by lab reception to the sample submitter.
11. Attach a shipping label on top of the cooler to prominently display the destination.

Note 1: The storage temperatures provided on the “Summary of Sample Preservation and Hold Time Requirements” table published on BC’s Laboratory Standards and Quality Assurance webpage and available at: https://www2.gov.bc.ca/gov/content?id=A9BE9DDAB0674DD29D1308C4BEE7FBB4 are **laboratory storage temperatures**. Samples collected for analytical tests where laboratory storage is listed at ≤ 6º C should be maintained at a temperature of ≤ 10º C during transport to the laboratory.

Note 2: Certain sample types can be or should be preserved by freezing. Frozen samples should be transported separately from non-frozen samples.

Note 3: Bagged ice cubes are strongly recommended for cooling. Loose ice poses a potential source of sample contamination. Always double-bag ice and place it in the bottom of the cooler in a manner that maximizes package integrity.

Note 4: Do not use ice packs for cooling during moderate to hot weather periods. Ice packs do not provide enough cooling to maintain a temperature at or below the 10º C temperature point prescribed for the preservation of most sample types. Broken ice packs pose a potential source of contamination. If ice packs are used, ensure they are sealed within a sturdy bag.

Note 5: Do not use blocks of ice. Ice blocks are heavy, will shift during transport, and in doing so may break glass sample bottles.

Note 6: Do not use dry ice. Dry ice may freeze sample materials, potentially compromising a samples fitness for its intended analytical test and may shatter glass sample containers. Dry ice may be a safety hazard and may contravene courier protocols and TDG requirements.

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7 Revision History

- July 21, 2020: This section retitled as ‘Part D2’ and revised to include additional information regarding sediment sampling designs, sampling equipment and sampling methods. Appendix 2 removed and replaced with Standard Operating Procedures.
- October 10, 2013: Part D republished without change. Appendix 2 - Sample containers, Storage^{TM}, Preservation and Holding Times updated.
- February 28, 2001: Part D republished without change. Note added to Appendix 2 requiring use of glass or Teflon^{TM} containers for samples to be analyzed for mercury.
- November 1996: Initial publication.

Appendix 1

Generic Field Checklist

(for water, sediment, biota and effluents)

Generic Field Checklist

General:

☐Cooler/s
☐ Ice
☐ Camera
☐ Rope
☐ Tape
☐ Log Book/s
☐ Pencil
☐ Shipping labels
☐ Way bills
☐ Requisition forms
☐ Resealable bags
☐ De-ionized water

Labeled Sample Bottles:

☐ General chemistry #____
☐Dissolved Metals #____
☐Total Metals #____
☐Total Organic Carbon #____
☐Low-level nutrients #____
☐Coliforms #____
☐Sediments #____
☐Zooplankton #____
☐Phytoplankton #____
☐Periphyton #____
☐Invertebrates #____
☐Tissue cups #____
☐Macrophytes # ____

Sampling Equipment & Field Measurements:

☐DO Sampler
☐Thermometer
☐DO meter
☐pH meter
☐Conductivity meter
☐Hydrolab
☐Secchi disc
☐Van Dorn, rope, messenger
☐Through Ice Sampler
☐Auger (bit sharpened, skimmer)
☐GPS
☐Sediment grab, messenger
☐Sediment corer
☐Sieves
☐Zooplankton tow nets
☐Benthic invertebrate sampler (Hess, drift net, Surber)
☐Periphyton kit (cup, denture brush, baster)
☐Macrophyte sample kit (buckets, garbage bags, float tray, plant press, blot paper, herbarium sheets, newsprint, corrugated cardboard)

Filtration and Preservation Equipment:

☐Syringe(s)
☐45 µ membrane filters
☐Hose
☐Tweezers
☐Preservative Vials
☐Disposal Container (for used vials)
☐70% ethanol
☐Formalin
☐Lugol’s solution
☐Magnesium carbonate

Generic Field Checklist Continued

Boat Equipment:

☐Canoe (or boat)
☐Paddles
☐Motor
☐Fuel
☐Life jackets
☐Ropes
☐Anchor
☐Tool kit

Personal Gear:

☐Drinking water
☐Lunch
☐Survival suit
☐Rain gear
☐Gum boots
☐Waders (hip, chest)
☐Sun screen
☐Flash light

Safety:

☐WHMIS guidelines
☐First Aid Kit
☐Epinephrine autoinjector
☐Goggles (or safety glasses)
☐Rubber gloves
☐Phone/Radio
☐Satellite Phone

Appendix 2

Standard Operating Procedures

Sampling Method/Media: **General Inorganics/Organics Sediment Sampling**	**Standard Operating Procedure for Sediment Sampling**
Revision No: Original **Revision Date: 21 July, 2020**	**Reference No: SOP D2-01** **Parent Document: BC Field Sampling Manual – Part D2**

1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for the collection of representative samples of sediment from freshwater environments, including streams, rivers, lakes, as well as marine environments, including intertidal and subtidal zones. Sediment samples can be collected for field screening or laboratory analysis either by hand or specialized equipment.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on sediment sampling is included in Part D2 – Sediment Sampling of the BCFSM which must be used in conjunction with the information provided in this SOP.

Additionally, SOP D1-01 Field Identification and Classification of Soils, SOP D1-09 Soil Sample Collection and Handling for Volatile Organic Compounds, and SOP D1-10 Soil Sample Collection and Handling for General Organics and Inorganics are relevant to sediment sampling and as such should be reviewed and considered along with the information provided in this SOP.

Additional information is provided in Guidance documents, the Environmental Management Act (EMA) and the Contaminated Sites Regulation (CSR), which are available on the Contaminated Sites webpage at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Sediment sampling conducted within the provincial jurisdiction of BC for regulatory purposes must be carried out with consideration to the EMA, the CSR, Part D2 of the BC Field Sampling Manual, and this document.

2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

3. Quality Control

Quality control measures should be considered and incorporated into all aspects of a sampling program. The degree and types of quality control measures incorporated into a sampling program are generally based on its sampling objectives. The following quality control measures should be considered and planned for prior to heading out to the field:

- The number and types of quality control samples;
- Contaminant control protocols;
- Choosing the correct sample collection techniques, handling procedures and preservation;
- Ensuring that sample hold times are accommodated;

The types and numbers of quality control samples should be determined based on the objectives of the sampling program but at a minimum should constitute 10% of the total suite of samples collected.

Consult with the testing laboratory and the most current table of sample preservation & hold time requirements provided by ENV to ensure your sample containers, preservation methods and hold times are understood and accommodated.

The table of sample preservation & hold time requirements is available at: https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/summary-of-sample-preservation-and-hold-time-requirements.pdf.

Detailed information regarding quality control is provided in Section 2 of Part D2 of the BCFSM.

4. Principle of the Sampling Method

In general, the methods of sediment sampling are categorized according to the equipment deployed to collect the sediment material. The equipment, and thereby the method chosen is based on the aquatic characteristics of the sampling site and the objectives of the sampling program. Regardless of the sampling method the procedures for sample collection, handling and processing is generally consistent. This SOP provides field procedures applicable to all sampling methods designed. The procedures are designed to assist samplers in collecting sediment samples that are representative of their parent material and in maintaining the chemical and physical integrity of those samples.

General considerations for sediment sample collection include ensuring that samples are representative of their parent material, sample integrity is controlled and maintained, cross-contamination does not occur, proper chain-of-custody procedures are followed for sample transport, and that sampling procedures and sediment characteristics are clearly and effectively documented.

5. Recommended Equipment and Materials

Documents and forms:

- Site plan, results of previous investigations, etc.;
- Sediment sample logs;
- Field book or electronic tablet for logging field notes; and
- Sample submission and chain-of-custody forms.

Field equipment:

- Disposable nitrile gloves;
- Pen, indelible VOC-free felt marker;
- Flagging tape;
- Laboratory supplied, pre-labelled sample jars/vials;
- Sealable bags;
- Cooler/s and an ample amount of ice;
- Handheld global positioning system device (GPS; especially important if sampling locations cannot be physically marked [e.g., marine sediment sampling]);
- Field screening instrument (if required), appropriate for the contaminants of concern and with appropriate calibration equipment;
- Sediment sampling equipment (see below);
- Mixing bowl and spoons (for mixing sediment samples);
- Laboratory detergent (e.g. Alconox™ or Liquinox™) and water solution or solvents (as necessary);
- Distilled water in squeeze bottle dispensers; and
- Paper towels.

Sediment sampling equipment:

- Sampling by hand: scoop, spoon or trowel
- Grab sampler (e.g., Eckman grab sampler, Ponar grab sampler)
- Core sampler (e.g., hand corer, gravity core sampler, piston core sampler, vibracore sampler)

The types of sediment sampling equipment listed above is not complete; other, less common sediment sampling techniques are included in Part D2 of the BCFSM but are not included in this SOP. The selection of appropriate sediment sampling equipment will be dependent upon the sampling design, depth of sediment desired for characterization, and site-specific conditions, including water depth, current and sediment properties. Part D2 of the BCFSM outlines these site-specific conditions and additional considerations that should be evaluated when selecting sediment sampling equipment for a given site and sampling program. The following section outlines sampling considerations for all methods of sediment sample collection and is designed to ensure that the sediment sample collected is representative of what is present at the sampling location and target depth.

6. Sampling Considerations

Sampling by Hand: Scoop, Spoon or Trowel

- If sediments are not inundated at the time of sampling (e.g., intertidal sediment sampling when the tide is out, stream sediment sampling in low flow conditions) or if the surface water body is shallow (wadeable), the simplest way to collect a sediment sample is by using a stainless steel scoop, spoon, or trowel. Dry sediments can be accessed directly.
- Wading: If sediments are submerged at a wadeable depth, a sample can be collected by wading into the water body while facing into the current (upstream) and scooping sediment from the required depth of sediment. Care must be taken to minimize the loss of fine-grained sediments during sampling and sample retrieval.
- Bank/Platform Sampling: In surface water bodies that are too deep to wade into but are less than 3 m deep, a scoop or spoon attached to a piece of conduit can be used from a bank or platform, with care taken to minimize the loss of fine-grained sediments during sampling and retrieval.

Grab Samplers

- Grab samplers are used to sample surficial sediments, typically silts and clays, but also sands and gravels although recovery of these coarse-grained sediments may not be complete.
- Free, vertical clearance is required to use any grab sampler. Grab samplers must be securely attached to ropes and are lowered vertically from a sampling platform such as a boat, or bridge, to the surface of the substrate being sampled. Depending on the weight of the sampler and the depth of the aquatic environment to be sampled, a winch and/or crane system may be required to assist in the sampler's deployment and retrieval.
- Prior to deployment, the grab sampler must be set to enable triggering once it contacts the sediment.
- The sampler must be lowered slowly through the water column to prevent premature closure.
- The trigger mechanism used to close the grab sampler is sampler-dependent. Some grab samplers close automatically in response to a reduction of tension in the deployment line (when the sampler contacts the sediments), while others may employ a messenger-trigger system. The operating instructions provided by the manufacturer for the grab sampler should be reviewed prior to use.


Figure 1: Using a winch/crane system with a Ponar grab sampler (standard size)

Core Samplers

- Core samplers are used to sample vertical columns of sediment. Core samples are especially useful in determining the historical deposition of sediment and contaminants as they preserve sequential sediment layering. Core samplers minimize the loss of material at the sediment-water interface. A wide array of coring devices is available, ranging from hand-driven push tubes to electronic vibracore samplers.
- Manually-deployed push tubes are used in shallow, wadeable waters, or for diver-collected samples. The tube should be approximately 30 cm in length to sample recently deposited sediments at depths of 20 cm or less. A tube of approximately 5 cm in diameter is typically deployed. It is important to note that soft and semi-consolidated sediments such as mud and clay have a greater adherence to the inside of the tube, while coarse or unconsolidated sediments may be difficult to sample without the use of a core catcher or end cap. When

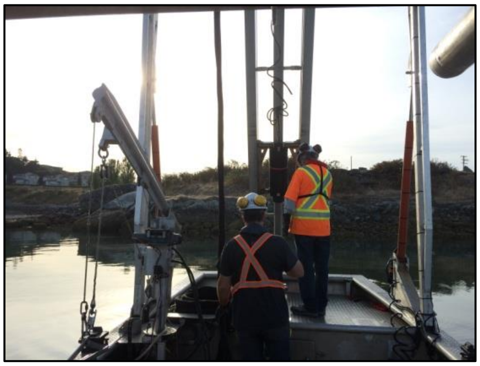
Figure 2: Vibracore sampling in marine environment

wading to obtain a sample, the sample should be retrieved while facing upstream to prevent sediment disturbance while the sample is being obtained.

- Gravity corers, piston corers and vibracorers are typically deployed and retrieved from a barge platform or large vessel. These types of corers are operated by trained professionals and as such, specific considerations and deployment procedures are not provided in this SOP.
- Sediment cores, collected using any of the above-listed devices, can be subject to spreading or compaction as they are driven into the sediment; both of these processes affect the physical integrity of the core sample. Spreading occurs when sediment is pushed to the side as the core barrel advances into the sediment. Compaction occurs when the sediment is pushed downward as the core barrel advances. An indication of one or both of these processes occurring is a difference between insertion depth and core depth. For example, if a core barrel is known to have been advanced 3 m into the sediment, but there is only 2.5 m of sediment in the core barrel.
- Core barrel liners can be used in any/all of the above-listed devices. Core barrel liners can be made of stainless steel, glass, Teflon®, polyvinyl chloride (PVC) or carbon steel. The material of the core liner should be selected based on the potential contaminants of concern under evaluation at a given site. Teflon® or plastic is preferred to glass, as they are less likely to break and result in sample loss and/or personal injury. Stainless steel barrels are also acceptable and provide a better cutting edge and greater strength than plastic or Teflon®. Teflon® and glass liners reduce the likelihood of interference due to metals contaminants from core barrels, cutting heads, etc.

7. Procedures

The sediment sampling procedures outlined below assume that the sampling program and logistics associated with the selected sampling method (e.g., renting appropriate equipment, hiring trained vessel operators, etc.) are complete. Guidance for the planning stage of sediment sampling programs is provided in Part D2 of the BCFSM and should be referenced in conjunction with this SOP.

Procedures associated with sediment sampling in freshwater or marine environments, regardless of the sampling methods/equipment employed, are as follows:

1. Obtain authorization from the owner for site access, if needed, and confirm that physical access to the site is possible.
2. Confirm the accuracy of the existing site plan and or keep sufficient notes so that a site plan can be developed or used to amend an existing site plan. Observe and evaluate the water body to be sampled. Confirm that the assumptions made during the sampling program's planning stage such as water depth, current speed, sediment grain size, etc. were accurate and that the equipment and methods available/selected for sediment sampling are appropriate and safe for the site's current conditions.
3. As part of field preparations thoroughly decontaminate all sampling equipment. Scrub the equipment with tap water followed by an adequate rinse with de-ionized water. If the sampling equipment was last used in sediments containing grease or hydrocarbons or if the equipment exhibits an oily film, a mild detergent (e.g., Alconox®) solution should be used followed by a very thorough rinse with deionized water.
4. Prepare and calibrate any field screening instruments, if required.
5. Select the first sampling location or navigate to a predetermined sampling location. Begin collecting samples in the suspected "cleanest" area of the site and continue toward the more contaminated areas (if relevant/applicable). For sediment quality monitoring begin collecting samples downstream working your way to the most upstream location of the reach.
6. The selected sampling locations should contain sufficient sediment for sampling. Avoid rocky areas or areas of bedrock. If possible, mark each sampling location; sampling locations along streams and small rivers, can be marked by securing flagging tape to shoreline vegetation. Flagging tape can be labelled to identify the sampling station, providing easy reference and efficient relocation if subsequent sampling is required. Ensure that GPS coordinates are collected and recorded at each sampling station.


Figure 3: Using flagging tape to mark sediment sampling location at shoreline.

7. If the sample requires homogenization, observations regarding the physical and olfactory characteristics of the sediment should be recorded prior to homogenization and again following homogenization. Record these characteristics, site conditions and key observations in a field book; include a photo of the sediment sample and a photo of the sampling location.
8. Collect and record field measurements as required.

Sampling by hand:

1. Using a scoop, spoon or trowel, scoop sediment to a predetermined sampling depth (e.g., 0-5 cm, as outlined in the sediment sampling program plan).
2. If the sediments being sampled are submerged, retrieve the scoop, spoon, or trowel slowly through the water column, to minimize the effect of turbulence which can result in the loss of fine-grained surface sediments.
3. A consistent and predetermined sediment volume should be retrieved from each sampling location, targeting sediment from the same sampling depth, to ensure the sample material represents the parent material. Ensure that sufficient sediment is obtained for the selected laboratory analyses including duplicates where required.
4. Place the retrieved sediments into a container such as a shallow pan or a mixing bowl. Allow the sediment to settle and any suspended materials to settle out of solution. Excess water may be carefully decanted from the container. Immediately record, in the field log book, observations regarding the appearance and odour of the sediment; be sure to include texture, colour, odour, presence of biota, presence of detritus, and the depth of sediment sampled.
5. With a clean spatula or spoon, either remove the top portion of the sediment (when this is outlined by the study design), or thoroughly stir the sediment to homogenize. Place aliquots of the processed sediment into pre-labelled laboratory supplied sediment sample bottles as needed.
6. Place the samples directly into a chilled cooler containing ice or ice packs.

Sampling with a grab sampler:

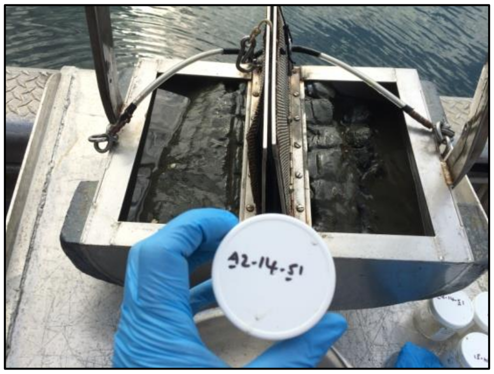

Figure 4: Ponar grab sampler full of sediment following retrieval.

1. Set the grab sampling device with the jaws cocked open. Great care should be taken while setting the jaws of the sampler to avoid an accidental closure which could result in serious injuries. Follow the operational instructions provided by the manufacturer of the device to ensure proper setting, effective deployment and retrieval of the sampling device for optimal sediment sample recovery.
2. Ensure that a rope is securely fastened to the sampler and that the other end of the rope is secured to the sampling platform (e.g., bridge or boat) to prevent device loss.
3. Slowly lower the sampler over the upstream side of the platform until it is resting on the sediment. The weight of the sampler is adequate to penetrate soft sediments. At this point, the slackening of the line will activate the mechanism that releases the jaws of Ponar and Petersen grabs. When using an Ekman grab sampler, a messenger must be sent down to 'trip' the release mechanism.
4. Retrieve the sampler slowly to minimize the effect of turbulence that can result in a loss of surface sediments.
5. Place a container, such as a shallow pan or a mixing bowl, beneath the sampler as soon as it reaches the sampling platform. View the sediment material through the devices' top mount screens or flaps to confirm that a complete sample has been retrieved. Note: If the jaws were not closed completely, the sample must be discarded.
6. Gently open the jaws of the grab sampler and in a controlled manner allow the sediments to empty into the container. A selection of one or more layers can be obtained if this is a goal of the sampling plan. For example, a sample of surface sediments (1 - 2 cm) can be obtained by carefully scooping off the top undisturbed layers while exposing deeper sediment material. In some lakes, a grab sample to a depth of 10 - 15 cm is typical and the vertical heterogeneity found within that grab sample may represent many years of lake or watershed changes.
7. If discrete samples from a layer are desired those samples can be obtained from that segregated layer. If a bulk sample or replicate samples are required, the full contents of the sampler or the target layer must be thoroughly mixed to create a homogenous matrix. Once mixed the sediment can be transferred into the appropriate sample containers.

Sampling with a core sampler:

The following protocol is intended to provide general methods for core sampling. This protocol assumes that any large coring equipment such as gravity corers, piston corers and vibracorers will be deployed from a large vessel or barge and operated by trained professionals. For this reason, procedures for the deployment of core sampling devices are not included however a description of core processing techniques and considerations is provided below.

1. Open the valve and set the trigger mechanism. Ensure the rope is securely fastened to the corer and the other end of the rope to the sampling platform.
2. Lower the corer to approximately 5 m above an area of undisturbed sediment and then allow it to fall freely. Note that drop depth varies with sampler size, weight, and sediment type. Sufficiently heavy corers can simply be lowered into the sediment to avoid any disturbance caused by impact.
3. Send the messenger down to release the trigger mechanism.
4. Carefully retrieve the corer in a controlled manner. With the corer still partially submerged place a stopper into the bottom opening to prevent any loss of sample material. Complete the retrieval and safely set the corer on deck.
5. Remove the liner from the corer and stopper the upper end. Store erect. Repeat steps a through d to obtain replicate cores; each of which should be at least 0.5 m in length.
6. Core processing typically takes place onshore but can be carried out on the sampling platform if space and time permits. When the cores are ready for processing carefully siphon off most of the water that overlays the sediment in the core tube; leave a small amount of water at the sediment-water interface. Take care to not disturb the sediment-water interface.
7. Make careful measurements of the total length of the core and precise points (to the nearest millimetre) of any visible layers of sediment. Record details of any changes in stratigraphy, such as colour and texture. Core processing considerations and techniques related to larger cores are described below.
8. A rubber stopper is inserted into the lower end of the corer to form a watertight seal inside the liner. The core is then gently and slowly forced upward to the top of the tube. Some advanced corers come equipped with this stopper allowing the increment of each sediment slice to be adjusted.
9. As the sediment core is extruded, carefully cut slices of the sediment core to a thickness of approximately one cm or more using clean spatulas placing each slice into pre-labelled laboratory supplied sample bottles. A core slicer greatly assists in this operation, but good samples can be obtained without this aid when done carefully.

When core samplers are obtained using large gravity corers, piston corers, or vibracorers, trained equipment operators will remove the sediment core from the equipment; typically, the sediment core will be in a liner. Core sample recovery is highly dependent on the drillers' technique and experience, and sediment conditions at the site. After the core barrel is advanced to the limit of the run, the core barrel and extensions are withdrawn from the hole. Typically, the recovered sediment core is collected from the core barrel in the liner material. Cores may be processed on the sampling platform or vessel, if space and time permits, or retained for evaluation on shore.

Processing Large Sediment Cores:

Figure 5: Retrieved sediment core in a stainless steel liner, ready for processing on shore.

1. As a result of the drilling technique, the outer surface of the core may be smeared or disturbed, and stratigraphic detail may be obscured. As such, the core should be split longitudinally to expose a fresh surface for logging and sampling.
2. Sediment cores should be logged in accordance with SOP D1-01. The exposed core should be photographed, with markers placed along the core to identify the depth at the top and bottom of the core run. Be sure to include the borehole number and project name in the photo.
3. Consideration should be given to collecting samples at changes in stratigraphy, or at predetermined depths (e.g., continuous, every 0.75 m or 1.5 m.
4. Samples for laboratory or headspace analysis may be collected directly from the recovered core. Laboratory and headspace samples should be collected from the inner portion of the core where possible to minimize the possibility of including

contamination which may have been collected along the outer surface of the core sample as the corer passed through shallower sediment.

5. Information specific to this method of drilling which should also be recorded includes the length of run and the length of core recovered. During extrusion, the core will have a tendency to compress or lengthen and as such these details should be logged to account for this.
6. Where 100% core recovery is not achieved, an opinion should be made regarding the depth interval of the missing sediment.
7. Samples collected for analysis of volatile organic compounds should not be homogenized. Samples collected for all other types of analyses require homogenization. Sediment samples must be thoroughly mixed to ensure that any given sub-sample is representative of the sampled sediment at that particular location and depth. Samples collected for organics analyses must be collected and mixed using non-plastic tools and the sampling container must be a glass bottle provided by the laboratory. Samples collected for metals analyses must be collected and mixed using non-metallic tools. If homogenization is occurring in a mixing bowl, adequate mixing can be achieved by stirring the material in a circular fashion, reversing direction and occasionally turning the material over. Repeat several times until the sample is well-mixed.

Figure 6: Sediment sample homogenization.

8. Samples collected for the analyses of volatile organic compounds should be collected according to SOP D1-09, and samples collected for the analysis of non-volatile compounds should be collected according to SOP D1-10.
9. For field screening, split the sample or collect a replicate sample from each sampling depth. In either case place the sediment in a sealable plastic bag and conduct vapour screening in accordance with SOP D1-02.
10. Fill the pre-labelled sample containers provided by the laboratory. Use a paper towel to clean the threads on the container and its lid to ensure a tight seal when closed. Complete the samples label by including date and time of sampling, as well as confirmation of requested analyses and any sample preservation conducte.
11. Decontaminate the sampling equipment between each sample collection. Wipe visible sediment with paper towel and thoroughly rinse any residual materials with potable or preferably, distilled water; pat dry with clean paper towel. If the equipment encountered grease, oil or petroleum hydrocarbons a mild detergent should be used for the decontamination process. Whenever a detergent is used for decontamination a rigorous rinse is required to mitigate the potential of phosphate compound residues. For larger equipment, the sampling devices may be cleaned with high pressure water or steam. Sampling devices should be visually inspected for cleanliness after washing.
12. Typically, any unused sample material is returned to the location from where the sample is collected. If the sediment is known or suspected to be contaminated or where sensitive water uses exist immediately downstream the material should be stored for appropriate disposal.
13. Complete the sample submission and chain-of-custody form.
14. Dispose of all wastes including in-field rinsate, liquids, used gloves and materials, in an appropriate manner. Always leave the site in a tidy condition.
15. At the completion of sampling, note equipment rental(s) and/or materials consumption as necessary. Return all equipment to the person or company responsible for the equipment.

8. References

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Revision History: 0.0 (New document)
Approval

The British Columbia Field Sampling Manual

Part D3

Composted Materials Sampling

Table of Contents

1. Introduction

This document sets out the sampling requirements for composted material, specified under terms of the **PRODUCTION AND USE OF COMPOST REGULATION** B.C. Reg.334/93, Deposited September 30, 1993.

2. Sampling and Analysis Requirements

The compost product must be sampled and analyzed as follows:

A sample of compost produced at each composting facility must be analyzed at intervals of at least every 1000 tonnes of compost produced or once in 3 months, whichever comes first, for:

Parameter	**Unit**
Total Nitrogen	% dry weight
Total Phosphorus	% dry weight
Total Potassium	% dry weight
Organic Matter	% dry weight
Salinity (EC)	mS cm-1
pH	(does not have units)
Foreign Matter	%
Arsenic	mg/kg dry weight
Cadmium	mg/kg dry weight
Chromium	mg/kg dry weight
Cobalt	mg/kg dry weight
Copper	mg/kg dry weight
Lead	mg/kg dry weight
Mercury	mg/kg dry weight
Molybdenum	mg/kg dry weight
Nickel	mg/kg dry weight
Selenium	mg/kg dry weight
Zinc	mg/kg dry weight

3. Trace Elements

Heavy metal concentrations, expressed in mg/kg dry weight, determine the appropriate use classification code; if any one parameter falls in a higher concentration grouping, the code for that higher grouping will apply.

3.1 Trace Element Concentration Codes

	Code →	**1**	**2**	**3**	**4**
Element	**Arsenic**	<13	>13 – 30	>30 - 50	>50
	Cadmium	<2.6	>2.6 – 5	>5 – 20	>20
	Chromium	<210	>210 – 250	>250 – 800	>800
	Cobalt	<26	>26 – 50	>50 – 300	>300
	Copper	<100	<100	>100 – 500	>500
	Lead	<150	>150 – 500	>500 – 1000	>1000
	Mercury	<0.8	>0.8 – 2	>2 – 10	>10
	Molybdenum	<5	>5 – 10	>10 – 40	>40
	Nickel	<50	>50 – 100	>100 – 500	>500
	Selenium	<2	>2 – 3	>3 – 10	>10
	Zinc	<315	>315 - 500	>500 - 1500	>1500

4. pH

The pH must range between 5.0 and 8.0.

5. Sampling Procedures

A single composite sample needs to be representative of the compost being tested.

- At least 5 to 10 samples should be taken from different locations around the pile.
- Samples should be taken from a depth greater than 25 cm and not more than 1 metre.
- Composite samples must be thoroughly mixed in a large container to provide a representative sample of the pile.

Laboratory staff should be consulted to determine the amount of compost required to carry out analyses.

6. Product Maturity

Mature means material that is highly stabilized, has been exposed to a long period of decomposition, is brown to black in colour, and

- will not reheat upon standing to greater than 20 degrees C above ambient temperature, or
- has shown a reduction of organic matter of greater than 60% by weight.

The regulation requires that a measure of product maturity be determined. Two alternative methods are acceptable under this regulation as the measurement procedure.

6.1 Reheating Test

A reheating test can be to used measure stability. Compost should be re-piled so it is at least 2 meters in diameter and 1.5 metres high. The pile should not be compressed and should be loose enough to allow the penetration of air. Moisture content of the pile should be somewhere between 35% and 60%. A dry pile will give the false impression that the compost is mature. Three days later the temperature of the compost should be measured at a point 60 cm into the pile. A comparison of this temperature with ambient air temperature gives a picture of the product maturity.

6.2 Ratio Between Organic Solids and Mineral Solids

Reduction of organic matter content during the composting process increases the percentage of mineral solids present. This ratio between organic solids and mineral solids present provides a picture of how close to maturity a compost product is. Before and after composting the material is tested for the percent organic matter (volatile solids) on a dry weight basis.

The calculation is:

$$\%\ \mathit{Reduction} = \left[1 - \frac{\%A\ (100 - \%B)}{\%B\ (100 - \%A)}\right] \times 100$$

where %A = % organic matter content of dry matter after decomposition; and,

%B = % organic matter content of dry matter before decomposition.

“Loss on ignition analysis” is used to determine the percentage organic matter content before and after decomposition. During composting the ratio of organic matter to inorganic matter changes due to decomposition and the mass of inorganic solids remains the same. Using this formula, it is possible to calculate the percentage "reduction of organic matter content" in the final product necessary to meet the required level of reduction for compost classified as mature or fresh.

7. Foreign Matter Content

Foreign matter content may be determined by passing a dried, weighed sample of the compost product through a 6 mm screen. The material remaining on the screen is visually inspected, and the foreign matter that can be clearly identified is separated and weighed. The weight of the separated foreign matter divided by the weight of the total sample multiplied by 100 is the percentage dry weight of the foreign matter content.

Foreign matter content by dry weight must be classified within one of the following categories before being utilized on land:

(i) 1%
(ii) >1% but ≤2%
(iii) >2% but ≤10%

8. Revision History

July 21, 2020: This section re-titled as Part D3 and republished without change.

October 10, 2013: This section republished without change. Appendix 2 – Sample containers, StorageTM, Preservation and Holding Times updated.

February 28, 2001: This section has been republished without change.