Associated Environmental

REPORT

Government of Northwest Territories Department of Infrastructure

Hay River Harbour Restoration – Monitoring Plan (Version 2.1) 2023-8461

APRIL 2024

REVISIONS PAGE

Hay River Harbour Restoration – Monitoring Plan (Version 2.1)	
Client:	Consultant:
Government of Northwest Territories Department of Infrastructure	Associated Environmental Consultants Inc.

Revision/ Issue	Date	Description	Prepared by/ Reviewed by	Reviewed By
1	2023-03-31	Submission for MVLWB water licence application	Associated	GNWT-INF
2	2023-06-20	Revised submission for IFT Specifications Addendum	Associated	GNWT-INF
3	2023-07-06	Revised submission, incorporating MVLWB comments in the Type B Water Licence (Version 1.1)	Associated	GNWT-INF
4	2023-12-15	Annual plan review and update for 2024 operations	Associated	GNWT-INF
5	2024-04-04	Submission for MVLWB annual review	Associated	GNWT-INF

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LIST OF ABBREVIATIONS

Abbreviation	Definition
CCME	Canadian Council of Ministers of the Environment
GNWT	Government of Northwest Territories
FAL	Canadian Sediment Quality Guidelines for the Protection of Freshwater Aquatic Life
INF	Department of Infrastructure
MTS	Marine Transportation Services
MVLWB	Mackenzie Valley Land and Water Board
NTU	Nephelometric turbidity units
PEHH	Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health
SNP	surveillance network program
TSS	total suspended solids

GLOSSARY

Term	Definition[1]
Background concentration	The level of a substance that is naturally occurring and not associated with dredging works
Barge	Vessel that does not have an independent form of propulsion and is primarily used to transport dredged material (dredgeate, sediment) to shore
Composite sample	A mixture of several samples taken at different locations and combined to make a single sample
Dewatering	The act of removing water from sediment or waste material
Dredging	The act of cleaning out the bed of a harbour, river, or other body of water by scooping out material from the bottom
Grab sample	A single sample that provides a snapshot of water quality at the exact time and location the sample was taken
Receiving waters	The waters in Great Slave Lake and the Hay River surrounding the dredging areas that may be affected by dredging works
Representative Sample	Multiple subsamples of soil combined to capture variability and accurately represent the whole
Sediment	Solid particles that are suspended or have settled at the bottom of a body of water
Soil	Sediment that has been dredged and dewatered

[1] These definitions are in the context of this monitoring plan.

1 INTRODUCTION

The Government of Northwest Territories (GNWT) – Department of Infrastructure (INF) retained Associated Environmental Consultants Inc. (Associated) to prepare a monitoring plan related to dredging works taking place in the marine navigation channel between Great Slave Lake and the Hay River (Dredge Area A) and within the three fingers of the East Channel of the river (Dredge Area B) (Figure 1-1). Dredging was proposed to begin on July 16, 2023, and continue until September 14, 2023. In 2023, dredging occurred only in Dredge Area A and was completed from August 11 to 13 and September 18 to October 7 due to a major wildfire evacuation in the Town of Hay River and the surrounding community. Dredging for Dredge Area B and the remainder of Dredge Area A is planned for July 16 to September 14, 2024, however, that window may begin earlier based on discussions ongoing with DFO and stakeholders at the time of this submission. This monitoring plan follows the Mackenzie Valley Land and Water Board (MVLWB) Standard Outline for Management Plans (2021) and provides guidance on monitoring the quality of water and the dredged material associated with the proposed dredging activities.

This report is provided as an annual review and update in winter 2023 to reflect changes in operations, contact information, or other details.

1.1 Project Description

In 2022, the Hay River experienced unusually high water levels, resulting in increased sediment being deposited in the Hay River Harbour and Great Slave Lake at the river outfall. The sediment, which had not been regularly maintained (removed) since 1997, had begun to fill the navigation channel. This has caused an emergency scenario, since the shallow water in the navigation channel poses a risk to vessels (i.e., MTS barges, Coast Guard, fishing, and recreational vessels) getting stuck in the sediment and not being able to enter or exit the Hay River Harbour. The goal of the dredging project is to remove the accumulated sediment so that marine users can travel along the navigation channel. If vessels cannot enter or exit the harbour, the supply for essential goods, including fuel for power and heat could be interrupted for up to 12 communities who rely on the barging system. The problem was further exacerbated by unusually low water levels in 2023, leading to limited access to the Hay River Harbour and the surrounding communities connected via Great Slave Lake.

The GNWT-INF has proposed dredging the navigation channel to mechanically excavate a navigation channel 30 m wide and 2.4 m deep for emergency use, to be completed by local contractors, where possible, and in coordination with GNWT – Marine Transportation Services where possible. The material dredged from the navigation channel would be loaded onto a barge, allowed to passively dewater, and when the barge is at capacity, the dredged material would be offloaded to haul trucks located on shore. The haul trucks would transfer the dredged material to temporary storage sites on Vale Island. The dredged material would be temporarily stored on Vale Island (contained within 1 m high berms) for ongoing passive dewatering. Once moved from the barge to land, the dredged material may be made available for public use (as a soil[1]), if appropriate, or would be transferred to a final management area.

This emergency dredging program will include removal and temporary storage of the following estimated (project total) volume of dredged material:

- Dredge Area A: the shipping lanes approaching the outfall to Great Slave Lake to a width of 30 m, dredging 16,000 m^3; and

[1] Dredged material will be predominantly sediment. Sediment is unconsolidated material deposited on the bed of a waterbody or in a low spot or depression on land where the water velocity is insufficient to move the material. Once on land and dewatered, the dredged material is considered soil (CCME 1999).

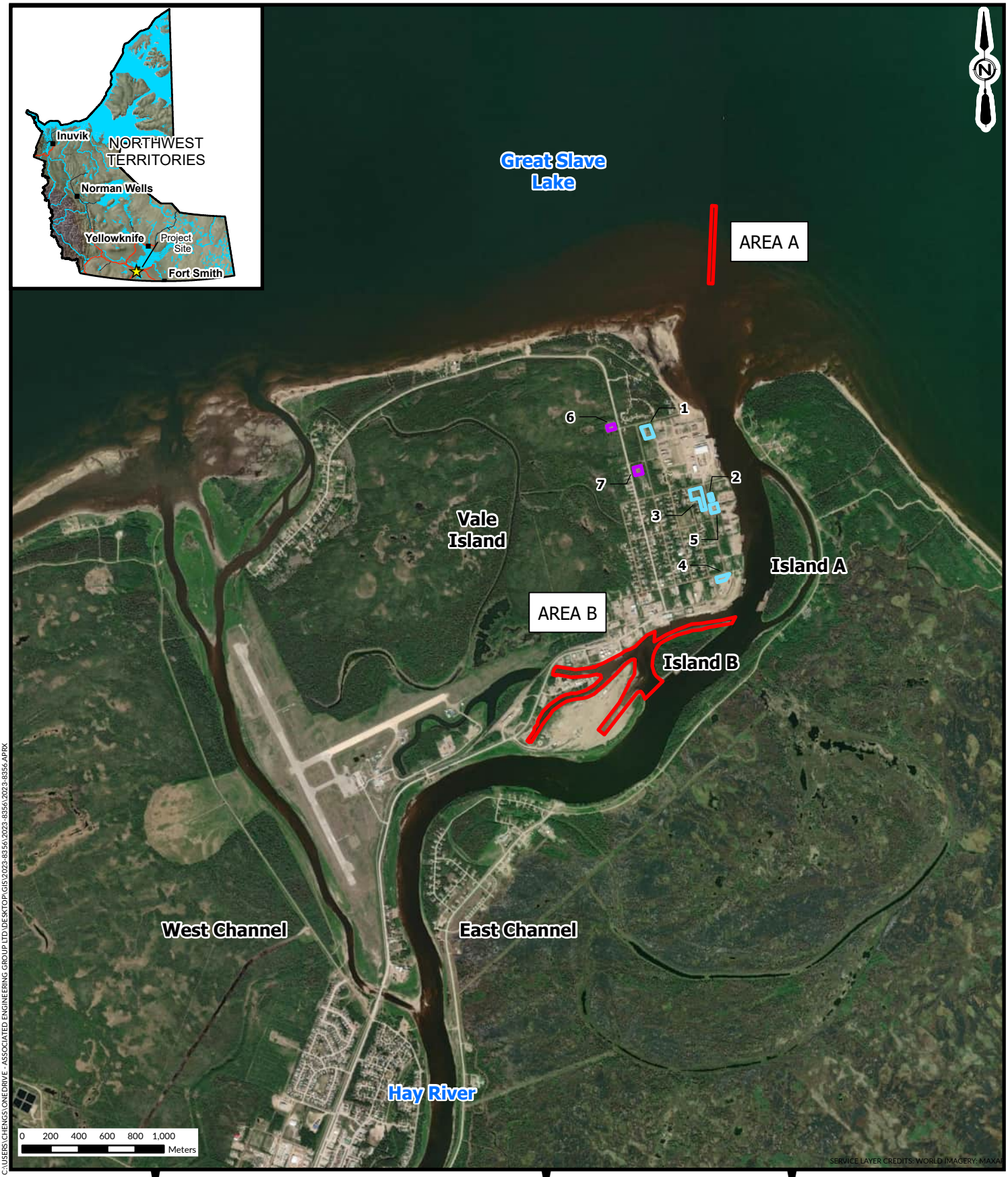
- Dredge Area B: the three fingers in the East Channel, dredging 68,000 m^3.

1.2 Monitoring Plan Objectives

The objectives of the monitoring plan are to guide monitoring of:

- Water quality, particularly total suspended solids (TSS), of the Hay River and Great Slave Lake outside the work area (receiving waters) during the dredging activities;
- Water quality of the runoff water collected from sumps during dewatering activities at the temporary storage sites on Vale Island (including surveillance network program [SNP] requirements); and
- Quality of the dewatered dredged material proposed to be stockpiled on Vale Island (to inform final management for the potential for reuse of the material; Figures 1-1 and 1-2).

The details of each monitoring objective are provided in Sections 3 and 4 of this document.



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Associated Environmental

Northwest Territories

LEGEND

- Dredging Areas
- Temporary Soil Storage
- Government of Northwest Territories
- Town of Hay River

AE PROJECT NO.	2023-8456
SCALE	1:36,000
COORD. SYSTEM	NAD 1983 UTM ZONE 11N
DATE	2024-03-01
REV	04
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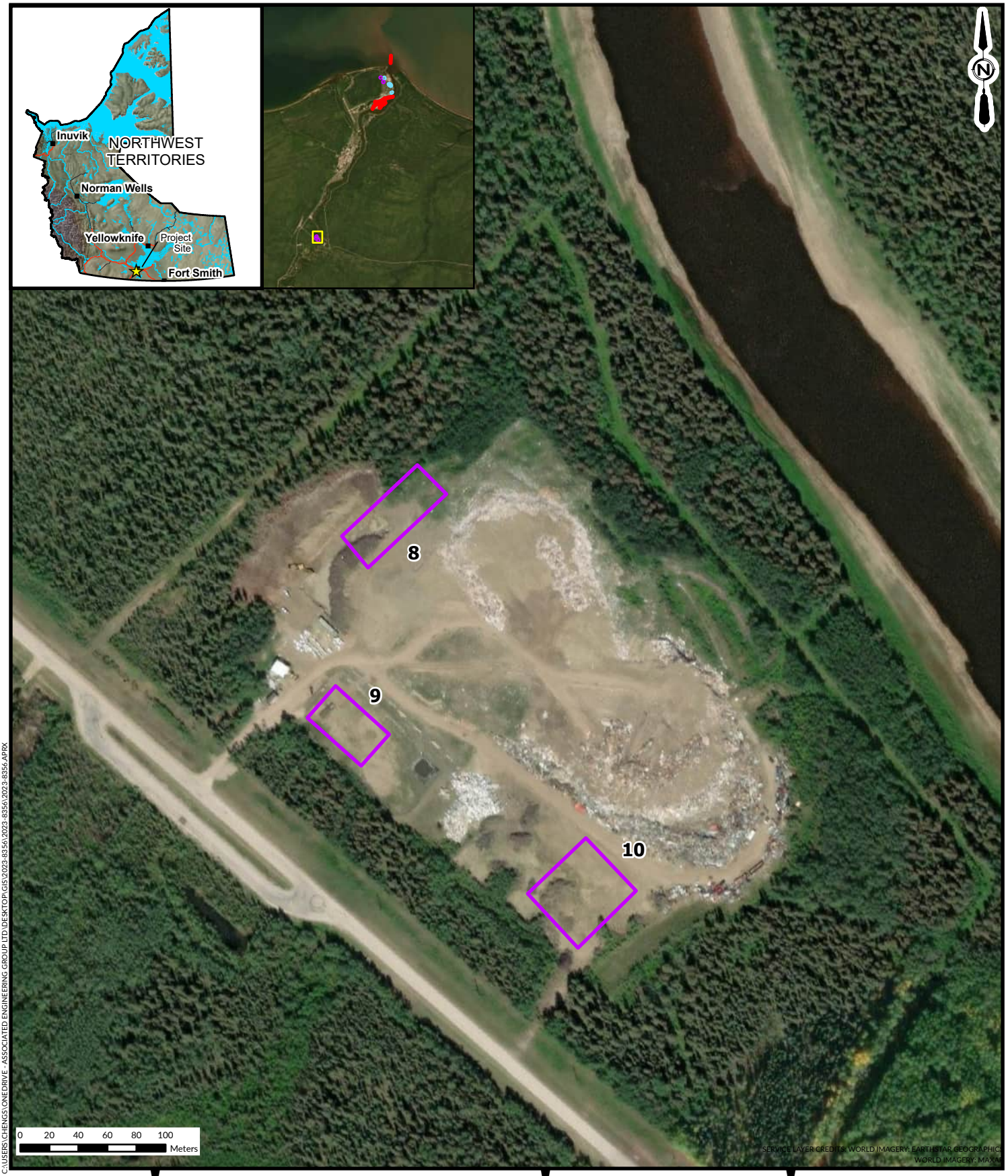
FIGURE 1-1
DREDGING AND PROJECT AREA

GOVERNMENT OF NORTHWEST TERRITORIES-DEPARTMENT OF INFRASTRUCTURE

HAY RIVER HARBOUR RESTORATION



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Associated Environmental

Northwest Territories

LEGEND

- Dredging Areas
- Temporary Soil Storage
- Government of Northwest Territories
- Town of Hay River

AE PROJECT NO.	2023-8456
SCALE	1:3,500
COORD. SYSTEM	NAD 1983 UTM ZONE 11N
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REV	04
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FIGURE 1-2
DREDGING AND PROJECT AREA

GOVERNMENT OF NORTHWEST TERRITORIES-DEPARTMENT OF INFRASTRUCTURE

HAY RIVER HARBOUR RESTORATION

1.3 Regulatory Framework

GNWT-INF is committed to environmental protection and will follow the applicable required regulatory framework to mitigate potential environmental impacts from this project. As part of the regulatory process, environmental planning and mitigation will form part of the necessary regulatory applications. Regulatory permits or authorizations include but are not limited to:

- Type B water licence from the MVLWB, regulated under the *Waters Act* (SNWT 2014, c. 18) (MV2023L8-005, issued June 27, 2023) (MVLWB 2023);
- Notice of minor works to Transport Canada, regulated under the *Minor Works Order* (SOR/2021-170) of the *Canadian Navigable Waters Act* (RSC, 1985, c. N-22); and
- Project review from Fisheries and Oceans Canada, regulated under the *Fisheries Act* (RSBC 1985, c. F-14), and the *Species at Risk Act* (SC 2002, c. 29) (LOA 23-HCAA-00530, issued June 28, 2023).

Samples collected as part of monitoring efforts will be compared to the following guidelines (CCME 2023):

- Water chemistry will be compared to the Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines for the Protection of Aquatic Life.
- Sediment chemistry will be compared to the CCME Canadian Sediment Quality Guidelines for the Protection of Freshwater Aquatic Life.
- Soil chemistry will be compared to the CCME Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health and the soil quality standards in the GNWT Environmental Guideline for Contaminated Site Remediation.

Given the duration of the project, the GNWT-INF may need to engage with qualified environmental professionals to adapt monitoring activities, while concurrently proceeding with updating the monitoring plan to meet the requirements of the Type B water licence.

In addition to this monitoring plan, the following plans have been created to support the dredging works:

- Engagement Plan;
- Sediment and Erosion Control Plan;
- Spill Contingency Plan; and
- Waste Management Plan.

1.4 Assumptions

Several assumptions were made in developing the Monitoring Plan. These include:

- Dredging will occur within the Fisheries and Oceans Canada allowable activity window (July 16 to September 14) (DFO 2023) to reduce the risk of harm to fish during spawning. At the time of this submission, the GNWT-INF is pursuing an earlier start to the dredging window with Fisheries and Oceans Canada (DFO), based on feedback and local knowledge through engagement.
- Based on the short duration of the project and on the naturally high turbidity of the river, a turbidity curtain is not considered essential for dredging in these areas. Due to the strong currents in the river and the large size of Dredge Area A, a turbidity curtain would be ineffective and potentially unsafe. A turbidity curtain is not anticipated to be used in Dredge Area B due to the shallow water, and vessel and fish movement considerations. Turbidity curtains can drag along the bottom, which results in more sediment being released,

increasing the turbidity levels in the water. Turbidity curtains will remain as an adaptive management strategy though, in the event site conditions change, new information becomes available or nephelometric turbidity units (NTU) monitoring becomes problematic. NTU is the only water quality parameter that will be monitored in real time and will be converted to TSS (mg/L) using the correlation curve developed prior to project commencement in 2024. Metals and other parameters that require laboratory analysis cannot be managed in real time.

- The dredged material will be stockpiled 30 m or more from any watercourse (for details, refer to the Sediment and Erosion Control Plan in Associated 2023b).
- Surficial sediment chemistry in the Hay River, as evaluated in 2018 and 2023 (discussed in greater detail in Section 2.3), is representative of the sediment that will be dredged.
- The stockpile dewatering rate is expected to match the rate of water infiltrating onto underlying soils, and thus, excess water in sumps is not expected. If excess water is present and does not infiltrate, and is near sump capacity, the water will be collected from sumps (i.e., water collected from dewatering stockpiles) and/or will be pumped off under the direction of an environmental professional. Note that pump-offs may occur only with GNWT-INF approval, in coordination with a Water Licence inspector, after submission and approval of a specific pump-off plan.
- Dredged material will be stockpiled at multiple properties on Vale Island; the stockpiles will be contained using berms, and water will be managed through sumps and infiltration to the ground.
- Water runoff will meet the guidelines (since preliminary analyses met the guidelines for soils).

The monitoring plan is meant to be adaptive and allow for changes based on new information or changing site conditions. The plan is a working document, with ongoing review from qualified professionals, using adaptive management practices (as discussed in Section 4).

2 SITE BACKGROUND

The Hay River is 1,114 km in length and has a watershed area that encompasses 48,200 km^2. It originates in northwest Alberta and travels through northern Alberta and British Columbia before discharging into Great Slave Lake on the southwestern side (Government of Canada 2023). The East Channel of the Hay River, at the outlet into Great Slave Lake, is used to supply goods to several communities. The West Channel is too shallow for commercial shipping, and aerial photos showed no evidence of commercial shipping having occurred along it. Dredging is proposed at the outlet of the Hay River into Great Slave Lake (Dredge Area A) and in the East Channel of the river (Dredge Area B) (Figure 1-1).

2.1 Dredge Area A

Dredge Area A is at the outlet of the Hay River, extending northward into Great Slave Lake, and is downstream of Dredge Area B. Dredge Area A is in open water in Great Slave Lake and is subject to high winds and lake currents, and is highly influenced by Hay River flow. The area is a depositional area for sediment, as evidenced by a turbid water gradient in the lake that can be seen in aerial imagery (Figure 1-1).

2.2 Dredge Area B

Dredge Area B is described as the area in the East Channel of the Hay River, specifically upstream of the river outlet into Great Slave Lake. The East Channel contains several side channels (fingers), which are planned for dredging

(Figure 1-1). The upstream end of the three fingers in Dredge Area B is disconnected from the Hay River by the Hay River Highway and is thus not expected to be affected by the proposed dredging activities.

2.3 Historical Water and Sediment Quality

Water quality has actively been monitored at the following two locations near the dredge areas as part of the Northwest Territories community-based monitoring program (DataStream Initiative 2023), which started in 2012 (locations shown in Figure 3-1):

- Hay River, at the mouth of the river (station ID: HAY-GSL); and
- Hay River, upstream of the West Channel (station ID: HAY-U/S).

These data were used to better understand the background concentrations of TSS around the dredge areas and to determine the response framework, described in Section 4. Data are available online through Mackenzie DataStream (DataStream Initiative 2023). Turbidity monitoring updates for 2024 is based on this community based monitoring program and turbidity monitoring data and observations from 2023 operations.

Analytical results from sediment samples collected from the in situ sediment samples collected in 2017 and 2023 (Appendix A) and during 2023 dredging operations (Appendix B) were compared to the CCME Soil Quality Guidelines for the Protection of Environmental and Human Health and the GNWT Contaminated Sites Remediation (CSR) criteria. All samples were below the CCME soil quality guidelines and GNWT CSR for parkland/residential land use for all contaminants of concern (Associated 2023c).

3 MONITORING PLAN

Water quality in the receiving waters will be monitored during the dewatering process on the barge and after the dredged material is transferred to Vale Island. The dewatered dredged material will be monitored to determine whether it may be reused off site. The monitoring plan has been split into the following parts:

- Monitoring Water Quality in Receiving Waters (Section 3.1);
- Monitoring Water Quality for Dewatering Activities on Vale Island (Section 3.2); and
- Monitoring Quality of Dewatered Dredged Material (Section 3.3).

The effects on the receiving environment during dredging are expected to be minimal based on the short duration of dredging activities and the contingencies in place, as documented in the monitoring plan response framework (Section 4).

3.1 Monitoring Water Quality in Receiving Waters

3.1.1 Monitoring Locations

Receiving waters are defined as the waters in Great Slave Lake (Dredge Area A) and the Hay River (Dredge Area B) that surround the dredging areas (Figure 3-1". Six locations have been selected for monitoring around Dredge Area A (Figure 3-2) and four locations have been selected for Dredge Area B. The Dredge Area A locations have been updated from the original placement as a result of observations and data from 2023. A sediment curtain is not anticipated to be used during dredging.

Initial monitoring in Great Slave Lake (pre-2023) indicated that substantial variation in turbidity is evident throughout the lake under baseline conditions (i.e., no dredging). As such, four reference stations were identified being needed in combination with an adaptive management strategy. The need for four reference stations was confirmed during the 2023 dredging operations. The distance of monitoring locations and reference locations are situated relatively close to one another (100 m and 300 m, respectively). This is required in the current program due to the lack of homogeneity in turbidity across the lake that was previously noted (i.e., reference stations further from the barge are unlikely to represent conditions near the barge). There is a potential that with the prevailing winds and high currents that even some of the 300 m stations could be impacted by dredging. Monitoring is adaptable however and would utilize reference area locations with wind and water current observations considered to ensure that suitable references stations are being used in evaluating potential impacts from dredging (i.e., reference stations downwind/water current may not be utilized for turbidity detection purposes, but rather those that are located upstream would be utilized).

The 8 monitoring locations for Dredge Area A were chosen based on aerial imagery of the existing turbidity plume entering Great Slave Lake from the Hay River, available fisheries background information for the area and visual observations and data from 2023 dredging operations. Dredge Area A is not believed to have adequate spawning habitat for fish species that are considered important from a resource management perspective due to the high turbidity and sedimentation in this area (Associated 2023a). Based on this knowledge, three monitoring locations are proposed on each of the east and west sides of the dredging works (six locations in total) to account for any changing currents that may occur during dredging activities (Table 3-1, Figure 3-2). Each side (east and west) will be evaluated separately. A triangle shape will be set up with two background references (REF) compared against a monitoring station (A) approximately 100 m from Dredge Area A. The two references on each respective side will be averaged to account for depth changes and wave variability, then compared to the monitoring station near Dredge Area A for high level action level response. For both Dredge Areas A and B, monitoring locations will be field fit to adapt to changing site conditions.

Table 3-1 Monitoring Locations in Dredge Area A

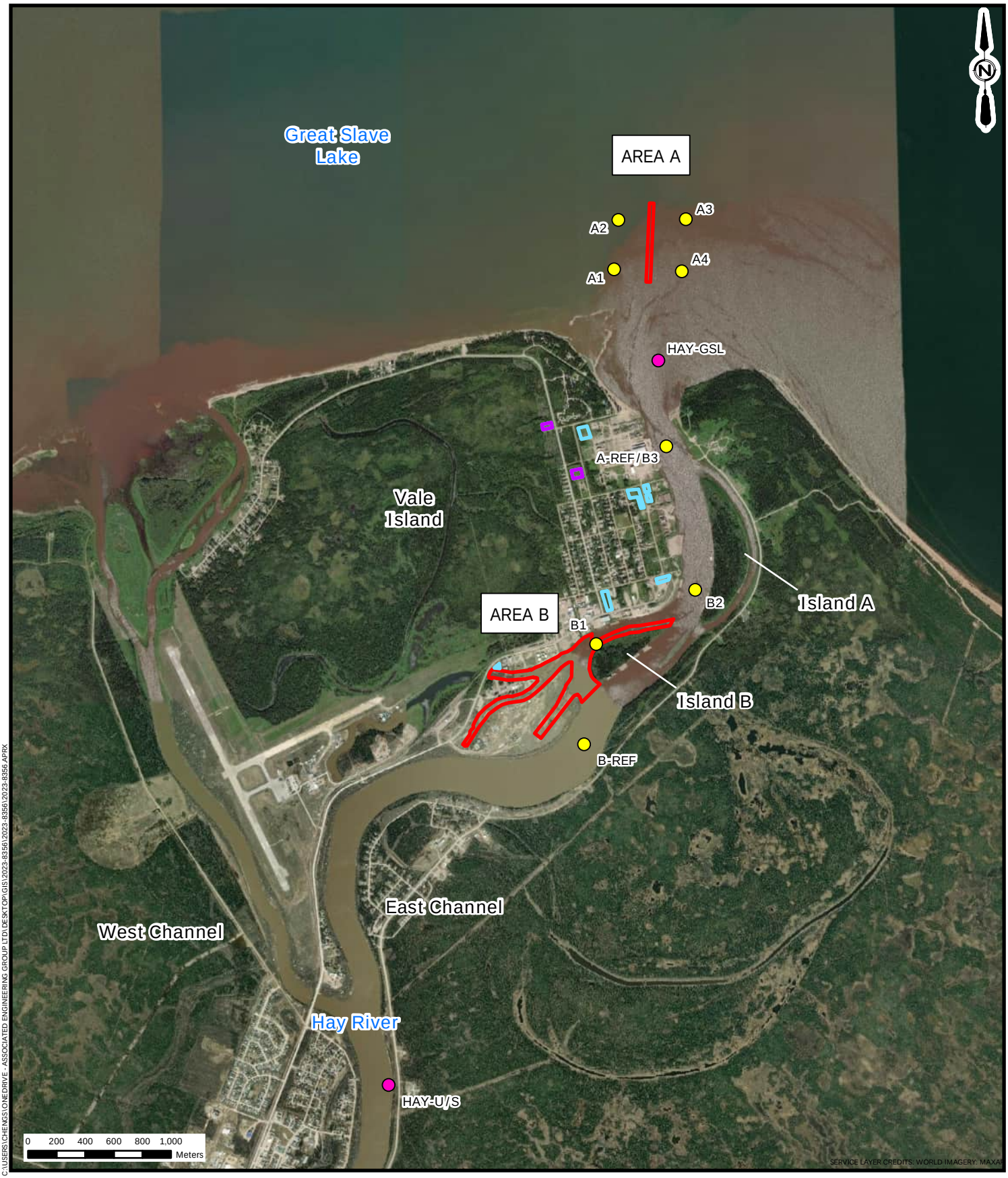
Site Name	Location and Rationale	UTM Coordinates (Zone 11V)
REF_NW	200 m from REF_SW, in the northwest corner and 300 m from A_W	6749449.0000m E 568285.0000m N
REF_SW	200 m from REF_NW, in the southwest corner and 300 m from A_W	6749406.0000 m E 568279.9197 m N
A_W	100 m west of Dredge Area A to capture potential plumes moving in a westerly direction	6749364.6297 m E 568660.2768 m N
REF_NE	200 m from REF_SE, in the northeast corner and 300 m from A_E	679406.0000 m E 569378.0000 m N
REF_SE	200 m from REF_NE, in the southeast corner and 300 m from A_E	6749206.0057 m E 569376.4907 m N
A_E	100 m east of Dredge Area A to capture potential plumes moving in an easterly direction	6749362.2512 m E 568890.5521 m N

The monitoring locations along the Hay River in Dredge Area B were chosen based on knowledge of the flow dynamics in the area, which has very low velocity. The monitoring locations were selected to represent background

conditions (REF), conditions immediately downstream of the dredging works (B1 and B2), and conditions at a far-field site further downstream (B3) (Table 3-2, Figure 3-1).

Table 3-2 Receiving Environment Monitoring Locations in Dredge Area B

Site Name	Location and Rationale	UTM Coordinates (Zone 11 V)
REF	Approximately 200 m upstream of Dredge Area B; this site will act as background for NTU for Dredge Area B.	568307.08 m E 6745721.73 m N
B1	Directly downstream of Dredge Area B, on the northwest side of Island B; this site will act as a NTU monitoring site for the dredging occurring in the northern fingers of Dredge Area B.	568391.95 m E 6746421.90 m N
B2	Directly downstream of Dredge Area B, on the southwest side of Island A; this site will act as a NTU monitoring site for the dredging occurring near Island B.	569084.08 m E 6746800.36 m N
B3	Downstream of Dredge Area A, approximately 1 km east of Island B; this site will act as the monitoring point of the dredging occurring on the north side of Island B.	568882.98 m E 6747803.11 m N



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Associated Environmental

LEGEND
- Historical Monitoring Locations
- Proposed Monitoring Locations
- Dredging Areas
- Temporary Soil Storage (GNWT)
- Temporary Soil Storage (Town of Hay River)

AE PROJECT NO.	2023-8356
SCALE	1:35,600
COORD. SYSTEM	NAD 1983 UTM ZONE 11N
DATE	2023-03-29
REV	04
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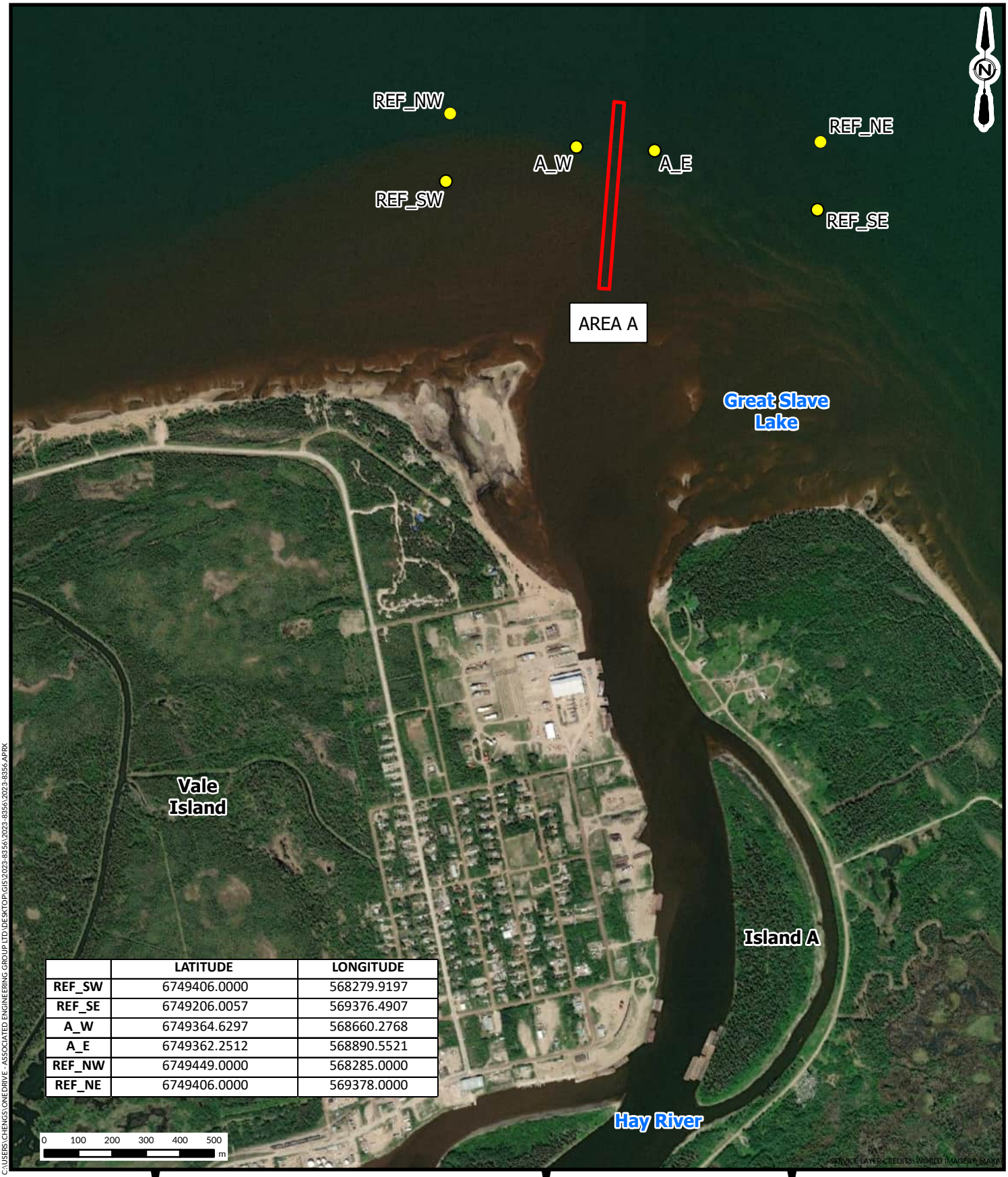
FIGURE 3-1
BASELINE SAMPLING LOCATIONS

GOVERNMENT OF NORTHWEST TERRITORIES-DEPARTMENT OF INFRASTRUCTURE

HAY RIVER HARBOUR RESTORATION



	LATITUDE	LONGITUDE
REF_SW	6749406.0000	568279.9197
REF_SE	6749206.0057	569376.4907
A_W	6749364.6297	568660.2768
A_E	6749362.2512	568890.5521
REF_NW	6749449.0000	568285.0000
REF_NE	6749406.0000	569378.0000

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Northwest Territories

LEGEND

- Updated turbidity monitoring locations

AE PROJECT NO.	2023-8461
SCALE	1:15,000
COORD. SYSTEM	NAD 1983 UTM ZONE 11N
DATE	2023-12-21
REV	00
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FIGURE 3-2
LOCATIONS FOR WATER QUALITY MONITORING IN DREDGE AREA A

GOVERNMENT OF NORTHWEST TERRITORIES-DEPARTMENT OF INFRASTRUCTURE

HAY RIVER HARBOUR RESTORATION

3.1.2 Frequency and Parameters

Before dredging operations each year, two 20 L grab samples will need to be collected at each location to create a TSS–turbidity correlation curve following the standard operating procedures outlined in Appendix C. Samples will be collected by an environmental monitor at least 2 weeks before dredging starts to allow for adequate time for analysis at locations A1 and B1 (the sites representative of Dredge Area A and Dredge Area B, respectively). This curve is required as standard industry sensors generally record only nephelometric turbidity units (NTUs), while historical data (historical locations are shown in Figure 3-1) and guidelines for TSS were reported in milligrams per litre. This curve may also be updated within a dredging season year if the site conditions change or new information becomes available.

During dredging, NTUs is to be monitored continuously, using real-time sensors, at the monitoring locations proposed in Section 3.1.1 and converted to TSS using the correlation curve (developed prior to project commencement). Sensors will be installed at a depth of 60% from the water surface and set to record NTU every 30 minutes. Data from the sensors may be downloaded remotely and will not require manual downloading.

Sensors in Dredge Area A will likely need to be attached to a buoy platform that is anchored to the lake bottom. Sensors in Dredge Area B will likely be anchored to the shore. The sensors will also require ongoing maintenance to verify that they are operating correctly, including potentially cleaning the sensors weekly to rid them of algae and other debris. Instructions for installing and using these sensors will be provided by the entity that supplies the sensors and will be followed to ensure proper use. In addition to the monitoring completed using NTU sensors, the environmental monitor will evaluate waters using similar technology (i.e., a hand-held water quality meter), for quality control purposes. The environmental monitor will measure background TSS at each monitoring location before dredging starts each day and will compare the results to those of the sensor stations to determine whether the sensors are operating correctly. The environmental monitor will measure background (either TSS or NTU), for quality control purposes.

Data collection is expected to occur 1 week before dredging begins to determine background TSS concentrations (extrapolated from NTU measurements) at the monitoring locations and to inform the response framework outlined in Section 4.1. Based on historical water quality data, background TSS concentrations are expected to fluctuate throughout the dredging period, ranging from 33 mg/L to 40 mg/L (DataStream Initiative 2023).

Turbidity data (both NTU and TSS) will be provided on a daily (24-hour) basis in an environmental report by the environmental monitor to the project team (including the environmental auditor). The report will include but not be limited to:

- Conversion factor (relationship between nephelometric turbidity units into milligrams per litre);
- Turbidity data from real-time sensors for a 24-hour period, in tabular format, in both nephelometric turbidity units and milligrams per litre (a graph form is acceptable, but tabular data must also be included in an appendix);
- Turbidity data from the hand-held water quality meter (or equivalent) for quality control purposes;
- Weather conditions (e.g., temperature, wind speed, wind direction, and precipitation, etc.);
- Clearly identified instances of non-compliance (i.e., exceedances) identified per guideline value (see Section 4.1);
- Documentation of all non-compliance instances, including:
    - Level of exceedance;

- Duration of exceedance;
- Mitigation measures taken;
- Verification of reporting of the exceedance;
- Any related communications with regulators regarding the exceedance event; and
- Future measures to be taken to avoid or further control exceedances.

- Minimum of three photos at the dredging location to represent turbidity conditions.

The monitoring plan will be continually evaluated and adjusted based on the data acquired; the response framework for the collected data is outlined in Section 4.1.

3.2 Monitoring Water Quality for Dewatering Activities on Vale Island

3.2.1 Monitoring Locations

An excavator situated on a barge will remove the dredged material and stockpile it onto a barge deck. An engineered filter medium (approved by GNWT-INF) will be installed on the deck, which will let water flow freely off of the barge but dredged material to remain on the deck, allowing for passive dewatering. The engineered filter medium will be inspected and actively maintained on a weekly basis (or as indicated by GNWT-INF) at a minimum. Maintenance will include:

- Physical removal of accumulated sediment from the engineered filter medium;
- Replacement of engineered filter fabric that shows observable limited function (i.e., torn, damaged, or poorly secured); and
- Additional maintenance as directed by the onsite engineer.

Records of maintenance of the engineered filter medium will be provided within 7 days of the maintenance activity and include before/after photos, at a minimum. When the barge is at capacity, the dredged material will be transferred to Vale Island, where it will be stockpiled at multiple properties and allowed to passively dewater further. The stockpiles will be contained using berms, and water will be directed into sumps for infiltration to the ground.

Before the initial use of any temporary storage site, grading will occur to ensure drainage is directed to a sump to contain any potential runoff. As noted in Schedule 1 of the current Type B water licence, the sumps will form the SNP station locations. The drainage grading must be inspected and approved by GNWT-INF before storage sites are used. Perimeter berms will be at least 1 m high and sufficiently compacted to mitigate potential seepage. The sump located at each temporary storage site must be appropriate for positive drainage, physically demarcated on site (i.e., using signage), and the location coordinates for the SNP station provided to GNWT-INF (Figures 3-3 and 3-4). Additional construction material requested to be brought to the site by the contractor must be clean and free of contaminants and must be approved by GNWT-INF before it is transported to the site.

Monitoring wells at each temporary stockpile location will be field verified by the contractor, and GPS coordinates provided to GNWT-INF. The legacy monitoring wells onsite are not included as part of the dredging project, but still need to be protected. A surface mound around the monitoring well is required and will consist of compacted clay. The compacted clay will be placed around the casing of the well to move surface water away from it. Concrete jersey barriers (or an approved alternative) will be installed in a triangular shape around each monitoring well to prevent physical damage to the wells. Water (resulting from precipitation and/or dewatering) will not be allowed to accumulate near the monitoring wells and will be actively managed (see Section 4.2 for further details on the management of excess water). A map of the anticipated monitoring well locations is shown in Figure 3-3.

When a temporary storage site is used, the environmental monitor must monitor the area daily for water accumulation and risk of erosion. If water accumulation (i.e., precipitation and/or dewatering) is noted, it must be actively managed to mitigate the potential release of water off site. Excess water that does not infiltrate to the ground will be managed using various techniques depending on the volume of water and the amount of dredged material (see Section 4.2 for further details on the management of excess water). Additional sediment and erosion control measures may be required during or after a temporary storage site is used. Formal weekly inspections of each temporary storage site will occur by the environmental monitor and be documented including photographs. A monthly summary (including the requirements in Schedule 1 of the Type B water licence from the MVLWB) must be provided to GNWT-INF (for submission to the MVLWB) by the environmental monitor within 10 calendar days of the month being reported.

When the dredged material is removed from water and placed on land, it is classified as soil. Water quality samples will be collected from sumps on the stockpile properties to validate the quality of the water that will be returned to the Hay River through ground infiltration. The frequency of sampling is proposed to be weekly (if water is present), but this will be re-evaluated before dredging activities start based on timing and frequency of offloading, dewatering activities, and relocation of dredged material (after dewatering).

3.2.2 Frequency and Parameters

Grab samples will be collected weekly in the sumps (if water is present), and will be sent to an accredited laboratory[2] and analyzed for parameters as mandated in the water licence;

- Field parameters
- Total and dissolved solids
- Major ions
- Total and dissolved metals
- Petroleum hydrocarbons (specifically fractions 1–4, and benzene, toluene, ethylbenzene, and xylenes [BTEX])

Individual parameters that will be analyzed from these parameter groups can be found in the water licence. Water sampling will be conducted according to the British Columbia Field Sampling Manual (Appendix B of Government of British Columbia 2013).

The monitoring plan will continually be evaluated and adjusted based on the data acquired; the response framework for the collected data is outlined in Section 4.2.

[2]Analytical analysis should have detection limits for constituents that are lower than applicable CCME water, sediment, and soil guidelines (when available).

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Associated Environmental

Northwest Territories

LEGEND

- Sump Location
- Monitoring wells

Temporary Soil Storage

- Government of Northwest Territories
- Town of Hay River

AE PROJECT NO.	2023-8461
SCALE	1:5,500
COORD. SYSTEM	NAD 1983 UTM ZONE 11N
DATE	2024-03-04
REV	00
DRAWN BY	SC
CHECKED BY	RL

FIGURE 3-3
MONITORING LOCATIONS

GOVERNMENT OF NORTHWEST TERRITORIES-DEPARTMENT OF INFRASTRUCTURE

HAY RIVER HARBOUR RESTORATION

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Associated Environmental

Northwest Territories

LEGEND

- Sump Location

Temporary Soil Storage

- Government of Northwest Territories
- Town of Hay River

AE PROJECT NO.	2023-8461
SCALE	1:3,000
COORD. SYSTEM	NAD 1983 UTM ZONE 11N
DATE	2024-03-04
REV	00
DRAWN BY	SC
CHECKED BY	RL

FIGURE 3-4
MONITORING LOCATIONS

GOVERNMENT OF NORTHWEST TERRITORIES-DEPARTMENT OF INFRASTRUCTURE

HAY RIVER HARBOUR RESTORATION

3.3 Monitoring Quality of Dewatered Dredged Material

3.3.1 Monitoring Locations

Stockpiles will be initially placed to physically separate the deposits from each day. This may include several barge loads depending on the productivity that day. The piles of dredged material for each day must be separated by 2 to 5 m (or as approved by GNWT-INF) until sampling results confirm that the material can be mixed. Each barge load placed must be representatively sampled (according to the volume of the barge load being deposited) by the environmental monitor on the day it was deposited at the temporary storage site. This will prevent mixing of potentially different materials until sampling results can be reviewed to confirm that mixing can occur. Different temporary storage sites may need to be used concurrently to maintain the physical distance requirement of the total day stockpile volume. Concurrent use of different stockpile locations will also contribute to passive dewatering efforts allowing increased time for infiltration.

The number of samples collected from each barge load will depend on the volume of the barge load. Larger volumes will require more samples (discussed in more detail in Section 3.3.2). Each sample will be a composite sample consisting of several individual samples. The individual samples will be collected from each barge load stockpile (e.g., on surface, at depth, along the sides) following the procedures outlined in the British Columbia Field Sampling Manual (Appendix B of Government of British Columbia 2020) and the Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment (CCME 2016). Samples will ultimately provide representation of the entire day's stockpile (i.e., one day may have five barge loads deposited, other days may have only one; each barge load may vary in volume depending on production factors and site conditions). The composite samples will be sent to an accredited laboratory for analysis.

3.3.2 Frequency and Parameters

Dredged material must be sampled on the day it is deposited at the temporary storage location. Each barge load must be sampled and georeferenced to the location from which the material was dredged, and the barge loads deposited that day must be physically separated from one another (by at least 5 m) and demarcated (using signage or staking) on site until sampling results confirm that piles may be mixed. Note: Material dredged from Dredge Area A and Dredge Area B cannot be stored the same temporary storage site unless approved in writing by GNWT-INF. Stockpile samples must be obtained and sent for laboratory analysis on a daily basis, per barge load, with an expedited (1-week maximum) laboratory turnaround time. This will ensure timely results and the effective use of the stockpile storage locations. The number of samples will be based on barge load volume as mandated by the water licence (Table 3-3).

Table 3-3 Composite Samples Required per Barge Load Volume Deposited at a Temporary Stockpile Location

Soil Volume (m^3)	Sample Quantity
1–50	1
51–100	2
101–1,000	3
1,001–2,000	4
2,001–4,000	5

Additional information regarding stockpile characterization can be found in the Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment (CCME 2016). The parameters evaluated will be similar to those evaluated in sump waters, with a few additional parameters to understand the soil characteristics.

Samples will be analyzed for:

- pH;
- Conductivity;
- Salinity;
- Total metals;
- Moisture content;
- Geotechnical characteristics including grain size by hydrometer; and
- Hydrocarbons (specifically petroleum hydrocarbon fractions 1–4, and BTEX).

The environmental monitor must provide data in a report (i.e., not e-mail), in tabular form (where possible), and must specify, for each day (24-hour period):

- The temporary stockpile location;
- Which dredge area (A or B) the material from the barge load(s) came from; if from Dredge Area B, specify which side channel (finger);
- The barge load number (for that day), georeferenced location the material was dredged from, and the volume of the barge load in cubic metres (note: the volume of the barge load is to be calculated per onsite engineer direction);
- Visual inspection and observation summary of each barge load deposited for signs of potential contamination (e.g., hydrocarbon smell, staining, foaming, sheen, etc.);
- The time each barge load was deposited at the temporary stockpile location;
- The time each barge load was sampled by the qualified environmental professional;
- The number of composite samples obtained for each barge load (per Table 3-3);
- Sample results for each composite sample from each barge load;
- Clearly identified exceedances, with their applicable guidelines (Section 1.3);
- Photographs (minimum total four) in each cardinal direction of each temporary storage location (this applies only to temporary storage sites that contain deposited material) and;
- The date the material was mixed.

Only truckloads from the same barge load can be mixed before samples are analyzed. Stockpiles deposited on different days must not be mixed until:

- The analytical results of barge load composite samples have been provided to GNWT-INF in report form (see above), including clearly identified exceedances with applicable guidelines and;
- Written approval has been granted by GNWT-INF to mix stockpiles deposited on different days.

Additional parameters may be required, depending on the planned end land use, and will thus be confirmed before sampling. The monitoring plan will continually be evaluated and adjusted based on the data acquired; the response framework for the collected data is outlined in Section 4.3.

3.4 Monitoring Summary

Table 3-4 summarizes the monitoring efforts.

Table 3-4 Monitoring Summary

Monitoring Location	Matrix	Parameter	Frequency	Point in Works	Relevant Section
A1, B1	Water	• Water samples for TSS–turbidity correlation curve	Once	2 weeks before dredging starts	Section 3.1.2, Appendix B
REF, A1, A2, A3, B1, B2, B3	Water	• Field parameters • Total and dissolved solids • Major ions • Total and dissolved metals • PHCs[1]	Before and after dredging at a given location[2]	Before and after dredging at a given location[2]	Section 3.1
REF, A1, A2, A3, B1, B2, B3	Water	• TSS (extrapolated from NTU measurements)	Every 30 minutes	During dredging	Section 3.1
Sumps	Water	• Field parameters • Total and dissolved solids • Major ions • Total and dissolved metals • PHCs[1]	Weekly, *when water present*	During dewatering on Vale Island	Section 3.2
Stockpiles	Dredged material	• pH • Conductivity • Salinity • Metals • PHCs[1] • Moisture content • Geotechnical characteristics • Additional parameters based on land use for the end product and applicable guidelines (such as TOC and nutrients).	Day of being placed at the stockpile storage location	During dewatering on Vale Island	Section 3.3

[1] Hydrocarbons will include PHC fractions 1–4 and benzene, toluene, ethylbenzene, and xylenes. [2] Before and after dredging at a given location refers to before initiation and at the conclusion of dredging at Areas A and B. PHC – X; TOC – X; TSS – X

3.5 Climate Change Considerations

Per MVLWB's Standard Outline for Management Plans, climate change impacts are to be considered as part of the management plans. Climate change impacts were not considered as part of this monitoring plan, as the dredging and associated monitoring are limited to a short period (i.e. several weeks). Climate change should not impact the water quality and dredged material sample results of the monitoring program due to its short-term nature.

3.6 Cumulative Impacts

Per MVLWB's Standard Outline for Management Plans, cumulative impacts must be considered. Due to the short-term nature of the project, no cumulative impacts are expected if the monitoring plan is followed. If changes in water quality from background occur, additional sampling may be required, as outlined in Section 4.

4 MONITORING AND RESPONSE FRAMEWORK

This section addresses the use of adaptative management practices to verify the effectiveness of the monitoring plan. The monitoring plan will be continually evaluated and adjusted based on the data acquired during monitoring. The monitoring and response framework uses early-warning triggers during dredging activities, which, if exceeded, lead to various contingency plans based on the magnitude and frequency of that exceedance. The overall objective of the monitoring and response framework using adaptive management practices is to limit the overall risks to aquatic receiving environments (during dredging activities) (Section 3.1) and terrestrial receiving environments (during dewatering activities) (Sections 3.2 and 3.3). Following the MVLWB's guidelines for management programs, this section describes the triggers and responses for the following sections of the monitoring plan outlined in Section 3:

- Monitoring Water Quality in Receiving Waters;
- Monitoring Water Quality for Dewatering Activities on Vale Island; and
- Monitoring Quality of Dewatered Dredged Material.

4.1 Monitoring Water Quality in Receiving Waters

The monitoring plan response framework for the receiving waters follows the CCME Canadian Water Quality Guidelines for the Protection of Aquatic Life guideline for TSS. The guideline is based on background conditions and on whether the flow is considered clear flow or high flow. Clear flow is defined as water with a TSS concentration of less than 25 mg/L, while high flow is defined as water with a concentration of TSS equal to or greater than 25 mg/L (CCME 1999). Based on TSS data from 2017–2021, concentrations in the Hay River and at the Hay River outlet ranged from 33 mg/L to 40 mg/L from July to September, with no instances of concentrations being below 25 mg/L (DataStream Initiative 2023) (Appendix D).

Based on this information, it is expected that the TSS levels in both dredging areas will be considered high flow for the duration of the dredging, and the following guidelines will apply (CCME 1999):

- A maximum increase of 25 mg/L from background concentrations when background concentrations are between 25 and 250 mg/L; and
- A maximum increase of 10% of background levels when background is >250 mg/L.

The guideline value for an exceedance will be as described above compared to the background monitoring location during active dredging operations. Dredge Areas A and B will have separate background monitoring stations. Note that the CCME guidelines for TSS are based on a 24-hour period to return to acceptable levels; they are not instantaneous readings. To achieve the goal of monitoring if dredging activities are potentially having a measurable impact on the immediate area, and using observations and data from 2023 dredging operations, a "high" action level response will be defined as an exceedance of four consecutive monitoring intervals (30 minute intervals) for a monitoring station compared to background, or a visible plume as observed by the environmental monitor onsite.

During the 2023 dredging operations in Great Slave Lake, there were TSS exceedances during natural events and from non-project related sources (e.g., passing vessels, excessive winds). This trend in the Lake is expected to occur in 2024 as well (due to unpredictable changes in wind and water currents). These low and medium action triggers further investigation. For example, a medium action could be an exceedance with a potential nearby influence (boat passing by); a low could be a sudden spike in turbidity, but has not triggered an exceedance.

If a high action level response is identified, and cannot be attributed to a natural (e.g., excessive winds also impacting the background monitoring station) or non–project-related source, (e.g., passing vessels at the time the guideline value exceedance was recorded for the four intervals), the following steps will be implemented:

- Work will be stopped.
- The dredging methods will be investigated with the dredging team to determine whether the methods led to the increase (and whether techniques can be modified) or if any outliers apply to the result (i.e., have background concentrations of TSS changed?).
- The water resource officer from GNWT – Environment and Climate Change (ECC) is to be informed within 48 hours of the exceedance, with the details of the cause, how it was remediated, and any stoppages that occurred.
- TSS will be allowed to return to background concentrations (if applicable).
- Dredging activities will be resumed with modified methods as required, with approval from GNWT-ECC.

For guideline value exceedances attributed to a natural or non–project-related source (i.e., medium action), the environmental monitor must inform GNWT-INF verbally and in writing immediately and document the following:

- The time the exceedance was discovered;
- The time GNWT-INF was notified;
- Whether work was stopped;
- Level of exceedance;
- Duration of exceedance;
- Mitigation measures taken (if any);
- Minimum of three supporting photographs.

Any abrupt changes in TSS (i.e., increase or decreases) or values nearing a guideline exceedance (i.e., low action) will be immediately communicated by the environmental monitor to the project team and included in daily reporting. The environmental monitor will evaluate and document potential contributing sources and overall risk assessment, and determine if additional preventative actions can be taken or additional mitigation measures employed.

If a guideline is consistently exceeded and disrupts work, the monitoring plan may be re-evaluated.

4.2 Monitoring Water Quality for Dewatering Activities on Vale Island

The dredged material will be moved to land after dewatering on the barges for several hours. It is expected that the material will have a low water content by the time it is placed on the temporary storage sites. The ongoing dewatering processes at the temporary storage sites will be primarily by evaporation and infiltration to the ground. The stockpiles will be more than 30 m away from watercourses and will be contained by berms. Sumps will be identified for each temporary stockpile location, per the SNP.

If excessive water is found to be collecting on any of the temporary storage sites from precipitation events or slow infiltration, resulting in sumps reaching capacity or the risk of release to locations off site, adaptive management measures will be enacted. These may include but not be limited to:

- A temporary slow-down of new dredged material being brought to the site and/or an increase of residence time of the dredged material on the barge before it is brought on land;
- Verification of engineered filter media performance on barges and enact maintenance or replacement protocols, as per the Sediment and Erosion Control Plan (Associated 2023b) or as directed by GNWT-INF;
- Redirection of new soil to alternative stockpile sites and/or use of multiple temporary storage sites concurrently;
- Collection of water in tanks on site, and potential removal by trucks and/or pump-off;
- Addition of more sumps, excavated sumps, and/or lined sumps at each temporary storage site;
- Pump-off off site to a well-vegetated area, with appropriate sediment and erosion control (SEC) measures in place. Note that pump-offs may occur only with GNWT-INF approval and in coordination with the water licence inspector, after the submission and approval of a specific pump-off plan. The plan must include detailed water quality and quantity (i.e., volume) considerations and measurements, specific proposed SEC measures and on-site guidance, and monitoring (including documentation) by an environmental professional. Direct re-entry to a watercourse will be avoided. Any guideline exceedances (and mitigations) will be included in the specific pump-off plan.

If water is present in the sumps, it will be sampled weekly for the same parameters sampled during stockpile monitoring. Sump water quality will be included in the Surveillance Network Program (SNP) report, provided within 30 days of the month being reported (as per the Water Licence). It is possible that there will be insufficient water for monitoring purposes; however, if sufficient volume is present, this information will be used for validation purposes only, as per Section 3.2.1.

4.3 Monitoring Quality of Dewatered Dredged Material

Stockpiles deposited each day will be physically demarcated by a minimum distance of 2 to 5 m (or as approved by GNWT-INF). Several barge loads may contribute to the daily total at a stockpile location (and must be sampled per barge load, per Section 3.3.2). This minimizes the potential volume of material that must be managed if contaminants are encountered during dredging activities.

Dredged material must meet applicable standards based on reuse guideline requirements before it is exported from the site. This includes GNWT's Environmental Guideline for Contaminated Site Remediation (GNWT 2003) for residential/parkland and commercial land uses.

If the dredged material meets guidelines, potential options for reuse include using it as fill material to raise land in the local area, as capping material at the solid waste disposal facility, or other purposes to be determined.

If the soil is contaminated at levels greater than regulatory guidelines, remediation and management options (including in-situ and ex-situ options) will be explored.

5 CONTINGENCIES

Contingency options for foreseeable scenarios that may impede the success of the monitoring plan include the following:

- Due to the high winds and varying turbulent conditions at Great Slave Lake, buoy platforms with turbidity sensors may not be feasible. If this is the case, monitoring locations will be accessed by boat, and TSS will be evaluated manually either directly using TSS or using NTUs and converted using the correlation curve. Measurements will still be completed approximately every 30 minutes at each monitoring location, but the frequency and timing of sampling may need to be adjusted based on safety considerations and active dredging activities in the area.
- An installation plan for turbidity sensors will be drafted before the sensors are installed and will include regulations set by Transport Canada (e.g., signage, lighting or reflective material).
- Turbidity sensors may be vandalized, stolen, or destroyed, or they may stop working during dredging. Sensors will be checked manually every morning before dredging starts. Additional turbidity monitoring equipment must be on site in a ready-to-deploy condition and include, at a minimum, the equipment required to deploy four additional monitoring locations (e.g., four buoys, four sensors, extra chain) per each dredge location (A and/or B).

This monitoring plan is meant to be adaptive and reviewed throughout dredging activities, and changes may be implemented as required, with oversight from appropriate qualified professionals.

CLOSURE

This report was originally prepared for the Government of Northwest Territories – Department of Infrastructure to supplement the Type B water licence application for the Hay River Harbour restoration project. This report is provided as an annual review and update in winter 2023 to reflect changes in operations, contact information, or other details.

The services provided by Associated Environmental Consultants Inc. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practising under similar conditions. No other warranty expressed or implied is made.

Respectfully submitted,

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APPENDIX A – SEDIMENT ANALYSIS LAB RESULTS

Hay River Harbour
Legend for Soil Quality Results

<	Less than reported detection limit
CCME Sediment FAL	CCME. Canadian sediment quality guidelines for the protection of freshwater aquatic life.
CCME SO CL CS	CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Commercial Land Use and Coarse-grained Soil.
CCME SO CL FS	CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Commercial Land Use and Fine-grained Soil.
CCME SO IL CS	CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Industrial Land Use and Coarse-grained Soil.
CCME SO IL FS	CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Industrial Land Use and Fine-grained Soil.
CCME SO RL/PL CS	CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Residential/ parkland Land Use and Coarse-grained Soil.
CCME SO RL/PL FS	CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Residential/ parkland Land Use and Fine-grained Soil.
N	Narrative type of guideline or standard, or Result Note.
NG	No Guideline
CCME Sediment FAL	Highlighted value exceeds CCME Sediment FAL
CCME SO CL CS	Highlighted value exceeds CCME SO CL CS
CCME SO CL FS	Highlighted value exceeds CCME SO CL FS
CCME SO IL CS	Highlighted value exceeds CCME SO IL CS
CCME SO IL FS	Highlighted value exceeds CCME SO IL FS
CCME SO RL/PL CS	Highlighted value exceeds CCME SO RL/PL CS
CCME SO RL/PL FS	Highlighted value exceeds CCME SO RL/PL FS

Hay River Harbour

Soil Quality Results

Sampling Location								Sample 01-A	Sample 01-B	Sample 01-B	Sample 2	Sample 3	SED-019-01	SED-019-02	SED-019-03	SED-019-04	SED-019-05	SED-019-06
Date Sampled								18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17
Lab Sample ID								BKQ530	BKQ531	BKQ532	BKQ533	BKQ534						
Sample Type								Normal	Normal	Duplicate	Normal	Normal						
Analyte	**Unit**	**Guideline**																
		CCME Sediment FAL	CCME SO CL CS	CCME SO CL FS	**CCME SO IL CS**	**CCME SO IL FS**	CCME SO RL/PL CS	CCME SO RL/PL FS										
Lab Results																		
General																		
Anion sum	meq/L	NG	NG	NG	NG	NG	NG	NG					14	20	15	10	14	11
Boron (hot water soluble)	mg/kg	NG	NG	NG	NG	NG	NG	NG	0.08	0.065	0.054	0.056	0.1	0.27	0.46	0.45	0.27	0.22	0.5
Boron (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG	0.22	0.2	0.18	0.17	0.23						
Calcium (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG						160	220	200	150	200	170
Calcium (in saturated paste) (mass/mass)	mg/kg	NG	NG	NG	NG	NG	NG	NG						56	120	100	59	69	100
Cation sum	meq/L	NG	NG	NG	NG	NG	NG	NG						12	16	15	12	15	13
Cation/EC ratio		NG	NG	NG	NG	NG	NG	NG						12	12	12	12	12	12
Chloride (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG						110	130	83	56	53	32
Chloride ion	mg/kg	NG	NG	NG	NG	NG	NG	NG						39	69	41	21	19	20
Conductivity (in saturated paste)	µS/cm	NG	4000	4000	4000	4000	2000	2000						1000	1300	1200	970	1200	1100
Grain size		NG	NG	NG	NG	NG	NG	NG	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse	Fine	Fine	Coarse	Coarse	Fine
Ion balance		NG	NG	NG	NG	NG	NG	NG						0.86	0.81	0.96	1.1	1.1	1.2
Magnesium (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG						31	38	34	28	42	37
Magnesium (in saturated paste) (mass/mass)	mg/kg	NG	NG	NG	NG	NG	NG	NG						11	20	17	11	15	23
Moisture	%	NG	NG	NG	NG	NG	NG	NG	23	19	18	17	22	22	36	31	27	30	45
Percent clay	%	NG	NG	NG	NG	NG	NG	NG	10	6.6	7.2	5.7	14						
Percent sand	%	NG	NG	NG	NG	NG	NG	NG	72	87	89	90	72						
Percent silt	%	NG	NG	NG	NG	NG	NG	NG	18	6.4	4	4.1	14						
pH (in 0.01M CaCl2)		NG	6 - 8	6 - 8	6 - 8	6 - 8	6 - 8	6 - 8						7.24	7.11	7.1	7.15	7.2	7.11
Potassium (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG						11	16	15	14	11	10
Potassium (in saturated paste) (mass/mass)	mg/kg	NG	NG	NG	NG	NG	NG	NG						4.1	8.5	7.7	5.4	4	6.5
Percent saturation	%	NG	NG	NG	NG	NG	NG	NG	37	33	30	33	46	36	53	50	38	35	62
Sieve - Pan	%	NG	NG	NG	NG	NG	NG	NG	34	15	15	13	26	29	56	58	31	14	68
Sieve analysis - #10 (>2.00mm)	%	NG	NG	NG	NG	NG	NG	NG	<0.20	<0.20	4.8	<0.20	<0.20						
Sieve analysis - #200 (>0.075mm)	%	NG	NG	NG	NG	NG	NG	NG	66	85	85	87	74	72	44	42	69	86	32
Sodium (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG						34	35	33	27	32	30
Sodium adsorption ratio		NG	12	12	12	12	5	5						0.66	0.57	0.57	0.52	0.54	0.55
Sodium ion	mg/kg	NG	NG	NG	NG	NG	NG	NG						12	18	17	10	11	19
Sulphate (in saturated paste) (mass/mass)	mg/kg	NG	NG	NG	NG	NG	NG	NG						190	400	310	160	210	300
Sulphate (in saturated paste)	mg/L	NG	NG	NG	NG	NG	NG	NG						530	770	620	420	590	480
Texture		NG	NG	NG	NG	NG	NG	NG	Sandy Loam	Loamy Sand	Sand	Sand	Sandy Loam						
Theoretical gypsum requirement	ton US/ha	NG	NG	NG	NG	NG	NG	NG						<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Glycols																			
Diethylene glycol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<10	<10	<10	<10	<10	<10
Ethylene glycol	mg/kg	NG	960	960	960	960	960	960						<10	<10	<10	<10	<10	<10
Propylene glycol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<10	<10	<10	<10	<10	<10
Tetraethylene glycol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<10	<10	<10	<10	<10	<10
Triethylene glycol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<10	<10	<10	<10	<10	<10
Hydrocarbons																			
Benzene	mg/kg	NG	0.030 [2.1]	0.0068 [3.1]	0.030 [4.1]	0.0068 [5.1]	0.0095 [6.1]	0.0068 [7.1]	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Ethylbenzene	mg/kg	NG	0.082 [2.2]	0.018 [3.2]	0.082 [4.2]	0.018 [5.2]	0.082 [6.2]	0.018 [7.2]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
F1 (C6-C10)	mg/kg	NG	NG	NG	NG	NG	NG	NG	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
F1 (CCME): (C6-C10) (less BTEX)	mg/kg	NG	240 [2.3]	170 [3.3]	240 [4.3]	170 [5.3]	30 [6.3]	170 [7.3]	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
F2 (C10-C16)	mg/kg	NG	260 [2.4]	230 [3.4]	260 [4.4]	230 [5.4]	150 [6.4]	150 [7.4]	<10	<10	<10	<10	<10	<10	10	<10	<10	<10	<10
F3 (C16-C34)	mg/kg	NG	1700 [2.5]	2500 [3.5]	1700 [4.5]	2500 [5.5]	300 [6.5]	1300 [7.5]	<50	<50	<50	<50	52	<50	92	63	<50	<50	120

Hay River Harbour

Soil Quality Results

Sampling Location								Sample 01-A	Sample 01-B	Sample 01-B	Sample 2	Sample 3	SED-019-01	SED-019-02	SED-019-03	SED-019-04	SED-019-05	SED-019-06
Date Sampled								18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17
Lab Sample ID								BKQ530	BKQ531	BKQ532	BKQ533	BKQ534						
Sample Type								Normal	Normal	Duplicate	Normal	Normal						
Analyte	**Unit**	**Guideline**																
		CCME Sediment FAL	CCME SO CL CS	CCME SO CL FS	**CCME SO IL CS**	**CCME SO IL FS**	CCME SO RL/PL CS	CCME SO RL/PL FS										
F4 (CCME): (>C34-C50)	mg/kg	NG	3300 [2.6]	6600 [3.6]	3300 [4.6]	6600 [5.6]	2800 [6.6]	5600 [7.6]	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Reached baseline at C50	mg/kg	NG	NG	NG	NG	NG	NG	NG	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Styrene	mg/kg	NG	50	50	50	50	5	5						<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Toluene	mg/kg	NG	0.37 [2.7]	0.08 [3.7]	0.37 [4.7]	0.08 [5.7]	0.37 [6.7]	0.08 [7.7]	<0.050	<0.050	<0.050	<0.050	<0.050	<0.020	<0.020	<0.020	<0.020	0.038	<0.020
Xylene	mg/kg	NG	11 [2.8]	2.4 [3.8]	11 [4.8]	2.4 [5.8]	11 [6.8]	2.4 [7.8]	<0.045	<0.045	<0.045	<0.045	<0.045	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
m,p-Xylene	mg/kg	NG	NG	NG	NG	NG	NG	NG	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
o-Xylene	mg/kg	NG	NG	NG	NG	NG	NG	NG	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Miscellaneous Organic Substances																			
Atrazine + desethylatrazine	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0080	<0.0080	<0.0080	<0.0080	<0.0080	<0.0080
Bromacil	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0090	<0.0090	<0.0090	<0.0090	<0.0090	<0.0090
Diuron	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Linuron	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0070	<0.0070	<0.0070	<0.0070	<0.0070	<0.0070
Simazine	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Tebuthiuron	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Phenolic Substances																			
2-Chlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
3 + 4-Chlorophenol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Cresol	mg/kg	NG	10	10	10	10	1	1						<0.0071	<0.0071	<0.0071	<0.0071	<0.0071	<0.0071
2,4-Dichlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
2,6-Dichlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,4-Dimethylphenol	mg/kg	NG	10	10	10	10	1	1						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,4-Dinitrophenol	mg/kg	NG	10	10	10	10	1	1						<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
2-Methyl-4,6-dinitrophenol	mg/kg	NG	10	10	10	10	1	1						<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
4-Chloro-3-methylphenol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2-Methylphenol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
3 + 4-Methylphenol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2-Nitrophenol	mg/kg	NG	10	10	10	10	1	1						<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
4-Nitrophenol	mg/kg	NG	10	10	10	10	1	1						<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Pentachlorophenol	mg/kg	NG	7.6	7.6	7.6	7.6	7.6	7.6						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Phenol	mg/kg	NG	3.8	3.8	3.8	3.8	3.8	3.8						<0.0010	0.0035	0.003	<0.0010	0.0032	0.0081
2,3,4,6-Tetrachlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,3,5,6-Tetrachlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,3,4-Trichlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,3,5-Trichlorophenol	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,4,5-Trichlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,4,6-Trichlorophenol	mg/kg	NG	5	5	5	5	0.5	0.5						<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Polycyclic Aromatic Hydrocarbons (PAHs)																			
Acenaphthene	mg/kg	0.00671 [1.1]	0.28 [2.9]	0.28 [3.9]	0.28 [4.9]	0.28 [5.9]	0.28 [6.9]	0.28 [7.9]	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Acenaphthylene	mg/kg	0.00587 [1.2]	320 [2.10]	320 [3.10]	320 [4.10]	320 [5.10]	320 [6.10]	320 [7.10]	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Acridine	mg/kg	NG	NG	NG	NG	NG	NG	NG	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	mg/kg	0.0469 [1.3]	32 [2.11]	32 [3.11]	32 [4.11]	32 [5.11]	2.5 [6.11]	2.5 [7.11]	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Benz[a]anthracene	mg/kg	0.0317	10 [2.12]	10 [3.12]	10 [4.12]	10 [5.12]	1 [6.12]	1 [7.12]	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0052	<0.0050	<0.0050	<0.0050	<0.0050
Benzo(c)phenanthrene	mg/kg	NG	NG	NG	NG	NG	NG	NG	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Benzo[a]pyrene	mg/kg	0.0319	72 [2.13]	72 [3.13]	72 [4.13]	72 [5.13]	20 [6.13]	20 [7.13]	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0062	<0.0050	<0.0050	<0.0050	0.0052
Benzo[b]fluoranthene + Benzo[j]fluoranthene	mg/kg	NG	NG	NG	NG	NG	NG	NG	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.011	0.017	0.01	0.011	0.0065	0.016
Benzo[e]pyrene	mg/kg	NG	NG	NG	NG	NG	NG	NG	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0077	0.013	0.0086	0.0098	0.0058	0.012

Hay River Harbour

Soil Quality Results

Analyte	Unit	Guideline							Sampling Location	Sample 01-A	Sample 01-B	Sample 01-B	Sample 2	Sample 3	SED-019-01	SED-019-02	SED-019-03	SED-019-04	SED-019-05	SED-019-06
									Date Sampled	18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17
									Lab Sample ID	BKQ530	BKQ531	BKQ532	BKQ533	BKQ534						
									Sample Type	Normal	Normal	Duplicate	Normal	Normal						
		CCME Sediment FAL	CCME SO CL CS	CCME SO CL FS	CCME SO IL CS	CCME SO IL FS	CCME SO RL/PL CS	CCME SO RL/PL FS												
Benzo[g,h,i]perylene	mg/kg	NG	N [2.14]	N [3.14]	N [4.14]	N [5.14]	N [6.14]	N [7.14]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0079	0.013	0.0087	0.0082	0.0061	0.015
Benzo[k]fluoranthene	mg/kg	NG	10 [2.15]	10 [3.15]	10 [4.15]	10 [5.15]	1 [6.15]	1 [7.15]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Chrysene	mg/kg	0.0571	N [2.16]	N [3.16]	N [4.16]	N [5.16]	6.2 [6.16]	6.2 [7.16]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0062	0.006	<0.0050	<0.0050	<0.0050	<0.0050
Dibenz[a,h]anthracene	mg/kg	0.00622 [1.4]	10 [2.17]	10 [3.17]	10 [4.17]	10 [5.17]	1 [6.17]	1 [7.17]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Fluoranthene	mg/kg	0.111	180 [2.18]	180 [3.18]	180 [4.18]	180 [5.18]	50 [6.18]	50 [7.18]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.013	0.017	0.0093	0.0066	<0.0050	0.0081
Fluorene	mg/kg	0.0212 [1.5]	0.25 [2.19]	0.25 [3.19]	0.25 [4.19]	0.25 [5.19]	0.25 [6.19]	0.25 [7.19]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0066	0.0059	<0.0050	<0.0050	0.0063
IACR (CCME)		NG	1.0 [2.20]	1.0 [3.20]	1.0 [4.20]	1.0 [5.20]	1.0 [6.20]	1.0 [7.20]							0.12	0.17	0.11	0.11	<0.10	0.15
Indeno[1,2,3-cd]pyrene	mg/kg	NG	10 [2.21]	10 [3.21]	10 [4.21]	10 [5.21]	1 [6.21]	1 [7.21]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0058	<0.0050	<0.0050	<0.0050	0.0079
1-Methylnaphthalene	mg/kg	NG	NG	NG	NG	NG	NG	NG		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0052	<0.0050	<0.0050	<0.0050	<0.0050
2-Methylnaphthalene	mg/kg	0.0202 [1.6]	NG	NG	NG	NG	NG	NG		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Naphthalene	mg/kg	0.0346 [1.7]	0.013 [2.22]	0.013 [3.22]	0.013 [4.22]	0.013 [5.22]	0.013 [6.22]	0.013 [7.22]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Carcinogenic PAHs (as B(a)P TPE)	mg/kg	NG	0.6 [2.23]	0.6 [3.23]	0.6 [4.23]	0.6 [5.23]	0.6 [6.23]	0.6 [7.23]		<0.0071	<0.0071	<0.0071	<0.0071	<0.0071	<0.0071	0.012	<0.0071	<0.0071	<0.0071	0.011
Carcinogenic PAHs (IACR for coarse soil, AB Tier 1)		NG	NG	NG	NG	NG	NG	NG		<0.10	<0.10	<0.10	<0.10	<0.10						
Carcinogenic PAHs (IACR for fine soil, AB Tier 1)		NG	NG	NG	NG	NG	NG	NG		<0.10	<0.10	<0.10	<0.10	<0.10						
Perylene	mg/kg	NG	NG	NG	NG	NG	NG	NG		0.041	0.031	0.025	0.016	0.05	0.092	0.23	0.17	0.11	0.11	0.25
Phenanthrene	mg/kg	0.0419	0.046 [2.24]	0.046 [3.24]	0.046 [4.24]	0.046 [5.24]	0.046 [6.24]	0.046 [7.24]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0065	0.013	0.008	<0.0050	<0.0050	0.0088
Pyrene	mg/kg	0.053	100 [2.25]	100 [3.25]	100 [4.25]	100 [5.25]	10 [6.25]	10 [7.25]		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.013	0.018	0.011	0.012	0.0053	0.011
Quinoline	mg/kg	NG	NG	NG	NG	NG	NG	NG		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.019
Volatile Organic Compounds																				
Bromodichloromethane	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Bromoform	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Bromomethane	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Carbon tetrachloride	mg/kg	NG	50	50	50	50	5	5							0.00086	<0.00050	0.0018	0.0019	0.0033	<0.0011
Chlorobenzene	mg/kg	NG	10	10	10	10	1	1							0.003	0.0028	0.0042	0.0049	0.0096	<0.0010
Chloroform	mg/kg	NG	50	50	50	50	5	5							<0.0012	<0.00080	0.0023	0.0025	0.004	<0.00080
Chloromethane	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Dibromochloromethane	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,2-Dibromoethane	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.0020	<0.0020	<0.0067	<0.0060	<0.0093	<0.0020
1,2-Dichlorobenzene	mg/kg	NG	10	10	10	10	1	1							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,3-Dichlorobenzene	mg/kg	NG	10	10	10	10	1	1							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,4-Dichlorobenzene	mg/kg	NG	10	10	10	10	1	1							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,1-Dichloroethane	mg/kg	NG	50	50	50	50	5	5							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,2-Dichloroethane	mg/kg	NG	50	50	50	50	5	5							<0.0020	<0.0020	<0.0020	<0.0020	0.0037	<0.0020
1,1-Dichloroethylene	mg/kg	NG	50	50	50	50	5	5							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
cis-1,2-Dichloroethylene	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
trans-1,2-Dichloroethylene	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Dichloromethane	mg/kg	NG	50	50	50	50	5	5							<0.030	<0.030	<0.030	0.063	0.46	<0.030
1,2-Dichloropropane	mg/kg	NG	50	50	50	50	5	5							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
cis-1,3-Dichloropropene	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
trans-1,3-Dichloropropene	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,3-Dichloropropene (cis + trans) (calculated)	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.028	<0.028	<0.028	<0.028	<0.028	<0.028
Ethyl chloride	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Methyl methacrylate	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
Methyl tert-butyl ether	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
1,1,1,2-Tetrachloroethane	mg/kg	NG	NG	NG	NG	NG	NG	NG							<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
1,1,2,2-Tetrachloroethane	mg/kg	NG	50	50	50	50	5	5							<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Tetrachloroethylene	mg/kg	NG	0.5	0.5	0.6	0.6	0.2	0.2							<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
1,2,3-Trichlorobenzene	mg/kg	NG	10	10	10	10	2	2							<0.040	<0.040	<0.040	<0.040	<0.040	<0.040

Hay River Harbour

Soil Quality Results

Sampling Location									Sample 01-A	Sample 01-B	Sample 01-B	Sample 2	Sample 3	SED-019-01	SED-019-02	SED-019-03	SED-019-04	SED-019-05	SED-019-06
Date Sampled									18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	18-Jan-23	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17	14-Oct-17
Lab Sample ID									BKQ530	BKQ531	BKQ532	BKQ533	BKQ534						
Sample Type									Normal	Normal	Duplicate	Normal	Normal						
Analyte	**Unit**	**Guideline**																	
		CCME Sediment FAL	CCME SO CL CS	CCME SO CL FS	**CCME SO IL CS**	**CCME SO IL FS**	CCME SO RL/PL CS	CCME SO RL/PL FS											
1,2,4-Trichlorobenzene	mg/kg	NG	10	10	10	10	2	2						<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
1,3,5-Trichlorobenzene	mg/kg	NG	10	10	10	10	2	2						<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
1,1,1-Trichloroethane	mg/kg	NG	50	50	50	50	5	5						<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,1,2-Trichloroethane	mg/kg	NG	50	50	50	50	5	5						<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Trichloroethylene	mg/kg	NG	0.01	0.01	0.01	0.01	0.01	0.01						<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Trichlorofluoromethane	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,3,5-Trimethylbenzene	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Trimethylbenzene (mixed isomers)	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Vinyl chloride	mg/kg	NG	NG	NG	NG	NG	NG	NG						<0.0012	<0.00030	<0.0020	<0.0037	<0.0084	<0.00066
Metals																			
Antimony	mg/kg	NG	40	40	40	40	20	20	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Arsenic	mg/kg	5.900	12	12	12	12	12	12	6.6	6.1	5	5	7	6	8.2	8.6	6.9	6.1	9.6
Barium	mg/kg	NG	2000	2000	2000	2000	500	500	150	130	130	140	160	120	170	140	100	99	160
Beryllium	mg/kg	NG	8	8	8	8	4	4	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	0.43	<0.40	<0.40	<0.40	<0.40
Cadmium	mg/kg	0.600	22	22	22	22	10	10	0.3	0.21	0.23	0.16	0.3	0.2	0.58	0.59	0.33	0.37	0.84
Chromium	mg/kg	37.300	87	87	87	87	64	64	7.5	5.7	5.5	5.5	8.4	5.8	11	9.1	7.4	6	8.7
Chromium (hexavalent)	mg/kg	NG	1.4	1.4	1.4	1.4	0.4	0.4	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
Cobalt	mg/kg	NG	300	300	300	300	50	50	5.8	4.8	4	4.1	6.9	4.7	9	8.2	5.9	5.9	9.3
Copper	mg/kg	35.700	91	91	91	91	63	63	8.3	6.4	4.7	5.4	9.1	7.3	17	15	9.9	13	21
Lead	mg/kg	35.000	260	260	600	600	140	140	4.5	3.7	3	3	5.1	4.1	8.3	7	4.8	4.7	7.7
Mercury	mg/kg	0.170	24	24	50	50	6.6	6.6	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.068	0.062	<0.050	0.054	0.054
Molybdenum	mg/kg	NG	40	40	40	40	10	10	0.97	0.83	0.69	0.64	1	0.78	1.4	1.3	0.92	0.93	1.5
Nickel	mg/kg	NG	89	89	89	89	45	45	13	9.7	8.2	8.5	13	11	21	19	13	13	21
Selenium	mg/kg	NG	2.9	2.9	2.9	2.9	1	1	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.66	0.65	<0.50	<0.50	0.88
Silver	mg/kg	NG	40	40	40	40	20	20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Thallium	mg/kg	NG	1	1	1	1	1	1	<0.10	<0.10	<0.10	<0.10	0.1	<0.10	0.17	0.15	<0.10	0.11	0.17
Tin	mg/kg	NG	300	300	300	300	50	50	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Uranium	mg/kg	NG	33	33	300	300	23	23	1.2	0.95	1	0.75	0.96	0.88	1.2	1.3	1.1	1	1.8
Vanadium	mg/kg	NG	130	130	130	130	130	130	14	11	9.4	9.9	15	11	19	16	12	11	17
Zinc	mg/kg	123.000	410 [2.26]	410 [3.26]	410 [4.26]	410 [5.26]	250 [6.26]	250 [7.26]	49	35	40	29	47	43	83	75	50	52	82

Hay River Harbour

Guideline Notes for Soil Quality Results

1. Notes for CCME. Canadian sediment quality guidelines for the protection of freshwater aquatic life. (CCME Sediment FAL)
General Notes:
The CCME sediment quality guidelines for the protection of freshwater aquatic life provide Interim sediment quality guidelines (ISQGs) and probable effect levels (PELs). The Interim sediment quality guidelines have been used in this report.
Note 1.1 for Acenaphthene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
Note 1.2 for Acenaphthylene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
Note 1.3 for Anthracene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
Note 1.4 for Dibenz[a,h]anthracene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
Note 1.5 for Fluorene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
Note 1.6 for 2-Methylnaphthalene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
Note 1.7 for Naphthalene:
Provisional; adoption of marine ISQG developed using the modified NSTP approach.
2. Notes for CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Commercial Land Use and Coarse-grained Soil. (CCME SO CL CS)
General Notes:
There are different guidelines based on site-specific factors for some analytes. The most stringent guidelines were used.
Note 2.1 for Benzene:
The guideline for benzene is 0.030 mg/kg for the following: • Surface soil (≤1.5m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5). • Subsoil (>1.5m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5). • Surface soil (≤1.5m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6). • Subsoil (>1.5m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).
Note 2.2 for Ethylbenzene:
The guideline for ethylbenzene is 0.082 mg/kg for the following: • Surface soil (≤1.5m) with coarse soil texture • Subsoil (>1.5m) with coarse soil texture
Note 2.3 for F1 (CCME): (C6-C10) (less BTEX):
This Tier 1 Level is for coarse, surface soil; and includes protection of potable groundwater. The standard for F1 excludes benzene, toluene, ethylbenzene and xylenes. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent guideline was used in this report.
Note 2.4 for F2 (C10-C16):
This Tier 1 Level is for coarse, surface soil. "Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 2.5 for F3 (C16-C34):
This Tier 1 Level is for coarse, surface soil. "Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 2.6 for F4 (CCME): (>C34-C50):
This Tier 1 Level is for coarse, surface soil. "Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 2.7 for Toluene:
The guideline for toluene is 0.37 mg/kg for the following: • Surface soil (≤1.5m) with coarse soil texture • Subsoil (>1.5m) with coarse soil texture

Note 2.8 for Xylene:
The guideline for xylenes is 11 mg/kg for the following: • Surface soil (≤1.5m) with coarse soil texture • Subsoil (>1.5m) with coarse soil texture
Note 2.9 for Acenaphthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthene is 0.28 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 2.10 for Acenaphthylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthylene is 320 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 2.11 for Anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Anthracene is 32 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 2.12 for Benz[a]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 2.13 for Benzo[a]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]pyrene is 72 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 2.14 for Benzo[g,h,i]perylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Benzo[g,h,i]perylene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 2.15 for Benzo[k]fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[k]fluoranthene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 2.16 for Chrysene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Chrysene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 2.17 for Dibenz[a,h]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Dibenz[a,h]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 2.18 for Fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluoranthene is 180 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 2.19 for Fluorene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluorene is 0.25 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 2.20 for IACR (CCME):
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
Note 2.21 for Indeno[1,2,3-cd]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Indeno[1,2,3-cd]pyrene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 2.22 for Naphthalene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Naphthalene is 0.013 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 2.23 for Carcinogenic PAHs (as B(a)P TPE):

Guideline for B(A)P Total Potency Equivalent is 0.6 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 1,000,000 (10-6).
Guideline for B(A)P Total Potency Equivalent is 5.3 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 100,000 (10-5).
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
For soil contaminated with coal tar or creosote mixtures, the calculated Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) concentration for soil samples should be multiplied by a safety factor of 3 prior to comparison with the guideline to account for carcinogenic potential of alkylated and other PAHs present for which a Potency Equivalence Factor (PEF) does not currently exist, but which are likely to contribute to mixture carcinogenic potential. / The most stringent guideline was used in this report.

Note 2.24 for Phenanthrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Phenanthrene is 0.046 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 2.25 for Pyrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Pyrene is 100 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 2.26 for Zinc:

Reference: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health; Factsheet for Zinc, 2018.
Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.

3. Notes for CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Commercial Land Use and Fine-grained Soil. (CCME SO CL FS)

General Notes:

There are different guidelines based on site-specific factors for some analytes. The most stringent guidelines were used.

Note 3.1 for Benzene:

The guideline for benzene is 0.0068 mg/kg for the following:
- Surface soil (≤1.5m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Subsoil (>1.5m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Surface soil (≤1.5m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).
- Subsoil (>1.5m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).

Note 3.2 for Ethylbenzene:

The guideline for ethylbenzene is 0.018 mg/kg for the following:
- Surface soil (≤1.5m) with fine soil texture
- Subsoil (>1.5m) with fine soil texture

Note 3.3 for F1 (CCME): (C6-C10) (less BTEX):

This Tier 1 Level is for fine, surface soil and includes protection of potable groundwater. The standard for F1 excludes benzene, toluene, ethylbenzene and xylenes.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent guideline was used in this report.

Note 3.4 for F2 (C10-C16):

This Tier 1 Level is for fine, surface soil and includes protection of potable groundwater.
"Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent standard was used in this report.

Note 3.5 for F3 (C16-C34):

This Tier 1 Level is for fine, surface soil.
"Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.

Note 3.6 for F4 (CCME): (>C34-C50):
This Tier 1 Level is for fine, surface soil. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 3.7 for Toluene:
The guideline for toluene is 0.08 mg/kg for the following: • Surface soil (≤1.5m) with fine soil texture • Subsoil (>1.5m) with fine soil texture
Note 3.8 for Xylene:
The guideline for xylenes is 2.4 mg/kg for the following: • Surface soil (≤1.5m) with fine soil texture • Subsoil (>1.5m) with fine soil texture
Note 3.9 for Acenaphthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthene is 0.28 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 3.10 for Acenaphthylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthylene is 320 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 3.11 for Anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Anthracene is 32 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.12 for Benz[a]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.13 for Benzo[a]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]pyrene is 72 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.14 for Benzo[g,h,i]perylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Benzo[g,h,i]perylene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.

Note 3.15 for Benzo[k]fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[k]fluoranthene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.16 for Chrysene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Chrysene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 3.17 for Dibenz[a,h]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Dibenz[a,h]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.18 for Fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluoranthene is 180 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.19 for Fluorene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluorene is 0.25 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 3.20 for IACR (CCME):
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
Note 3.21 for Indeno[1,2,3-cd]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Indeno[1,2,3-cd]pyrene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 3.22 for Naphthalene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Naphthalene is 0.013 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 3.23 for Carcinogenic PAHs (as B(a)P TPE):

Guideline for B(A)P Total Potency Equivalent is 0.6 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 1,000,000 (10-6).
Guideline for B(A)P Total Potency Equivalent is 5.3 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 100,000 (10-5).
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
For soil contaminated with coal tar or creosote mixtures, the calculated Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) concentration for soil samples should be multiplied by a safety factor of 3 prior to comparison with the guideline to account for carcinogenic potential of alkylated and other PAHs present for which a Potency Equivalence Factor (PEF) does not currently exist, but which are likely to contribute to mixture carcinogenic potential. / The most stringent guideline was used in this report.

Note 3.24 for Phenanthrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Phenanthrene is 0.046 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 3.25 for Pyrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Pyrene is 100 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 3.26 for Zinc:

Reference: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health; Factsheet for Zinc, 2018.
Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.

4. Notes for CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Industrial Land Use and Coarse-grained Soil. (CCME SO IL CS)

General Notes:

There are different guidelines based on site-specific factors for some analytes. The most stringent guidelines were used.

Note 4.1 for Benzene:

The guideline for benzene is 0.030 mg/kg for the following:
- Surface soil with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Subsoil with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Surface soil with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).
- Subsoil with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).

Note 4.2 for Ethylbenzene:

The guideline for ethylbenzene is 0.082 mg/kg for the following:
- Surface soil with coarse soil texture
- Subsoil with coarse soil texture

Note 4.3 for F1 (CCME): (C6-C10) (less BTEX):

This Tier 1 Level is for coarse, surface soil and includes protection of potable groundwater. The standard for F1 excludes benzene, toluene, ethylbenzene and xylenes.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent guideline was used in this report.

Note 4.4 for F2 (C10-C16):

This Tier 1 Level is for coarse, surface soil.
"Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.

Note 4.5 for F3 (C16-C34):

This Tier 1 Level is for coarse, surface soil.
"Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.

Note 4.6 for F4 (CCME): (>C34-C50):
This Tier 1 Level is for coarse, surface soil. "Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 4.7 for Toluene:
The guideline for toluene is 0.37 mg/kg for the following: • Surface soil with coarse soil texture • Subsoil with coarse soil texture
Note 4.8 for Xylene:
The guideline for xylenes is 11 mg/kg for the following: • Surface soil with coarse soil texture • Subsoil with coarse soil texture
Note 4.9 for Acenaphthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthene is 0.28 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 4.10 for Acenaphthylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthylene is 320 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 4.11 for Anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Anthracene is 32 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.12 for Benz[a]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.13 for Benzo[a]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]pyrene is 72 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.14 for Benzo[g,h,i]perylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Benzo[g,h,i]perylene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.

Note 4.15 for Benzo[k]fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[k]fluoranthene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.16 for Chrysene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Chrysene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 4.17 for Dibenz[a,h]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Dibenz[a,h]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.18 for Fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluoranthene is 180 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.19 for Fluorene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluorene is 0.25 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 4.20 for IACR (CCME):
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
Note 4.21 for Indeno[1,2,3-cd]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Indeno[1,2,3-cd]pyrene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.22 for Naphthalene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Naphthalene is 0.013 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 4.23 for Carcinogenic PAHs (as B(a)P TPE):
Guideline for B(A)P Total Potency Equivalent is 0.6 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 1,000,000 (10-6). Guideline for B(A)P Total Potency Equivalent is 5.3 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 100,000 (10-5). Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. For soil contaminated with coal tar or creosote mixtures, the calculated Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) concentration for soil samples should be multiplied by a safety factor of 3 prior to comparison with the guideline to account for carcinogenic potential of alkylated and other PAHs present for which a Potency Equivalence Factor (PEF) does not currently exist, but which are likely to contribute to mixture carcinogenic potential. / The most stringent guideline was used in this report.
Note 4.24 for Phenanthrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Phenanthrene is 0.046 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.25 for Pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Pyrene is 100 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 4.26 for Zinc:
Reference: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health; Factsheet for Zinc, 2018. Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.
5. Notes for CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Industrial Land Use and Fine-grained Soil. (CCME SO IL FS)
General Notes:
There are different guidelines based on site-specific factors for some analytes. The most stringent guidelines were used.
Note 5.1 for Benzene:
The guideline for benzene is 0.0068 mg/kg for the following: • Surface soil with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5). • Subsoil with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5). • Surface soil with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6). • Subsoil with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).
Note 5.2 for Ethylbenzene:
The guideline for ethylbenzene is 0.018 mg/kg for the following: • Surface soil with fine soil texture • Subsoil with fine soil texture
Note 5.3 for F1 (CCME): (C6-C10) (less BTEX):
This Tier 1 Level is for fine, surface soil and includes protection of potable groundwater. The standard for F1 excludes benzene, toluene, ethylbenzene and xylenes. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent guideline was used in this report.
Note 5.4 for F2 (C10-C16):
This Tier 1 Level is for fine, surface soil and includes protection of potable groundwater. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent guideline was used in this report.
Note 5.5 for F3 (C16-C34):
This Tier 1 Level is for fine, surface soil. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.

Note 5.6 for F4 (CCME): (>C34-C50):
This Tier 1 Level is for fine, surface soil. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 5.7 for Toluene:
The guideline for toluene is 0.08 mg/kg for the following: • Surface soil with fine soil texture • Subsoil with fine soil texture
Note 5.8 for Xylene:
The guideline for xylenes is 2.4 mg/kg for the following: • Surface soil with fine soil texture • Subsoil with fine soil texture
Note 5.9 for Acenaphthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthene is 0.28 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 5.10 for Acenaphthylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthylene is 320 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 5.11 for Anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Anthracene is 32 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.12 for Benz[a]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.13 for Benzo[a]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]pyrene is 72 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.14 for Benzo[g,h,i]perylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Benzo[g,h,i]perylene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.

Note 5.15 for Benzo[k]fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[k]fluoranthene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.16 for Chrysene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Chrysene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 5.17 for Dibenz[a,h]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Dibenz[a,h]anthracene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.18 for Fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluoranthene is 180 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.19 for Fluorene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluorene is 0.25 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 5.20 for IACR (CCME):
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
Note 5.21 for Indeno[1,2,3-cd]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Indeno[1,2,3-cd]pyrene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 5.22 for Naphthalene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Naphthalene is 0.013 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 5.23 for Carcinogenic PAHs (as B(a)P TPE):

Guideline for B(A)P Total Potency Equivalent is 0.6 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 1,000,000 (10-6).
Guideline for B(A)P Total Potency Equivalent is 5.3 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 100,000 (10-5).
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
For soil contaminated with coal tar or creosote mixtures, the calculated Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) concentration for soil samples should be multiplied by a safety factor of 3 prior to comparison with the guideline to account for carcinogenic potential of alkylated and other PAHs present for which a Potency Equivalence Factor (PEF) does not currently exist, but which are likely to contribute to mixture carcinogenic potential. / The most stringent guideline was used in this report.

Note 5.24 for Phenanthrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Phenanthrene is 0.046 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 5.25 for Pyrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Pyrene is 100 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 5.26 for Zinc:

Reference: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health; Factsheet for Zinc, 2018.
Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.

6. Notes for CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Residential/ parkland Land Use and Coarse-grained Soil. (CCME SO RL/PL CS)

General Notes:

There are different guidelines based on site-specific factors for some analytes. The most stringent guidelines were used.

Note 6.1 for Benzene:

The guideline for benzene is 0.030 mg/kg for the following:
- Surface soil (<=1.5 m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Subsoil (>1.5 m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).

The guideline for benzene is 0.0095 mg/kg for the following:
- Surface soil (<=1.5 m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).

The guideline for benzene is 0.011 mg/kg for the following:
- Subsoil (>1.5 m) with coarse soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6). / The most stringent guideline was used in this report.

Note 6.2 for Ethylbenzene:

The guideline for ethylbenzene is 0.082 mg/kg for the following:
- Surface soil with coarse soil texture
- Subsoil with coarse soil texture

Note 6.3 for F1 (CCME): (C6-C10) (less BTEX):

Standard assumes contamination near residence, and is for coarse, surface soil. The standard for F1 excludes benzene, toluene, ethylbenzene and xylenes.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.

Note 6.4 for F2 (C10-C16):

This Tier 1 Level is for coarse, surface soil.
"Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.

Note 6.5 for F3 (C16-C34):
This Tier 1 Level is for coarse, surface soil. "Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 6.6 for F4 (CCME): (>C34-C50):
This Tier 1 Level is for coarse, surface soil. "Coarse" means coarse-textured soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 6.7 for Toluene:
The guideline for toluene is 0.37 mg/kg for the following: • Surface soil with coarse soil texture • Subsoil with coarse soil texture
Note 6.8 for Xylene:
The guideline for xylenes is 11 mg/kg for the following: • Surface soil with coarse soil texture • Subsoil with coarse soil texture
Note 6.9 for Acenaphthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthene is 0.28 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 6.10 for Acenaphthylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthylene is 320 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 6.11 for Anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Anthracene is 2.5 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 6.12 for Benz[a]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]anthracene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 6.13 for Benzo[a]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]pyrene is 20 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 6.14 for Benzo[g,h,i]perylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Benzo[g,h,i]perylene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 6.15 for Benzo[k]fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[k]fluoranthene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 6.16 for Chrysene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Chrysene based on non-carcinogenic effects is 6.2 mg/kg based on Table 2 of CCME PAHs Factsheet 2010.
Note 6.17 for Dibenz[a,h]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Dibenz[a,h]anthracene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 6.18 for Fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluoranthene is 50 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 6.19 for Fluorene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluorene is 0.25 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 6.20 for IACR (CCME):
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
Note 6.21 for Indeno[1,2,3-cd]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Indeno[1,2,3-cd]pyrene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 6.22 for Naphthalene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Naphthalene is 0.013 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 6.23 for Carcinogenic PAHs (as B(a)P TPE):

Guideline for B(A)P Total Potency Equivalent is 0.6 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 1,000,000 (10-6).
Guideline for B(A)P Total Potency Equivalent is 5.3 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 100,000 (10-5).
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
For soil contaminated with coal tar or creosote mixtures, the calculated Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) concentration for soil samples should be multiplied by a safety factor of 3 prior to comparison with the guideline to account for carcinogenic potential of alkylated and other PAHs present for which a Potency Equivalence Factor (PEF) does not currently exist, but which are likely to contribute to mixture carcinogenic potential. / The most stringent guideline was used in this report.

Note 6.24 for Phenanthrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Phenanthrene is 0.046 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 6.25 for Pyrene:

Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected.
Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.
The environmental Soil Quality Guideline for Pyrene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 6.26 for Zinc:

Reference: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health; Factsheet for Zinc, 2018.
Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.

7. Notes for CCME. Canadian Soil Quality Guidelines; and Canada-Wide Standards for Petroleum Hydrocarbons in Soil - for Residential/ parkland Land Use and Fine-grained Soil. (CCME SO RL/PL FS)

General Notes:

There are different guidelines based on site-specific factors for some analytes. The most stringent guidelines were used.

Note 7.1 for Benzene:

The guideline for benzene is 0.0068 mg/kg for the following:
- Surface soil (<=1.5 m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Subsoil (>1.5 m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 100,000 (10-5).
- Surface soil (<=1.5 m) with fine soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).
- Subsoil with (> 1.5 m) fine soil texture, and based on a lifetime incremental cancer risk of 1 in 1,000,000 (10-6).

Note 7.2 for Ethylbenzene:

The guideline for ethylbenzene is 0.018 mg/kg for the following:
- Surface soil with fine soil texture
- Subsoil with fine soil texture

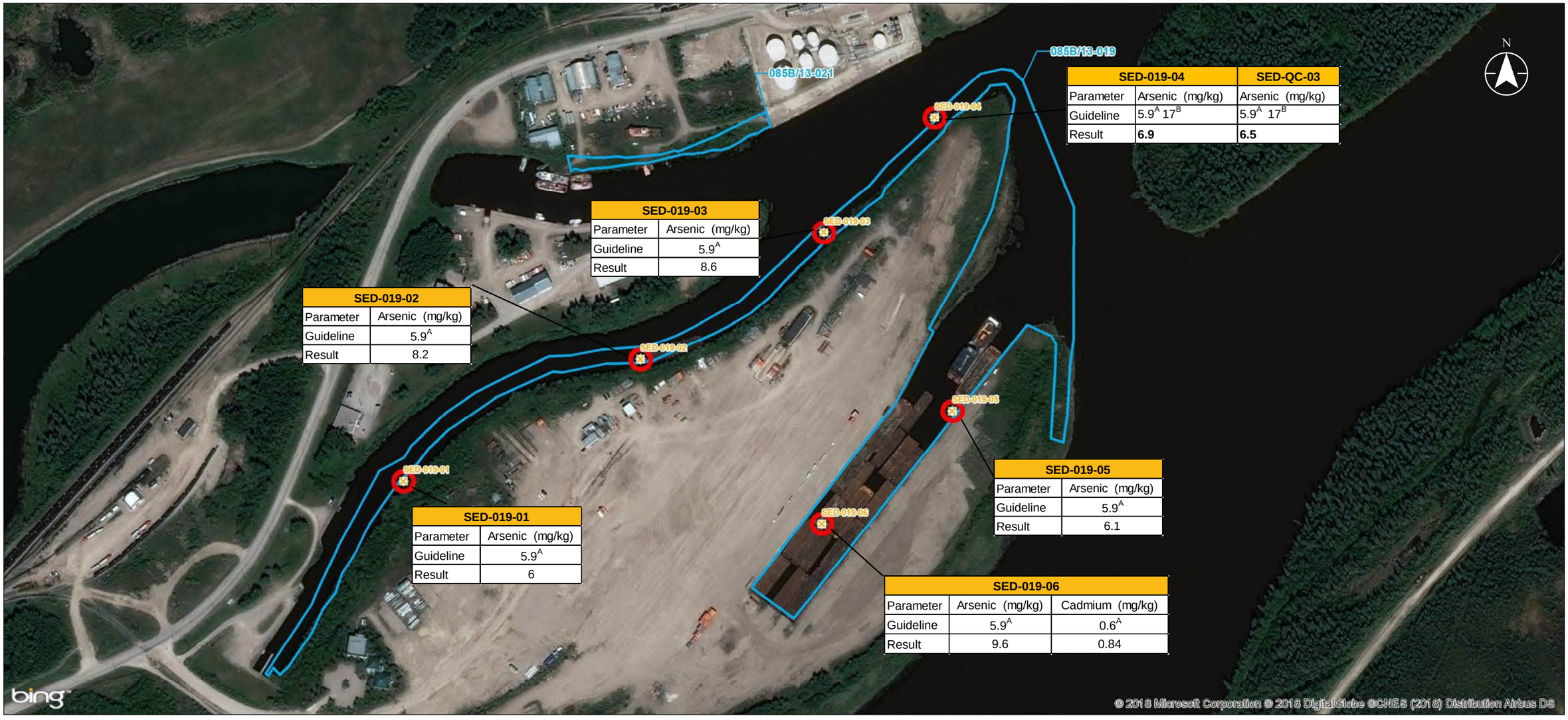
Note 7.3 for F1 (CCME): (C6-C10) (less BTEX):

This Tier 1 Level is for fine, surface soil that includes protection of potable groundwater. The standard for F1 excludes benzene, toluene, ethylbenzene and xylenes.
Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil. / The most stringent guideline was used in this report.

Note 7.4 for F2 (C10-C16):
This Tier 1 Level is for fine, surface soil. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 7.5 for F3 (C16-C34):
This Tier 1 Level is for fine, surface soil. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 7.6 for F4 (CCME): (>C34-C50):
This Tier 1 Level is for fine, surface soil. "Fine" means fine-textured soil having a median grain size of <75 µm as defined by the American Society for Testing and Materials. Reference: Canadian Council of Ministers of the Environment, Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil, 2008. Table 1 - Summary of Tier 1 Levels for surface soil.
Note 7.7 for Toluene:
The guideline for toluene is 0.08 mg/kg for the following: • Surface soil with fine soil texture • Subsoil with fine soil texture
Note 7.8 for Xylene:
The guideline for xylenes is 2.4 mg/kg for the following: • Surface soil with fine soil texture • Subsoil with fine soil texture
Note 7.9 for Acenaphthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthene is 0.28 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 7.10 for Acenaphthylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Acenaphthylene is 320 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 7.11 for Anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Anthracene is 2.5 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.12 for Benz[a]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]anthracene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).

Note 7.13 for Benzo[a]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[a]pyrene is 20 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.14 for Benzo[g,h,i]perylene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Benzo[g,h,i]perylene based on non-carcinogenic effects is not available in Table 1 and 2 of CCME PAHs Factsheet 2010.
Note 7.15 for Benzo[k]fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Benzo[k]fluoranthene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.16 for Chrysene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. An environmental Soil Quality Guideline for Chrysene based on non-carcinogenic effects is 6.2 mg/kg based on Table 2 of CCME PAHs Factsheet 2010.
Note 7.17 for Dibenz[a,h]anthracene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Dibenz[a,h]anthracene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.18 for Fluoranthene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluoranthene is 50 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.19 for Fluorene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Fluorene is 0.25 mg/kg based on non-carcinogenic effects (from Table 2 of CCME PAHs Factsheet 2010).
Note 7.20 for IACR (CCME):
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects.

Note 7.21 for Indeno[1,2,3-cd]pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Indeno[1,2,3-cd]pyrene is 1 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.22 for Naphthalene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Naphthalene is 0.013 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.23 for Carcinogenic PAHs (as B(a)P TPE):
Guideline for B(A)P Total Potency Equivalent is 0.6 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 1,000,000 (10-6). Guideline for B(A)P Total Potency Equivalent is 5.3 mg/kg based on an incremental lifetime cancer risk (ILCR) of 1 in 100,000 (10-5). Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. For soil contaminated with coal tar or creosote mixtures, the calculated Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) concentration for soil samples should be multiplied by a safety factor of 3 prior to comparison with the guideline to account for carcinogenic potential of alkylated and other PAHs present for which a Potency Equivalence Factor (PEF) does not currently exist, but which are likely to contribute to mixture carcinogenic potential. / The most stringent guideline was used in this report.
Note 7.24 for Phenanthrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Phenanthrene is 0.046 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.25 for Pyrene:
Assess the hazard to human health from carcinogenic effects of PAHs by doing steps 1 and 2. Step 1 is: Calculate a Benzo[a]pyrene Total Potency Equivalents (B[a]P TPE) to ensure that humans are protected from direct contact with contaminated soil. Step 2 is: Calculate the Index of Additive Cancer Risk (IACR) to ensure that potable water resources are protected. Assess the hazard to environmental health from non-carcinogenic effects of PAHs by doing step 3. Step 3 is: Compare PAHs individually to the appropriate environmental Soil Quality Guideline which were developed based on non-carcinogenic effects. The environmental Soil Quality Guideline for Pyrene is 10 mg/kg based on non-carcinogenic effects (from Table 1 of CCME PAHs Factsheet 2010).
Note 7.26 for Zinc:
Reference: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health; Factsheet for Zinc, 2018. Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.



SED-019-04		SED-QC-03
Parameter	Arsenic (mg/kg)	Arsenic (mg/kg)
Guideline	5.9[A] 17[B]	5.9[A] 17[B]
Result	**6.9**	**6.5**

SED-019-03	
Parameter	Arsenic (mg/kg)
Guideline	5.9[A]
Result	8.6

SED-019-02	
Parameter	Arsenic (mg/kg)
Guideline	5.9[A]
Result	8.2

SED-019-01	
Parameter	Arsenic (mg/kg)
Guideline	5.9[A]
Result	6

SED-019-05	
Parameter	Arsenic (mg/kg)
Guideline	5.9[A]
Result	6.1

SED-019-06		
Parameter	Arsenic (mg/kg)	Cadmium (mg/kg)
Guideline	5.9[A]	0.6[A]
Result	9.6	0.84

Approximate Sediment Sample Location

Laboratory Analytical Results Exceeding Applicable Guidelines

Water Lease Boundary

0 100 200 metres

1:4,000 (At original document size of 11x17)

Notes

1. Coordinate System: NAD 1983 UTM Zone 11N
2. Base features: Geogratis, ©Department of Natural Resources Canada, All rights reserved.
3. Water Lot Boundaries depicted on figures are provided by ATLAS. Boundaries are expected to depict the ordinary high water mark during time of establishment of the lease.
4. The base image shows water levels at the time of image capture, which may differ from the water levels during water lot establishment.
5. Surface water and Sediment sample locations depicted on figures represent the shore water interface on the collection date.
6. [A] - Canadian Environmental Quality Guidelines, Sediment Quality Guidelines for the Protection of Aquatic Life, Interim Freshwater Sediment Quality Guideline

Stantec

Northwest Territories

Project Location
Hay River,
Northwest Territories

144930085
Prepared by SB on 2018-01-31
Technical Review by EB on 2018-02-01
Independent Review by DSM on 2018-02-02

Client/Project
Government of Northwest Territories - CSD
2017 MTS Properties
Limited Phase I/II Environmental Site Assessment

Figure No.
A5-10

Title
Hay River Water Lease 085B/13-019
Sample Location Plan Showing Sediment Sample Exceedances

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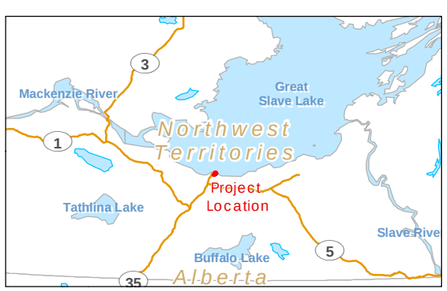
SED-021-02		
Parameter	Arsenic (mg/kg)	Cadmium (mg/kg)
Guideline	5.9[A]	0.6[A]
Result	8.9	0.76

SED-021-01		
Parameter	Arsenic (mg/kg)	Acenaphthene (mg/kg)
Guideline	5.9[A]	0.00671[A]
Result	6.9	0.014



Approximate Sediment Sample Location

Laboratory Analytical Results Exceeding Applicable Guidelines

Water Lease Boundary

0 25 50 metres

1:1,000 (At original document size of 11x17)

Notes

1. Coordinate System: NAD 1983 UTM Zone 11N
2. Base features: Geogratis, ©Department of Natural Resources Canada, All rights reserved.
3. Water Lot Boundaries depicted on figures are provided by ATLAS. Boundaries are expected to depict the ordinary high water mark during time of establishment of the lease.
4. The base image shows water levels at the time of image capture, which may differ from the water levels during water lot establishment.
5. Surface water and Sediment sample locations depicted on figures represent the shore water interface on the collection date.
6. ^ - Canadian Environmental Quality Guidelines, Sediment Quality Guidelines for the Protection of Aquatic Life, Interim Freshwater Sediment Quality Guideline

Stantec

Northwest Territories

Project Location
Hay River,
Northwest Territories

144930085
Prepared by SB on 2018-01-31
Technical Review by EB on 2018-02-01
Independent Review by DSM on 2018-02-02

Client/Project
Government of Northwest Territories - CSD
2017 MTS Properties
Limited Phase I/II Environmental Site Assessment

Figure No.
A5-11

Title
Hay River Water Lease 085B/13-021
Sample Location Plan Showing Sediment Sample Exceedances

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APPENDIX B – DREDGEATE ANALYSIS LAB RESULTS

Hay River Emergency Dredging Project - Soil Analytical Results

		Sample Results									Guidelines					
											CCME SQG PEHH			GNWT CSR		
Parameters	Sample ID / Units	HR23-SP01-001 Depth: 0.15 - 2m	HR23-SP01-001D Depth: 0.15 - 2m	HR23-SP01-002 Depth: 0.15 - 2m	HR23-SP01-002D Depth: 0.15 - 2m	HR23-SP01-003 Depth: 0.15 - 2m	HR23-SP01-003D Depth: 0.15 - 2m	HR23-SP01-004 Depth: 0.15 - 2m	HR23-UN01-001 Depth: 0.15 - 2m	HR23-SP01-005 Depth: 0.15 - 2.5m	Concentration (mg/kg dry weight) Residential/ Parkland	Concentration (mg/kg dry weight) Commercial	Concentration (mg/kg dry weight) Industrial	Coarse - Residential/Parkland (mg/kg)	Coarse - Commercial (mg/kg)	Coarse - Industrial (mg/kg)
	Date	13-Sep-23	13-Sep-23	13-Sep-23	13-Sep-23	13-Sep-23	13-Sep-23	24-Sep-23	24-Sep-23	30-Sep-23						
	Type	Dredgate	Dredgate	Dredgate	Dredgate	Dredgate	Dredgate	Dredgate	Berm Material	Dredgeate						
Calculated Parameters																
Anion Sum	meq/L	21	30	23	24	18	13	7.9	12	6.6						
Cation Sum	meq/L	25	32	24	26	20	15	9.5	14	8.6						
Cation/EC Ratio	N/A	14	13	12	12	12	12	13	13	11						
Available (KCl) Nitrate (N)	mg/kg	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0						
Calculated Calcium (Ca)	mg/kg	120	190	110	120	110	69	39	68	35						
Calculated Magnesium (Mg)	mg/kg	17	25	15	16	16	10	6.5	11	5.5						
Calculated Sodium (Na)	mg/kg	8.5	15	10	13	12	9.9	4.7	24	7						
Calculated Potassium (K)	mg/kg	5.3	7.5	5.2	5.9	5.2	4.2	2.8	4.2	1.9						
Calculated Chloride (Cl)	mg/kg	<3.1	<3.9	<3.1	4.2	<3.7	<3.3	<2.9	17	<3.0						
Calculated Sulphate (SO4)	mg/kg	310	560	340	360	320	200	110	190	94						
Elements																
Soluble (Hot water) Boron (B)	mg/kg	0.27	0.41	0.32	0.32	0.46	0.65	0.21	0.83	0.13	**No data**	**No data**	**No data**	**No data**		
Hex. Chromium (Cr 6+)	mg/kg	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	**0.4**	**1.4**	**1.4**	**0.4**		
Nutrients																
Available (KCl) Ammonia (N)	mg/kg	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	**No data**	**No data**	**No data**			
Available (Mod Kel) Phosphorus (P)	mg/kg	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	**No data**	**No data**	**No data**			
Available (Mod Kel) Potassium (K)	mg/kg	24	88	45	42	32	39	15	62	13						
Available (CaCl2) Sulphur (S)	mg/kg	110	350	150	140	110	68	32	59	41	**No data**	**No data**	**No data**			
Available (KCl) Total Kjeldahl Nitrogen (Calc)	mg/kg	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<50						
Available (KCl) Total Nitrogen (N)	mg/kg	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<50						
Available (KCl) Nitrite (N)	mg/kg	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	**No data**	**No data**	**No data**			
Soluble Parameters																
Soluble Chloride (Cl)	mg/L	<10	<10	<10	13	<10	<10	<10	46	<10	**No data**	**No data**	**No data**			
Soluble Conductivity	dS/m	1.8	2.4	2	2	1.7	1.2	0.75	1.1	0.8						
Soluble (CaCl2) pH	pH	7.43	7.42	7.42	7.41	7.36	7.26	7.22	7.59	7.52	**6 to 8**	**6 to 8**	**6 to 8**			
Sodium Adsorption Ratio	N/A	0.35	0.43	0.44	0.53	0.47	0.51	0.34	1.2	0.54	**5**	**12**	**12**	**5**		
Soluble Calcium (Ca)	mg/L	380	490	370	390	300	210	130	180	120	**No data**	**No data**	**No data**			
Soluble Magnesium (Mg)	mg/L	54	65	48	49	44	31	22	28 (1)	18						
Soluble Sodium (Na)	mg/L	27	39	33	42	33	30	16	64	24						
Soluble Potassium (K)	mg/L	17	19	17	18	14	13	9.7	11	6.5						
Saturation %	%	31	39	31	32	36	33	29	38	30						
Soluble Sulphate (SO4)	mg/L	1000	1500	1100	1100	870	600	380	500	320	**No data**	**No data**	**No data**			
Theoretical Gypsum Requirement	tonnes/ha	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20						
Physical Properties																
Grain Size	N/A	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE						
Sieve - #10 (>2.00mm)	%	1	0.77	0.27	0.84	0.73	0.91	0.36	6.5	1.2						
Sieve - #200 (>0.075mm)	%	78	73	74	84	76	72	92	56	83						
Sieve - Pan	%	22	27	26	16	24	28	8.5	44	17						
Ext. Pet. Hydrocarbon																
F1 (C6-C10)	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	**30**	**320**	**320**	**30**	**310**	**310**
F1 (C6-C10) - BTEX	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10						
F2 (C10-C16 Hydrocarbons)	mg/kg	14	<10	<10	<10	<10	<10	<10	140	23	**150**	**260**	**260**	**150**	**760**	**760**
F3 (C16-C34 Hydrocarbons)	mg/kg	230	81	180	83	140	100	<50	520	120	**300**	**1700**	**1700**	**400**	**1700**	**1700**
F4 (C34-C50 Hydrocarbons)	mg/kg	77	<50	<50	<50	88	53	<50	200	<50	**2800**	**3300**	**3300**	**2800**	**3300**	**3300**
Reached Baseline at C50	mg/kg	Yes	Yes	Yes	Yes	Yes	Yes			Yes						
Surrogate Recovery (%)																
O-TERPHENYL (sur.)	%	100	108	107	102	92	102			116						
Physical Properties																
% sand by hydrometer	%	91	60	84	78	82	83	97	57	94						
% silt by hydrometer	%	4.2	24	9.1	12	11	11	<2.0	24	<2.0						
Clay Content	%	4.7	16	7.1	9.5	7.4	5.5	2.4	18	4.6						
Texture	N/A	SAND	SANDY LOAM	LOAMY SAND	SANDY LOAM	LOAMY SAND	LOAMY SAND	SAND	SANDY LOAM	SAND						
Moisture	%	11	12	14	13	12	14	10	9.4	19						
Elements																
Total Antimony (Sb)	mg/kg	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.59	<0.50	**20**	**40**	**40**	**20**	**40**	**40**
Total Arsenic (As)	mg/kg	5.5	7.2	6.4	6.7	7.1	6.4	3.9	8	4.9	**12**	**12**	**12**	**12**	**12**	**12**
Total Barium (Ba)	mg/kg	130	160	140	150	170	150	85	190	100	**500**	**2000**	**2000**	**500**	**2000**	**2000**
Total Beryllium (Be)	mg/kg	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	**4**	**8**	**8**	**4**	**8**	**8**
Total Cadmium (Cd)	mg/kg	0.19	0.41	0.28	0.31	0.32	0.34	0.11	0.48	0.12	**10**	**22**	**22**	**10**	**22**	**22**
Total Chromium (Cr)	mg/kg	5.3	12	8.3	10	7.1	12	3.7	18	4.1	**64**	**87**	**87**	**64**	**87**	**87**
Total Cobalt (Co)	mg/kg	4.1	6.9	4.9	5.5	5.3	5.3	3.1	7.5	3.3	**50**	**300**	**300**	**50**	**300**	**300**
Total Copper (Cu)	mg/kg	5.1	12	8.6	11	9.6	8.4	7.5	17 (1)	3.4	**63**	**91**	**91**	**63**	**91**	**91**
Total Lead (Pb)	mg/kg	3.5	6.2	4.5	6	6.2	6.9	2.6	14	2.7	**140**	**260**	**600**	**140**	**260**	**600**
Total Mercury (Hg)	mg/kg	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	**6.6**	**24**	**50**	**6.6**	**24**	**50**
Total Molybdenum (Mo)	mg/kg	0.65	1.2	0.82	0.94	0.87	0.99	<0.40	1.8	0.49	**10**	**40**	**40**	**10**	**40**	**40**
Total Nickel (Ni)	mg/kg	8.4	17	11	13	11	13	5.8	22	6.5	**45**	**89**	**89**	**50**	**50**	**50**
Total Selenium (Se)	mg/kg	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	**1**	**2.9**	**2.9**	**1**	**3.9**	**3.9**
Total Silver (Ag)	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	**20**	**40**	**40**	**20**	**40**	**40**
Total Thallium (Tl)	mg/kg	<0.10	0.13	<0.10	<0.10	<0.10	0.1	<0.10	0.14	<0.10	**1**	**1**	**1**	**1**	**1**	**1**
Total Tin (Sn)	mg/kg	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	**50**	**300**	**300**	**50**	**300**	**300**
Total Uranium (U)	mg/kg	0.81	1	0.8	1.1	1.2	0.96	0.69	1	0.69	**23**	**33**	**300**	**23**		
Total Vanadium (V)	mg/kg	11	19 (1)	13	15	14	14	7.2	20 (2)	8.2	**130**	**130**	**130**	**130**	**130**	**130**
Total Zinc (Zn)	mg/kg	35	71	50	63	60	100	25	76	24	**250**	**410**	**410**	**200**	**360**	**360**
Field Preserved Volatiles																
Benzene	mg/kg	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	**0.011**	**Table**	**Table**	**0.5**	**5**	**5**
Toluene	mg/kg	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	**0.37**	**Table**	**Table**	**0.8**	**0.8**	**0.8**

Parameters	Sample ID / Units	HR23-SP01-001 Depth: 0.15 - 2m	HR23-SP01-001D Depth: 0.15 - 2m	HR23-SP01-002 Depth: 0.15 - 2m	HR23-SP01-002D Depth: 0.15 - 2m	HR23-SP01-003 Depth: 0.15 - 2m	HR23-SP01-003D Depth: 0.15 - 2m	HR23-SP01-004 Depth: 0.15 - 2m	HR23-UN01-001 Depth: 0.15 - 2m	HR23-SP01-005 Depth: 0.15 - 2.5m	**Concentration (mg/kg dry weight) Residential/ Parkland**	**Concentration (mg/kg dry weight) Commercial**	**Concentration (mg/kg dry weight) Industrial**	**Coarse - Residential/Parkland (mg/kg)**	**Coarse - Commercial (mg/kg)**	**Coarse - Industrial (mg/kg)**
Ethylbenzene	mg/kg	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	**0.082**	**Table**	**Table**	**1.2**	**20**	**20**
m & p-Xylene	mg/kg	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040						
o-Xylene	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.028	<0.020						
Xylenes (Total)	mg/kg	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	**2.4**	**2.4**	**2.4**	**1**		
Surrogate Recovery (%)																
1,4-Difluorobenzene (sur.)	%	100	102	103	101	102	103	96	97	97						
4-Bromofluorobenzene (sur.)	%	97	97	100	97	98	98	112	111	101						
D10-o-Xylene (sur.)	%	80	85	107	97	95	90	101	104	105						
D4-1,2-Dichloroethane (sur.)	%	94	96	97	96	97	97	90	93	98						
Misc. Inorganics																
Total Organic Carbon (C)	mg/kg	3700	3800	3900	6700	8400	6900	3800	14000	3500						

RDL = Reportable Detection Limit
N/A = Not Applicable
(1) Matrix spike exceeds acceptance limits due to matrix interference.

outcome

Hay River Emergency Dredging Project - Soil Analytical Results

		Sample Results								Guidelines					
										CCME SQG PEHH			GNWT CSR		
Parameters	Sample ID / Units	HR23-SP01-006 Depth: 0.15 - 2.5m	HR23-SP01-007 Depth: 0.15 - 2.5m	HR23-SP01-008 Depth: 0.15 - 2.5m	HR23-SP01-009 Depth: 0.15 - 0.5m	HR23-SP01-010 Depth: 0.15 - 0.5m	HR23-SP01-011 Depth: 0.15 - 0.5m	HR23-SP01-012 Depth: 0.15 - 2.5m	HR23-SP01-013 Depth: 0.15 - 2.5m	Concentration (mg/kg dry weight) Residential/ Parkland	Concentration (mg/kg dry weight) Commercial	Concentration (mg/kg dry weight) Industrial	Coarse - Residential/Parkland (mg/kg)	Coarse - Commercial (mg/kg)	Coarse - Industrial (mg/kg)
	Date	01-Oct-23	02-Oct-23	03-Oct-23	09-Oct-23	09-Oct-23	09-Oct-23	09-Oct-23	09-Oct-23						
	Type	Dredgeate	Dredgeate	Dredgeate	Dredgeate	Dredgeate	Dredgeate	Dredgeate	Dredgeate						
Calculated Parameters															
Anion Sum	meq/L	2.8	11	6	8	2.3	4.6	5.4	3						
Cation Sum	meq/L	4.2	13	8	10	4.3	6.2	7.4	4.9						
Cation/EC Ratio	N/A	11	11	11	13	11	12	12	11						
Available (KCl) Nitrate (N)	mg/kg	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0						
Calculated Calcium (Ca)	mg/kg	17	53	32	39	16	23	29	19						
Calculated Magnesium (Mg)	mg/kg	2.9	8.1	5.8	7.1	2.6	4	5.2	3.3						
Calculated Sodium (Na)	mg/kg	4.1	8.2	7.5	8	4.9	6.2	7.2	4.4						
Calculated Potassium (K)	mg/kg	1.5	2.4	2.1	2.7	1.7	2.2	2.4	1.9						
Calculated Chloride (Cl)	mg/kg	<3.1	4.4	<3.1	5.7	<3.0	4.1	4.2	<3.0						
Calculated Sulphate (SO4)	mg/kg	41	150	88	100	32	58	74	43						
Elements															
Soluble (Hot water) Boron (B)	mg/kg	0.12	0.28	0.15	0.24	0.12	0.14	0.14	0.11	**No data**	**No data**	**No data**	**No data**		
Hex. Chromium (Cr 6+)	mg/kg	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	**0.4**	**1.4**	**1.4**	**0.4**		
Nutrients															
Available (KCl) Ammonia (N)	mg/kg	<2.0	2.9	<2.0	<2.0	<2.0	38	<2.0	<2.0	**No data**	**No data**	**No data**			
Available (Mod Kel) Phosphorus (P)	mg/kg	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	**No data**	**No data**	**No data**			
Available (Mod Kel) Potassium (K)	mg/kg	10	19	12	21	11	13	15	11						
Available (CaCl2) Sulphur (S)	mg/kg	14	53	24	36	9.5	16	24	13	**No data**	**No data**	**No data**			
Available (KCl) Total Kjeldahl Nitrogen (Calc)	mg/kg	<50	<5.0	<5.0	<10	<10	38	<10	<10						
Available (KCl) Total Nitrogen (N)	mg/kg	<50	<5.0	<5.0	<10	<10	38	<10	<10						
Available (KCl) Nitrite (N)	mg/kg	<2.0	2.3	<2.0	<2.8	<2.8	<2.8	<2.8	<2.8	**No data**	**No data**	**No data**			
Soluble Parameters															
Soluble Chloride (Cl)	mg/L	<10	15	<10	20	<10	14	14	<10	**No data**	**No data**	**No data**			
Soluble Conductivity	dS/m	0.4	1.1	0.76	0.81	0.38	0.53	0.6	0.43						
Soluble (CaCl2) pH	pH	7.34	7.49	7.54	7.42	6.37	7.32	7.41	7.42	**6 to 8**	**6 to 8**	**6 to 8**			
Sodium Adsorption Ratio	N/A	0.44	0.51	0.58	0.58	0.54	0.58	0.58	0.44	**5**	**12**	**12**	**5**		
Soluble Calcium (Ca)	mg/L	55	190	100	140	54	79	96	65	**No data**	**No data**	**No data**			
Soluble Magnesium (Mg)	mg/L	9.6	28	19	25	8.9	14	17	11						
Soluble Sodium (Na)	mg/L	13	28	24	28	16	21	24	15						
Soluble Potassium (K)	mg/L	4.9	8.2	6.9	9.3	5.6	7.7	7.8	6.3						
Saturation %	%	31	29	31	29	30	29	31	30						
Soluble Sulphate (SO4)	mg/L	130	530	290	360	110	200	240	140	**No data**	**No data**	**No data**			
Theoretical Gypsum Requirement	tonnes/ha	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20						
Physical Properties															
Grain Size	N/A	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE	COARSE						
Sieve - #10 (>2.00mm)	%	1.1	0.66	1	<0.20	<0.20	<0.20	1.4	0.98						
Sieve - #200 (>0.075mm)	%	83	88	94	88	94	93	93	92						
Sieve - Pan	%	17	12	5.7	12	5.9	7.1	6.8	7.6						
Ext. Pet. Hydrocarbon															
F1 (C6-C10)	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	**30**	**320**	**320**	**30**	**310**	**310**
F1 (C6-C10) - BTEX	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10						
F2 (C10-C16 Hydrocarbons)	mg/kg	<10	23	<10	47	<10	<10	35	<10	**150**	**260**	**260**	**150**	**760**	**760**
F3 (C16-C34 Hydrocarbons)	mg/kg	58	160	<50	100	<50	<50	63	<50	**300**	**1700**	**1700**	**400**	**1700**	**1700**
F4 (C34-C50 Hydrocarbons)	mg/kg	<50	83	<50	<50	<50	<50	<50	<50	**2800**	**3300**	**3300**	**2800**	**3300**	**3300**
Reached Baseline at C50	mg/kg	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes						
Surrogate Recovery (%)															
O-TERPHENYL (sur.)	%	115	117	111	106	111	105	106	104						
Physical Properties															
% sand by hydrometer	%	96	92	95	90	95	94	93	95						
% silt by hydrometer	%	<2.0	3.3	<2.0	2.2	<2.0	<2.0	<2.0	<2.0						
Clay Content	%	4	4.7	4.9	7.5	4.8	4.9	4.8	4.6						
Texture	N/A	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND						
Moisture	%	18	16	9.2	18	18	17	16	13						
Elements															
Total Antimony (Sb)	mg/kg	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	**20**	**40**	**40**	**20**	**40**	**40**
Total Arsenic (As)	mg/kg	4.3	5.3	4.7	6.7	4.6	4.6	5	4.6	**12**	**12**	**12**	**12**	**12**	**12**
Total Barium (Ba)	mg/kg	96	120	100	150	94	120	110	110	**500**	**2000**	**2000**	**500**	**2000**	**2000**
Total Beryllium (Be)	mg/kg	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	**4**	**8**	**8**	**4**	**8**	**8**
Total Cadmium (Cd)	mg/kg	0.1	0.18	0.15	0.52	0.14	0.12	0.13	0.16	**10**	**22**	**22**	**10**	**22**	**22**
Total Chromium (Cr)	mg/kg	3.6	5.1	3.8	5.5	3.6	3.9	4.3	3.4	**64**	**87**	**87**	**64**	**87**	**87**
Total Cobalt (Co)	mg/kg	2.9	4	3.3	4.6	3.1	3.1	3.5	3.1	**50**	**300**	**300**	**50**	**300**	**300**
Total Copper (Cu)	mg/kg	2.6	4.9	3.7	6.1	2.7	7.3 (1)	3.7	2.7	**63**	**91**	**91**	**63**	**91**	**91**
Total Lead (Pb)	mg/kg	2.3	3.9	2.6	3.6	2.3	2.5	2.8	2.3	**140**	**260**	**600**	**140**	**260**	**600**
Total Mercury (Hg)	mg/kg	<0.050	0.06	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	**6.6**	**24**	**50**	**6.6**	**24**	**50**
Total Molybdenum (Mo)	mg/kg	0.42	0.58	0.42	0.66	<0.40	0.4	0.47	0.43	**10**	**40**	**40**	**10**	**40**	**40**
Total Nickel (Ni)	mg/kg	5.5	8.1	6.3	9.3	5.7	6	6.8	5.7	**45**	**89**	**89**	**50**	**50**	**50**
Total Selenium (Se)	mg/kg	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	**1**	**2.9**	**2.9**	**1**	**3.9**	**3.9**
Total Silver (Ag)	mg/kg	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	**20**	**40**	**40**	**20**	**40**	**40**
Total Thallium (Tl)	mg/kg	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**1**	**1**	**1**	**1**	**1**	**1**
Total Tin (Sn)	mg/kg	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	**50**	**300**	**300**	**50**	**300**	**300**
Total Uranium (U)	mg/kg	0.76	0.81	0.57	0.88	0.68	1.3 (1)	0.7	1.3	**23**	**33**	**300**	**23**		
Total Vanadium (V)	mg/kg	7.9	10	8.1	11	7.2	8.8	8.7	7.4	**130**	**130**	**130**	**130**	**130**	**130**
Total Zinc (Zn)	mg/kg	23	34	24	55	30	24	25	25	**250**	**410**	**410**	**200**	**360**	**360**
Field Preserved Volatiles															

Parameters	Sample ID / Units	HR23-SP01-006 Depth: 0.15 - 2.5m	HR23-SP01-007 Depth: 0.15 - 2.5m	HR23-SP01-008 Depth: 0.15 - 2.5m	HR23-SP01-009 Depth: 0.15 - 0.5m	HR23-SP01-010 Depth: 0.15 - 0.5m	HR23-SP01-011 Depth: 0.15 - 0.5m	HR23-SP01-012 Depth: 0.15 - 2.5m	HR23-SP01-013 Depth: 0.15 - 2.5m	**Concentration (mg/kg dry weight) Residential/ Parkland**	**Concentration (mg/kg dry weight) Commercial**	**Concentration (mg/kg dry weight) Industrial**	**Coarse - Residential/Parkland (mg/kg)**	**Coarse - Commercial (mg/kg)**	**Coarse - Industrial (mg/kg)**
Benzene	mg/kg	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	**0.011**	**Table**	**Table**	**0.5**	**5**	**5**
Toluene	mg/kg	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	**0.37**	**Table**	**Table**	**0.8**	**0.8**	**0.8**
Ethylbenzene	mg/kg	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	**0.082**	**Table**	**Table**	**1.2**	**20**	**20**
m & p-Xylene	mg/kg	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040						
o-Xylene	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020						
Xylenes (Total)	mg/kg	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045	**2.4**	**2.4**	**2.4**	**1**		
Surrogate Recovery (%)															
1,4-Difluorobenzene (sur.)	%	96	99	97	99	101	99	101	102						
4-Bromofluorobenzene (sur.)	%	98	99	100	94	96	96	97	98						
D10-o-Xylene (sur.)	%	105	101	90	120	119	124	117	120						
D4-1,2-Dichloroethane (sur.)	%	99	98	99	104	104	104	105	103						
Misc. Inorganics															
Total Organic Carbon (C)	mg/kg	3300	4000	2300	4200	1800	1600	2300	1500						

RDL = Reportable Detection Limit
N/A = Not Applicable
(1) Matrix spike exceeds acceptance limits due to matrix interference.

APPENDIX C – STANDARD OPERATING PROCEDURES

Continuous Water-Quality Sampling Programs: Operating Procedures

Prepared by
Watershed and Aquifer Science
Science and Information Branch
BC Ministry of Environment

for the
Resources Information Standards Committee

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Abstract

There is an increasing use of continuous water-quality sampling equipment in water-quality studies conducted in British Columbia. The people that collect the data are not necessarily those that use the data and thus there must be standards for collecting and validating the data before it is available for use by others. This manual begins with an overview of the quality assurance, quality control, and quality assessment requirements of a sampling program. Each subsequent chapter describes the recommended procedures for each stage of the sampling program and identifies how the procedures incorporate the quality assurance and quality control requirements. These stages are designing a station, collecting the field and laboratory data during a field visit, and validating the data. A main component of the validation procedure is to determine data grades, which are a measure of the sensor error at the time of a field visit. The derivation and use of the data grades is discussed in detail.

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For further information about the Resources Information Standards Committee, please access the RISC website at http://srmwww.gov.bc.ca/risc/.

This edition supersedes "Automated Water-quality Monitoring – Field Manual", by White, 1999.

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A. Introduction

"Water is the best of all things."
C Pindar

Technological advances in water-quality sampling and recording instruments allow for an almost continuous record of the concentrations of water-quality variables in streams and rivers. However, the data collected are only as good as the quality assurance and quality control procedures, and the quality assessment measures incorporated into the sampling program. The purpose of this manual is to describe and explain these requirements for conducting Continuous Water-Quality (CWQ) sampling programs funded by the province of British Columbia. Each major stage of a water-quality sampling program – designing a station, completing the required field and laboratory procedures, and validating the data – represents a chapter in the manual. New terms are explained when they are introduced within the text and are defined in the glossary of terms. The manual begins with an overview of the quality assurance, quality control and quality assessment requirements of continuous water-quality sampling programs.

This manual supersedes White (1999). It covers the same general topics, but there are some important differences and new ideas. Some of these differences include the following:

- An overview of the quality assurance, quality control and quality assessment requirements of a continuous water-quality sampling program.
- The use of data grades based on sensor error with a detailed explanation of the sources of sensor error and the criteria for the data grade.
- A strong emphasis on servicing the equipment, with step-by-step procedures.
- A separate section on validation with Excel programs that complete the calculations.

Continuous electronic monitoring generates large volumes of data. In British Columbia, the Water Inventory Management (WIDM) system is currently used as a repository for hydrometric, snow pillow, manual snow survey, and automated water-quality data, and is available for use by individuals to store, edit, graph, and archive their data. It is an Oracle based application designed to capture continuous time series data from remote and manual sites. Also, it has the capacity to capture written information (meta-data) about the station design and the field observations. Changes are planned to allow direct input of field data onto computer based field forms, and to complete some basic calculations. Information about WIDM and the status of the revisions is available from the WIDM's Applications Manager, BC Ministry of Environment. At the time of writing, the new features of WIDM are not operational. However this manual includes standardized Resources Inventory Standards Committee (RISC) forms that will be incorporated into the computer- based WIDM forms.

New automated water sampling equipment is continually being produced and new software is being developed to analyze automated water-quality data. Therefore this manual does not address specific instruments or software. The objective is to explain the required procedures. In cases where these are instrument-specific, the operator should contact the supplier for details.

B. Quality Assurance, Quality Control, and Quality Assessment Requirements of a Continuous Water-Quality Sampling Program

"Quality is never an accident; it is always the result of high intention, sincere effort, intelligent direction and skillful execution; it represents the wise choice of many alternatives."
William A. Foster

The quality assurance, quality control, and quality assessment requirements for collecting discrete water samples are defined and discussed by Taylor (1987) and Clark (2000a, 2000b). Wagner (2004) provides working definitions for continuous water-quality sampling programs. Details of the sampling vary among the different authors, but the objectives are always the same: to ensure that proper procedures are followed, to measure possible error (bias and variability), and to document the details. The specific requirements for quality assurance, quality control and quality assessment are explained below.

B.1 Quality Assurance

Quality assurance refers to any components of the water sampling program that cannot be measured directly. These are the procedures implemented to *control* all of the components of the sampling program. It means that appropriate equipment must be used, standard procedures must be followed, and any deviations must be recorded and explained.

B.2 Quality Control

Quality control refers to all of the data collected and used to measure bias and variability. Its measures must be defined and then included in the write-up of sampling procedures and subsequent calculations. In a continuous water-quality sampling program, the measures of quality control are the characteristics of the sensors (particularly how accurate they are), the performance of the deployed sensors (or, conversely, the extent of sensor error), and the duration of equipment malfunctions.

B.3 Quality Assessment

Quality assessment refers to the system of activities used to ensure that the quality assurance procedures are implemented and that the quality control elements are evaluated. In automated water-quality monitoring programs, quality assessment is the validation process. Secondary components of quality assessment are data approval and data audits. Data approval and data audits are not considered in this document.

The components of quality assessment reflect the stages of the sampling program. Information is documented on the following components:

- Station location and deployment method
- Important characteristics of the equipment
- Sampling schedule and station maintenance
- Field and laboratory data
- Sampling period data – data anomalies and data gaps

Each of these components of quality assessment is outlined below. To streamline the acquisition of the information, standard RISC forms are used (Appendix 1), Excel programs are included (Appendices 2 and 3), and a summary table to record the results of the assessment (validation) is included (Appendix 4).

B.3.1 Station Location and Deployment Method

Information on the station location is added to *RISC CWQ - 01. Station Design Part 1: Site Description.* Each site is identified by a unique name and number, an Environmental Monitoring System (EMS) number, and a global position (latitude and longitude or UTM). This form also includes a general description of the site, the equipment present, access instructions, and the type of deployment used. Details about the station location and deployment methods are given in Sections C.1 and C.3, respectively.

B.3.2 Sampling Equipment

Information on the sampling equipment at the field sampling site is added to *RISC CWQ - 01. Station Design Part 2: Data Source, Sensors, and Sensor Parameters*. Details about the sampling equipment are discussed in Section C.2. The possible combinations of source, sensors, and sensor parameters are explained in Section C.2.1.4. A portable sonde is required for field visits. Specifications of the sensors on the portable sonde are added to *RISC CWQ – 03. Specifications of the Portable Sensors' Parameters*.

B.3.3 Sampling Schedule and Station Maintenance

Information about the site conditions at the beginning and end of each field visit and information on the type of maintenance needed during each field visit are added to the *RISC CWQ – 02. Station Log and Maintenance Form*. The sampling schedule is derived from a series of these forms.

B.3.4 Field and Laboratory Data

The field and laboratory data are the subject of Chapter D. They are collected during the field visit and added to the three parts of *RISC CWQ – 04. Field and Laboratory Data*.

- Part 1: The pre-cleaning, post-cleaning, and re-deployment data.
- Part 2: Sources of standard calibration solutions and calibration data for the **deployed sonde** (C1 & C2).
- Part 3: Sources of standard calibration solutions and calibration data for the **portable sonde.**

The purposes of the field and laboratory procedures are to service the sensors, obtain the information required to determine the data grades, and compare different procedures used in collecting the data. The data grades, which are similar to the data ratings used by Wagner et al. (2006), are based on the accuracies of the sensors at the time of the field visit. A decrease

in accuracy is called sensor error. The sources of sensor error and their measurement are explained in Section D.4.

The required calculations are completed in an Excel program. This is in Appendix 2.

B.3.5 Sampling Period Data – Initial analysis for data gaps and data anomalies

The sampling period data are collected while the operator is absent. If the sensors are in good to excellent working order, based on the data grade, the sampling period data should also be good to excellent. However, before the sampling period data are released, the operator should complete an initial assessment for the following features:

- Unreasonable values
  - Negative values, except for temperature
  - Values that exceed the range of the sensors
  - Truncated values
  - Adjacent values that exceed the accuracy of the sensors
- Abrupt changes
- Prolonged changes
- Data gaps

The Excel program in Appendix 3 flags data points that are unreasonable and gives the number of data gaps. The details are discussed in Chapter E. The numbers (and percentage) of data gaps and the number of flagged data points are tabulated in Appendix 4 as part of the final validation.

C. Station Design

"*Where observation is concerned, chance favours only the prepared mind.*"
Louis Pasteur

The station design is dictated by the purpose of the study and includes three inter-related parts: the site location, the sampling equipment, and the deployment method. The information on the location, equipment, and deployment method for each station is added to the two parts of *RISC CWQ – 01. Station Design*.

C.1 Site Location

The general location of the site depends on the purpose of the study. The specific location depends on accessibility and safety, protection from vandalism, stream morphology and flow, and proximity to electrical power and telephone service (Wagner et al., 2006; Einarson, Environmental Impact Biologist, pers. comm.).

C.1.1 Accessibility and Safety

All automated water-quality sampling stations must be accessible, safe, and have a minimal chance of being damaged or destroyed by natural forces. The following features should be considered when establishing the location of the sampling site. The information can be obtained from maps, weather records, talking to residents, and a reconnaissance visit.

- The stations should be located near a road for easy access to the station.
- The station should have shallow sloping banks to ensure safe access to the stream.
- The potential for snow pack and ice to limit access and to damage the equipment should be determined.
- The presence of large trees and the potential for windfalls that could damage the station should be assessed.

C.1.2 Protection from Vandalism

Protection from vandalism is important to ensure that a valid and useful data record is obtained, and because the sampling equipment is expensive. The protection required depends on the arrangement of the equipment, but in general there are three components to keep secure: the sonde, the accessory equipment (data logger, batteries, & additional power sources), and the cables. In all cases, the sonde is protected in a deployment tube. The design of deployment tubes is the topic of Section C.3. There are several options that can be used to protect the components.

- In a self-contained system (Figure C-1), the data logger and batteries are contained within the sonde, and the sonde is locked in a deployment tube. The deployment tube is anchored to a bridge or other permanent structure and the cable is protected in a casing.
- Systems in which the sonde is physically separated from the accessory equipment present several options for protective structures. The accessory equipment can be protected in a walk-in shed (Figure C-2) or a locked box (Figure C-3). The sonde is then connected to the accessory equipment via a cable that is contained in casing (Figure C-4), and may be buried.

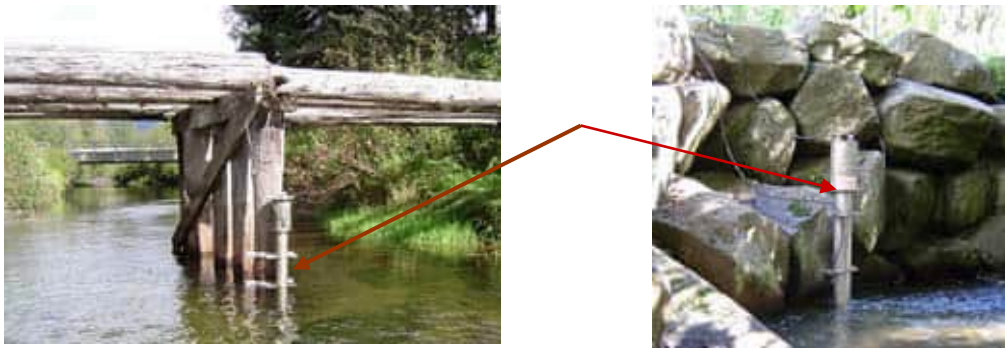

Figure C-1. A self-contained sonde provides its own protection and can be attached to a bridge or rock wall. Photos: Rod Shead

Figure C-2. A walk-in enclosure is one way to protect the equipment. Photo: Judith Burke

Figure C-3. A sturdy box that contains an external data logger and battery can be used to protect the equipment. Photo: Linda Gregory

C.1.3 Stream Morphology and Seasonal Flow Patterns

The gradient and shape of the channel and the seasonal flow patterns of the stream affect the velocity, bedload transport, flooding potential, damage due to moving debris, turbulence, and cross-sectional variability. Stream characteristics that minimize these effects and ensure the continued presence of water are identified below.

- There must be a pool of water removed from riffle areas, in which the sensor can be deployed, e.g. Figure C-4. This is important because of the specific characteristics of pools (see Glossary).
  - Pools are areas that are deeper than other areas and have a concave bottom that will help ensure that the sensors are underwater during low flow.
  - Pools are the areas that have the lowest velocity and a surface water gradient, near zero. Therefore, during high flow periods the deployment tube and sensors will be least susceptible to debris and bedload movement.
  - Pools are less turbulent and are areas of fewer bubbles, which obviates the effect of bubbles on optic measurements.

Figure C-4 Deployment tube in Beaver Creek. Note the cable in the casing and the location of the deployment tube on the downstream side of the stump where there is some pooling of water. The vertical tube is a pressure transducer used to measure water level. Photo: Julia Beatty

- A straight stretch of stream above and below the sampling location is required to minimize the cross-sectional variability. The distance upstream and downstream that is straight will depend on the size of the stream. In small streams it may be as little as 10 m and in large streams it may be 100 m. ***The variation in the water chemistry across the stream at the sampling site should be determined before the station is established.***
- There must be no tributaries in the general vicinity of the sampling site that could affect uniform flow and increase cross-sectional variability.
- There must be one stream channel along which all of the flow passes.

- There must be minimal signs of erosion and deposition in the stream at the sampling site.
- Stable banks are required to accommodate periods of high water. There must be no signs of high-water debris damage at the level of the sampling equipment. If the accessory equipment cannot be put above the expected high water level, it may be necessary to remove the equipment during high water periods in order to prevent potential damage to the equipment by turbulent water and by debris in the water. If velocity and debris movement are the main concerns, a steel deployment tube will protect the sonde (Figure C-5).

Figure C-5. A metal deployment tube may be required in high velocity and high debris flow conditions. Photo: Rod Shead

C.2 Sampling Equipment

This section provides an overview of the sampling equipment used in automated water-quality studies. It is considered in three parts: the instruments used to collect and store the sampling period data, the sources of power, and the ways in which the data can be retrieved. It is important to remember that although the parts are discrete, they must work together. Detailed information on specific connections and compatible components is best discussed with the supplier.

C.2.1 Collecting and Storing the CWQ Sampling Data

The data are collected using sensors and stored in either internal or external data loggers (Figure C-6).

C.2.1.1 Sensors

Sensors can be electrical, electrochemical, or optical. They respond to changing water conditions with an output signal that is processed and either displayed or recorded. The choice of a particular sensor depends on the parameters being studied, the required specifications, and the operating conditions. In addition, it is important to recognize that different sensors have different life spans.

Parameters

Sensors are available to measure a wide variety of variables, but the ones most commonly used at automated water-quality sampling sites are: conductivity, dissolved oxygen, pH, temperature, and turbidity. In addition, chlorophyll *a*, oxidation reduction potential (ORP), and total dissolved gas (or total gas pressure) are now measured at some sampling sites in British Columbia. Also, as the accuracy and detection limits for ion specific electrodes (ISEs) – used to measure chloride, nitrate and ammonium / ammonia – are improved, and as new sensors to detect coliforms and other micro-organisms are refined (e.g. Brown, 2004; Drake and Quist, 2004), more variables may be measured at continuous water-quality sampling locations.

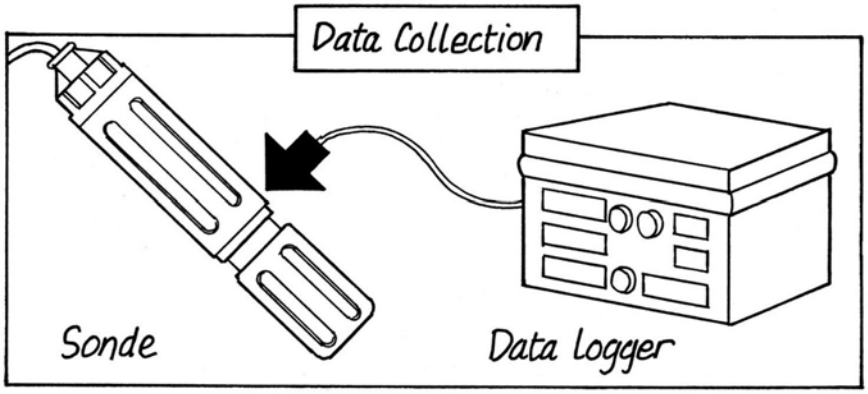

Figure C-6. The equipment used to collect the water-quality data. The sonde (left) may be self-contained or attached to a data logger.

Sensor devices may be individual or multi-parameter; the latter are referred to as sondes. Sensors that measure temperature and turbidity are examples of individual devices, which are used in single-variable studies (e.g. Eads and Lewis, 2002). Some of the newer sondes can measure more than 14 parameters (www.Hydrolab.com; www.YSI.com). Some sensors measure two parameters (e.g. temperature and conductivity, and pH and ORP). In addition, some parameters require readings of other parameters for compensation; dissolved oxygen in salt-water conditions needs to be compensated for both temperature and salinity.

Sensor specifications

These are accuracy, resolution, and range.

1. Accuracy

   The accuracy is the difference between the sensor reading in a standard solution and the true value. Accuracy may be recorded as a specific value (e.g. mg/l) and/or as a percent. As a percent, it may be the percent of a reading or percent of full scale (range). The difference is important (Table C-1).

   Sensors tend to be least accurate at the extremes of their measurement range. This is because a physical measurement is being converted into an electronic one, and thus any inherent electrical noise from the instrument's own electronics can become a significant component of actual measurement, especially at low signal levels. Instrument manufacturers may identify this aspect by using a two-tier accuracy specification based on sensor range. Turbidity accuracy, for example, may be expressed as ± 2 NTU or ± 5% of the reading, whichever is greater. So, for a given measurement of 20 NTUs, the accuracy would be 20 ± 2.0 NTU not 20 ± 1.0 NTU. Once the measurement exceeds 40

NTUs only the ± 5% of reading specification would apply because the inaccuracy is now greater than the minimum 2 NTU specification.

Table C-1. The difference between accuracy readings based on percent of reading and a percentage of full scale.

Reported Reading	Range of Sensor	Range of Accurate Readings
100 NTU ± 5% of reading	0 to 1000 NTU	± 0.05 x 100 = 95 to 105 NTU
100 NTU ± 5% of full scale	0 to 1000 NTU	± 0.05 x 1000 = 50 to 150 NTU

The data grades (Chapter E) are dictated by the accuracy of the measurements. Therefore, the accuracy of the equipment dictates the highest possible grade for the data. The present grades are dependent on the accuracy of frequently used sensors. As sensor technologies improve and these new sensors become commonly used in British Columbia, the criteria for different data grades may increase as well.

It is critical that the calibration standard solutions used are only those recommended by the manufacturer / supplier. If other solutions are used, the accuracy cannot be assured and no data grade can be assigned.

2. Resolution
   Resolution is the smallest interval that the sensor can detect.

3. Range
   The range refers to the lowest to highest values that can be detected with the same resolution and accuracy.

Operating environment

The operating environment includes the medium, temperature, and depth. In general, the sensors operate in fresh water, salt water, or polluted water, from –5 °C to + 45 °C, and to depths of 200m. The specifics of each sensor should be confirmed; this information is in the manuals (e.g. www.Hydrolab.com; www.YSI.com) and should be confirmed by the suppliers.

Life span

Not all sensors have the same operational characteristics and life span (Table C-2). Sensors such as pH, dissolved oxygen, and various ion-specific electrodes are consumptive. The components of the sensor are used up during the measurement process, and once depleted the sensor must be replaced. As a sensor reaches this endpoint, its ability to respond to changes in the environment diminishes with a resulting reduction in data quality. The sensors are inspected (D.5.4.3) and certain characteristics of some sensors (e.g. millivolt readings of pH sensors) are recorded (D.5.4.5) during each field visit. This information and the information on the expected life spans of the sensors (Table C-2) will aid the operator in assessing the conditions of the sensors.

Table C-2. A summary of sensor types and their typical lifespans

Sensor	Type	Typical Life Span
Temperature	Electrical	5+ years
Conductivity	Electrical	5+ years
pH/ORP	Electrochemical	1 to 3 years
Dissolved Oxygen	Electrochemical	3 to 5 years
Turbidity/Chlorophyll/Dye	Optical	5+ years
ISEs	Electrochemical	6 months to 1 year

C.2.1.2 Sensor Signal: Analogue vs. Digital (Serial) Signal Output

Water-quality sensors reflect changes in their state (electrical, optical, or electrochemical) by altering the strength of their signal output. A continuous increase in the signal output is typical of an analogue signal. The output is usually electrical, normally in volts or amperage (or sub-units of the same), but it may be of very low magnitude and non-linear. Therefore the signal must sometimes be magnified and transformed to a linear output. These analogue sensors typically have no ability to filter or store data internally, and the signal output, in many cases, cannot be adjusted by the end user.

Alternatively, the raw analogue signal can be converted to a digital signal. Digital signals can be massaged by the manufacturer. The manufacturer can filter and average the outputs, and compensate for conditions that would affect the raw values, in order to produce higher quality data. In addition, multiple analogue sensors can be combined into a single multi-parameter device because the individual signals can be converted to digital signals and then combined into a single data string.

Although we refer to these as digital sensors, the signal outputs are most commonly serial because the individual data values from each analogue sensor are sent in a specific sequence. Different devices can communicate with the digital output - PC, external data logger, and hand-held display units – and thus the sensor output may be in a variety of serial data formats. Three common formats are RS232, SDI-12, and RS485.

RS232

RS222 is the most common format. It is used to communicate between a digital sensor and a single serial device (e.g. PC, telephone modem) when calibrating and programming the sensors and retrieving stored data. While the format specifications state a maximum cable length of 15.4 m (50 ft), longer cables, based on manufacturer recommendations, may be used.

SDI-12

SDI-12 is used to communicate from multiple digital sensors to an external data logger. It uses multi-addresses so that each sensor is individually identified. This method is akin to the old telephone party line; all of the sensors are connected to a common three-wire communication and power cable. A master unit, typically the central data logger, issues a command to a sensor's specific (slave) address and that sensor responds. It is important that

no two sensors have the same address, because like the party line scenario, multiple sensors would respond and the master unit would not be able to differentiate among them. The general SDI-12 specification is designed to allow up to 62 m (200 ft) of cable between the sensor and the data logger.

RS485

The RS485 format is useful in situations where longer cables (>100 m or 328 ft) are required; the RS485 format allows for up to 1230 m (4000 ft) of cable to be used. Like the SDI-12, the RS485 has the ability to link multiple sensors to a central data logger or PC. The RS485 is not as popular for field monitoring situations, but it is the standard for on-line and process control operations.

C.2.1.3 Data Storage and Memory

Many digital sensors now have internal memory, which is used to store data and to perform some data processing – temperature compensation or data filtering. The data are most frequently recorded and stored in time intervals. Sensors that are capable of data processing may be able to filter out the maximum and minimum values and calculate mean values. However, in most cases, these types of data processing require a more powerful external data logger.

External data loggers can be viewed as a central collection point for all measured parameters. Although a sensor may have the ability to store data internally, in some situations an external data logger is preferable. External data loggers have four important capabilities:

1. External data loggers have more powerful data processing capabilities than internal data loggers. For example, external data loggers can determine maximum, minimum, or average values over a specific time range.
2. External data loggers can transmit data via telemetry (e.g. GOES Satellite).
3. External data loggers can interface simultaneously with other sensors such as hydrometric or meteorological, and include all of the output as part of total data package.
4. External data loggers can be connected to a large primary power source, which increases the deployment time. This allows for a longer deployment time than sensors with only internal batteries. (***Note****: A long deployment time is not necessarily an advantage*.)

The available memory given for an instrument depends on the way that the data are stored. It is best to check with the supplier as to the memory capability and thus the allowable deployment period and the required means of data retrieval. However, it must be emphasized that the deployment time is not dictated only by the available memory or power source (point 4 above). The extent of fouling, variable in-stream conditions such as storms, and possible calibration drift, must be considered as well.

C.2.1.4 Terminology Used in RISC CWQ -01 for the Possible Combinations of the Sensors and Data Loggers

The sensors and data loggers can assume a variety of configurations. The three general configurations are shown in Figure C-7. Arrangement 1 is found at site where there is one multi-parameter sonde attached to an external data logger. Arrangement 2 shows a self-contained system with an internal data logger and batteries. This is the arrangement in Figure C-1. Arrangement 3 is the attachment of two or more separate sensors to an external data

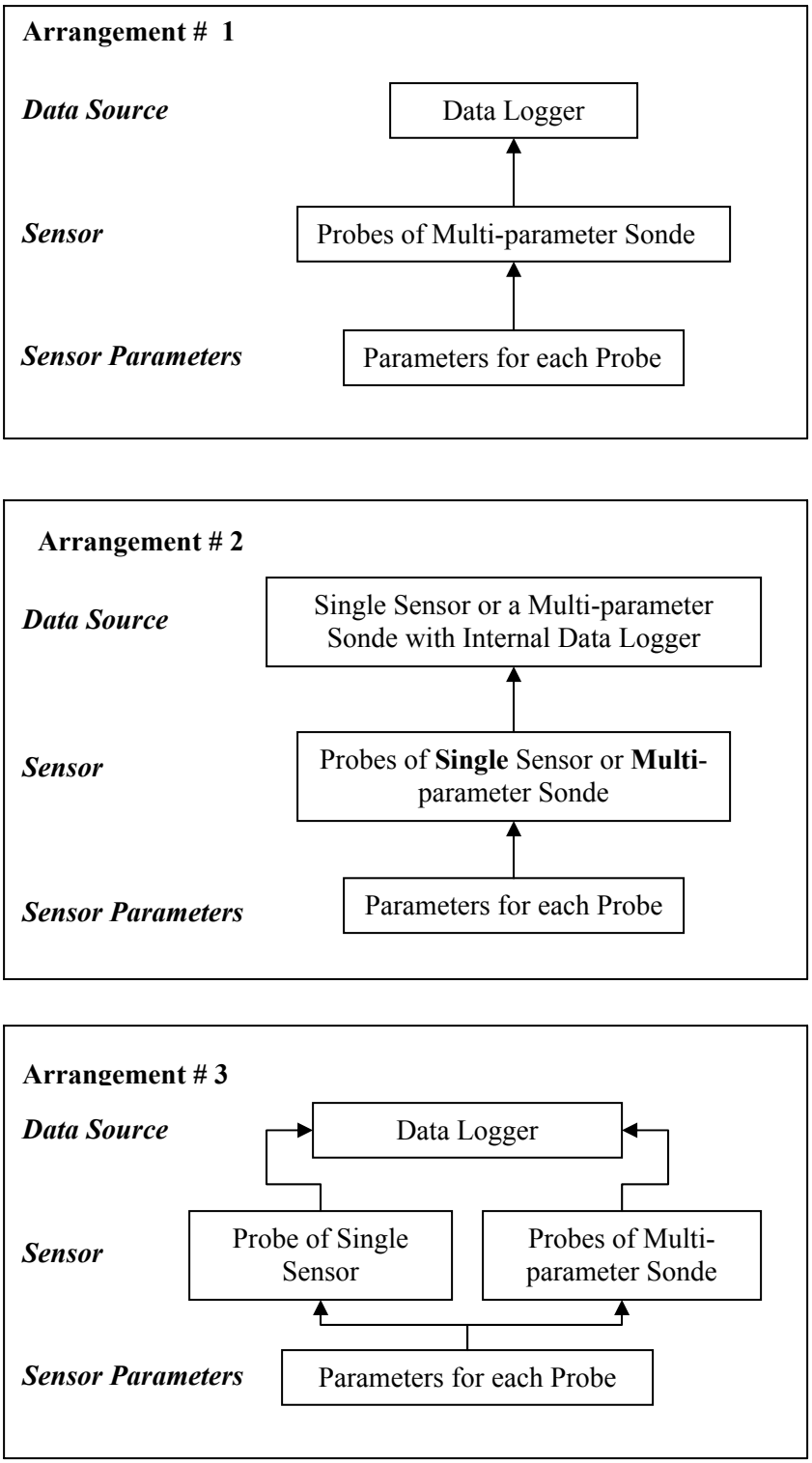

Figure C-7. Summary of the various combinations of data source, sensors, and sensor parameters used in completing RISC CWQ – 01. Station Design Part 2: Data Source, Sensors, and Sensor Parameters.

logger. Figure C-4 is an example of two instruments (a sonde and pressure transducer – used to measure water level - connected to an external data logger.

The sensor parameter, sensor and data source at each sampling location must be recorded on *RISC CWQ – 01. Station Design Part 2: Data Source, Sensors, and Sensor Parameters*. Because the arrangement of the equipment varies (Figure C-7), it is important that the form is completed correctly. The terms – sensor parameter, sensor, and sensor source - are explained in more detail below.

Sensor parameters
In all cases (arrangements 1, 2, and 3), the sensor parameters are the variables or parameters for each probe. Recall that one probe may measure two parameters.

Sensor
The sensor may be the probe of a single sensor (arrangements 2 and 3) or the probes of a multi-parameter sonde (arrangements 1 and 2). In cases where a sensor measures two variables (e.g. temperature and conductivity), the sensor is the same, but the sensor parameters are different.

Data source
The data source is an external data logger (arrangements 2 and 3) or an internal data logger (arrangement 1). Separate discrete sensors may be attached to an external data logger (arrangement 3).

C.2.2 Power Supply

The possible sources of power are shown in Figure C-8. In all cases, batteries power the sonde. If there is an external battery, it is connected to the sonde via a cable and if there is an auxiliary power source such as a solar panel, it is connected to the battery by a cable.

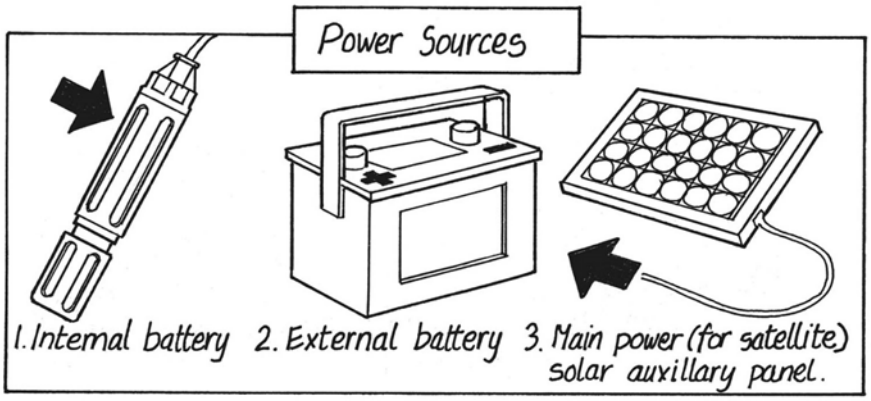

Figure C-8. The different ways that a sonde can be powered. The arrow on the left indicates the location of internal batteries in a sonde. If there is an external battery, it is attached by cable to the sonde. Auxiliary power can be used as shown by the arrow from the solar panel to the battery.

C.2.2.1 Batteries

The power to the sensor is *via* internal or external batteries (Figure C-8). Analogue sensors require an external power supply, which can be provided by a field display unit - such as a hand-held pH or dissolved oxygen meter - or through the data logger to which the sensor is

connected. Depending on the capacity required (amp-hours), external batteries should be either a good quality gel-cell type, or a deep discharge sealed lead-acid style. Automotive batteries are not designed for the repetitive drawing down and recharge cycles that are prevalent at remote stations. Residential (110V) and solar power sources can be used as auxiliary power to the primary battery, for recharge purposes, but should not be connected directly to an instrument because voltage spikes can occur and cause the entire system to fail. The use of a voltage regulator is highly recommended when connecting an auxiliary power source to the primary battery.

Digital sensors with internal memory may also be equipped with an internal battery supply, allowing for a completely stand-alone (self-contained) water-quality station. This package is the simplest to deploy, but lacks some of the advantages of the external data logger that are summarized above.

C.2.2.2 Field and Interface Cables

Depending on the instruments used, a myriad of cables may be required. For example, a cable may be needed to connect the sensor to a hand-held field display, PC, or external data logger, and to connect an external data logger and battery. These cables are instrument-specific, but some important questions should be addressed.

- What cable lengths are required at the particular sampling location?
- Are the cables interchangeable among sensors?
- Is a separate cable required for external power?
- Is a separate cable required for calibration?
- What cable is required to connect to a PC? Where is the connection?
- What cable is required to connect to the external data logger? Where is the connection?

Analogue sensors typically use a single cable that connects the sensor to a display unit or to an external data logger. Digital sensors may connect to a display unit using a field cable, or to a PC or external data logger *via* an interface cable.

If power is supplied through a separate cable, the appropriate connectors must be used, and the connections must be in a weatherproof enclosure (minimum IP – 56 / NEMA 4 rated) located well above the high water level.

C.2.3 External Devices for Communication and Data Retrieval

Communication and data retrieval can be done on-site with a laptop or hand-held display or remotely in real-time *via* a phone or satellite (Figure C-9).

C.2.3.1 On-site Communication and Retrieval

Laptops, hand-held displays, and more recently, personal digital assistants (PDAs) are the main ways used to communicate and operate digital sensors with a serial interface. Most come with a software package. Laptops have the greatest degree of flexibility, but hand-held units are designed for use in the field and are therefore sturdy and can operate in a variety of environmental conditions.

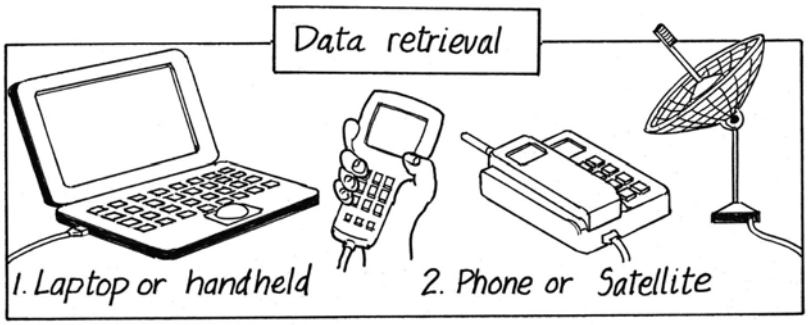

Figure C-9. Options for data retrieval.

Other means of communication include IrDA (infrared) and wireless technology (e.g., Bluetooth) that are used with PDAs. These wireless links allow the PDAs (which are lighter and easier to take into the field) to operate in the same manner as a PC, using specialized software. However, IrDAs do not function well in bright light and Bluetooth is not yet common in the environmental instrumentation market.

C.2.3.2 Real Time Communication and Data Retrieval

Real-time communication occurs when the on-site data are transmitted to a computer that is not at the sampling location. This is sometimes referred to as remote real time communication. Traditionally, telephone modems have been the major means of moving data from one location to another. Hard line or cellular phone coverage is available in urban areas and along main travel corridors. Outside of these areas, satellite phones can be used.

An important advantage to telephone modems is their ability to provide two-way communications between the base station and the field sensor/logger. That is, the same communication conduit can be used to reprogram sampling rates and other system functions, such as downloading the data. Field modems, which are used at the sensor/logger location, are designed to withstand the environmental conditions and power constraints imposed on them, unlike their less expensive office counterparts. Operating costs for this form of telemetry can vary tremendously, with land-lines typically being the least expensive and satellite being the most expensive.

Recently, there has been a movement by telephone service providers to reduce the cost of transmitting data by using a combination of the cellular network and the internet. This form of communication requires digital cellular coverage and uses an IP Modem. The IP modems are issued an IP address that identifies the computers on the Internet. The user calls the station using the appropriate software and the call is routed through the Internet and does not become a conventional cellular signal until the very last link. Users can access sensors in remote locations from any location in the world without incurring expensive long distance fees, because the last link between the tower and the modem is always a local call.

Radio networks are also used to provide two-way communications. A major limitation may be disruption of the signal due to terrain, in which case a number of repeater stations may be required to get the data back to the base station. However for localized networking, the use of spread spectrum radios is an attractive option. These radios are license-free and can transmit over a 20 km distance “line of site.” The initial equipment cost of a radio system is

higher than that of telephone modems, but their operational costs are significantly less because there are no service fees.

Satellite radio systems, such as GOES and ARGOS, provide one-way transmission of data, from the field sensor/logger to a base station. They are used most commonly at remote locations that are not readily accessible by road. The on-site data logging devices are programmed to transmit the stored readings at a specific interval; the data is retrieved at the base site via telephone modem. Access to the GOES network is available only to government agencies and their partner corporations, while private companies can apply to ARGOS for the transmission of their data. The initial hardware plus transmission costs for the ARGOS network are fairly substantial compared to the other telemetry options, and therefore are implemented only for special applications.

C.3 Sensor Deployment

Deployment refers to the way that the sensor comes into contact with the ambient water. There are two main deployment methods. The sensor is either placed in the stream or the stream water is brought out of the stream to the sensor; the former is called an in situ or "in-stream system" and the latter is called a "flow through system" (Wagner et al., 2006) or a side-stream system.

C.3.1 In-situ Deployment

Two factors must be considered: the design of the deployment tube, and type of deployment.

C.3.1.1 Deployment Tube Design

The sensors are in the stream and must be protected from moving debris (e.g. Figure C-10), sediment, and inquisitive aquatic or terrestrial animals, including humans. Therefore the sensors are housed in PVC or metal deployment tubes and attached to a flexible cable. The deployment tube protects the sonde, and the cable is used to retrieve the sonde. The design of the deployment tube is also important because it must allow free flow of stream water across the tube and the sensors.

Figure C-10. The deployment tube must protect the sensors from debris, such as leaves and branches, in the stream. Photo: Linda Gregory

There are three main designs of deployment tubes. In all cases, only the operator has access to the sonde from the top of the deployment tube because the top is capped and locked (Figure C-1 and C-4) or opens into the locked box (Figure C-3).

Style 1: A solid tube with the guard as the only protection for the sonde (Figure C-11)
In this type of deployment tube, the sensors protrude from the bottom of the sonde and are protected by the guard of the sonde. Because the sensors are protected only by the guard, debris may get trapped in the guard, temporarily or permanently, and damage the sensors, or affect the optical readings. In one case, inquisitive swimmers and rafters tried to investigate a sonde that was deployed in this way, and caused serious damage to the sonde.

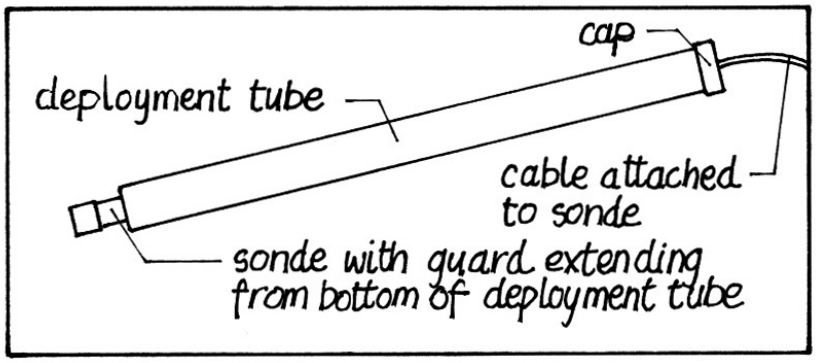

Figure C-11. A solid deployment tube with the sensors protruding from the bottom of the deployment tube and protected only by the guard.

Style 2: A solid tube with additional protection for the guard (Figure C-12)
This deployment tube has additional protection of the sensors from moving debris. The tube is solid, but the downstream half of the tube where the guard and sensors are located is cut out from the tube. There is ample access for the sensors to stream water and additional protection for the sensors, but the sonde is still visible from the bottom. This type of tube is common in British Columbia.

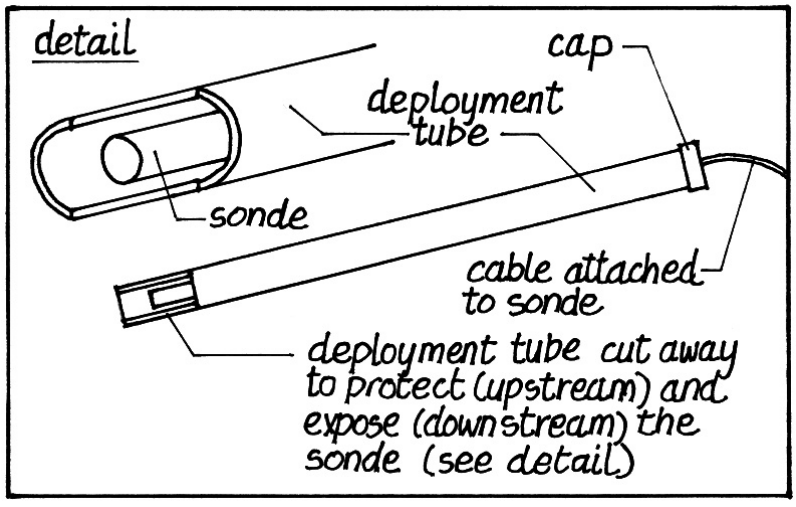

Figure C-12. A solid deployment tube with some additional protection for the sensors.

Style 3: A slotted deployment tube with a cap on the bottom (Figures C-13 & C-14)
In this deployment tube, the tube is slotted to allow free flow of water. Irregardless of the position of the sonde in the tube, the sensors are exposed to the stream water. In addition, both the guard and the deployment tube protect the sensors, and the sonde is protected – from vandalism - at the top and bottom. However, debris may be trapped within the guard as with the first design (Figure C-11) and in the tube.

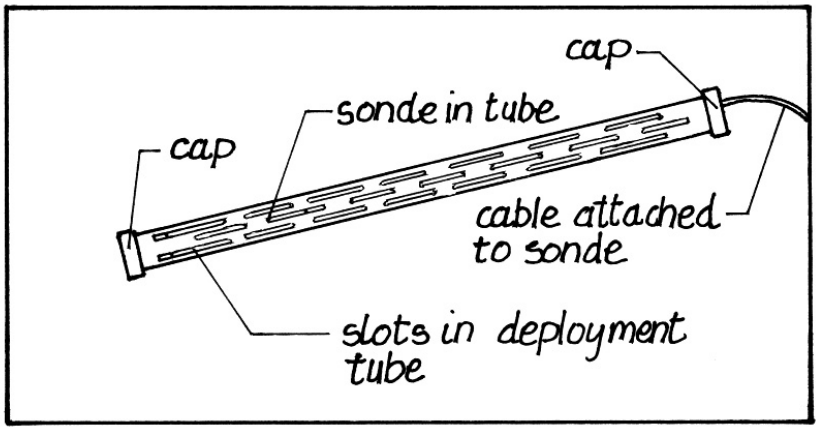

Figure C-13. A slotted deployment tube with a cap at the bottom and top. The slots allow free flow of stream water and the caps prevent access to the sonde.

Figure C-14. An example of a slotted deployment tube. The figure on the right shows the bar across the top that both prevents access to the sonde and sensors and helps support the sonde. Photos: Frank van der Have

C.3.1.2 Types of *in situ* Deployment

The deployment tube may be positioned in several different ways. It may be fixed vertically, fixed at an angle to the bank, or contained in a retractable boom. In lakes and slow moving water such as in reservoirs, the deployment tube may be anchored to a buoy or raft. This is referred to as surface deployment and is not considered in this manual. In some cases, the sensors are mounted in frames on the streambed. Unfortunately, the sensor may not be accessible during high flow periods and it may be damaged during by bedload movement. This typed of deployment is not commonly used in water-quality studies.

Fixed vertical deployment

Sensors that are fixed vertically may be stand-alone (Figure C-1 and Figure C-15) or they may be attached *via* a cable to a data logger. In both cases, the deployment tube is attached to a structure such as a bridge or piling or bedrock. If the sensors are attached to a data logger and / or have an external power source, they must be contained within a walk-in shelter (Figure C-2) or secured in a weatherproof box (Figure C-3).

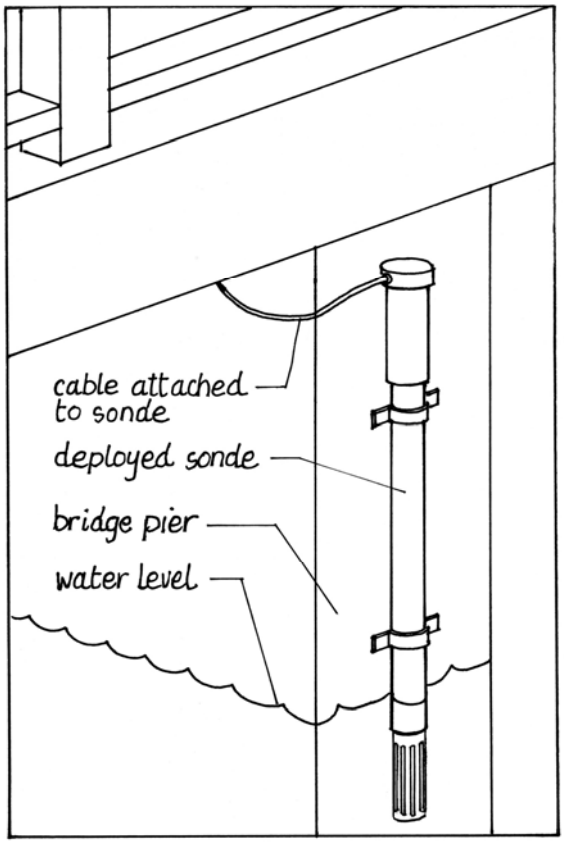

Figure C-15. Fixed vertical deployment. Note that the sensor is self-contained. There is no external battery or data logger.

Fixed angle deployment

The deployment tube is anchored to the stream bank on an angle, usually *via* posts, angle iron or a tree (Figure C-16). This method is useful for sites where the parameters include turbidity and chlorophyll *a*, which are measured using optics, and must have a bubble-free detection window. If the sensors do not have a wiper, keeping the sensor at an angle minimizes the build up of bubbles on the optics.

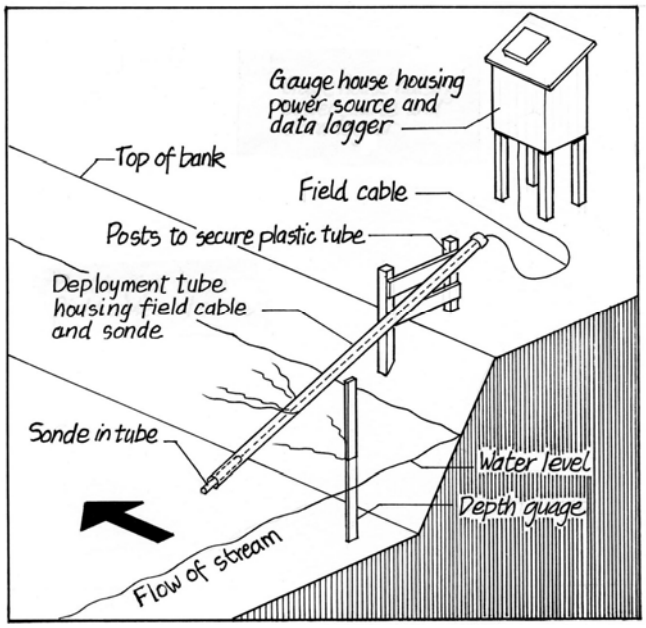

Figure C-16. Fixed angle deployment. Note that an external battery and a data logger are housed in a separate enclosure.

Retractable booms

Booms are articulating levers that allow modification of the orientation and depth of the sensor in the stream and ensure that the sensor remains a consistent distance above the substrate. They may be mounted to a bank, a bridge, or a cross-stream cable. An example of one attached to a bank is shown in Figure C-17. Because the sensor is oriented *with* the stream flow it is subject to hydroplaning at high velocities; therefore, the sensor must be appropriately weighted (Eads and Lewis, 2002).

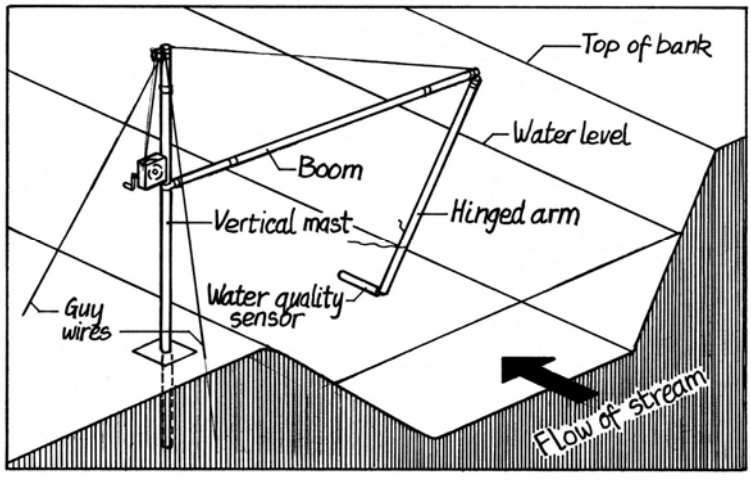

Figure C-17. Retractable boom. Note that the sensor is parallel to the stream-flow.

C.3.2 Flow-through Systems

Flow-through or side-stream deployment (e.g. Figure C-18) is used when instruments cannot be installed safely in the stream. There are five important conditions that necessitate the use of flow-through deployment:

- Excessive turbulence and bubbles
- Extreme danger of instrument damage from floating debris or bedload
- Insufficient water depth to meet operational requirements
- Unstable bank conditions or no structure available to anchor a deployment tube
- Severe cold and ice during the winter

There are two types of side-stream samplers: gravity-fed and pump-fed. An example of the former is shown in Figure C-18. In both cases, the water is drawn from the stream to the sampler and released by gravity, and the sensors are housed out of the stream in an adjacent shelter. The differences are reflected in the names; gravity-fed systems draw water by gravity, and pump-fed systems use a pump to draw water. The sensor may be contained in an adjacent shelter designed specifically for housing the sensor (Wagner et al., 2006) or the sensor may be housed in a building adjacent to the stream (Ryan et al., 2004).

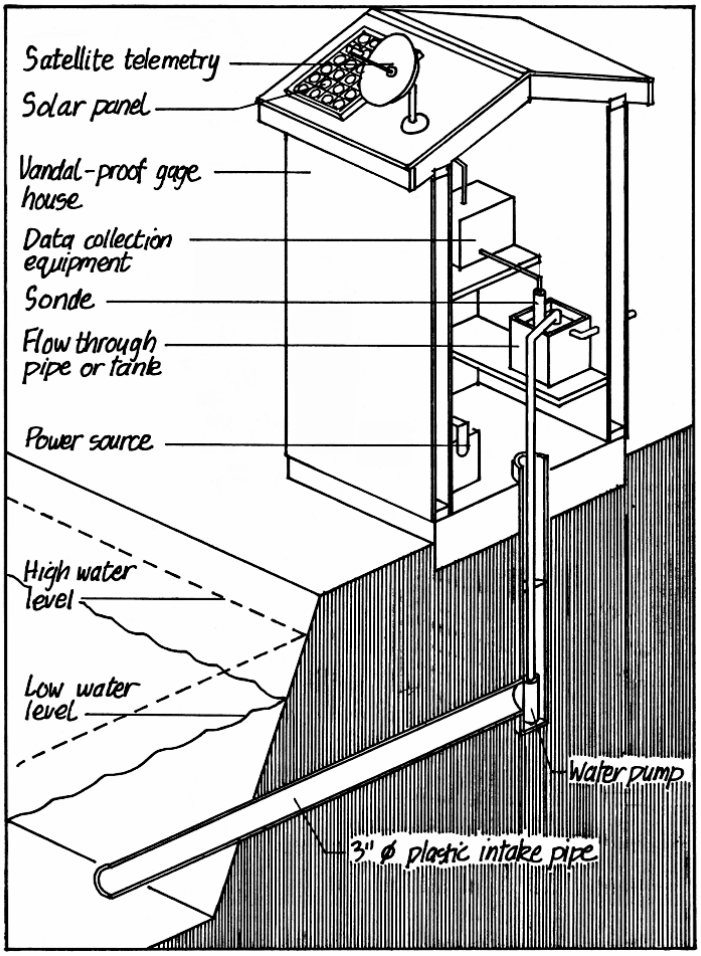

Figure C-18. The general design of a flow-through deployment system.

Several factors must be considered when using flow-through deployment.

- The samplers must be calibrated so that measurements in the sampling chamber and stream are correlated.
- The opening of the intake pipe must have a large diameter (and thus surface area) and be covered with a mesh. This ensures flow into the sampler and reduces the required time between servicing of the intake.
- If the samplers are located where freezing conditions may occur, intake hoses should be submerged or buried, the sampling chamber should not contain metal components, and the sampling chamber must be insulated.
- Because of the location of intake pipes and the possibility of mixing in intake pipes, side-stream samplers are not appropriate for dissolved oxygen or temperature measurements.
- Because the water is pumped into a standing chamber, sediment may precipitate on the bottom of the chamber and ultimately be mixed with the incoming water. This will have a significant effect on parameters such as turbidity. To avoid this problem, the container should be examined frequently for sediment build-up. Alternatively, the inflow should be at the top and the outflow at the bottom of the container and the container should be at an angle with the outflow at the lowest point.

C.3.3 Factors to Consider when choosing a Deployment Method

Several inter-related factors must be considered when choosing the most appropriate deployment method: study purpose, location, in-stream conditions, accessibility for retrieval, and power supply. Many of these considerations must also be asssessed when determining the most appropriate site. Of course budget is always a necessary consideration.

C.3.3.1 Location

At remote sites a deployment method that allows communication with the site is recommended, but not always possible. Communication with the data logger on-site reduces potential loss of data.

C.3.3.2 In-stream Conditions

Continuous water-quality sampling sites are used on small streams and large rivers. The stream gradient and seasonal flow patterns affect water depth, bedload and debris movement, and the extent of turbulence.

Depth

A minimum depth of water is required to ensure that the sensors are always in the water column. In addition, within the water column the sensors should be a minimum distance from the substrate - about 20 cm - to obviate effects of bedload transport, and a minimum distance from the surface to eliminate the effects of solar radiation. The later is particularly important for optical sensors – turbidity and chlorophyll *a* – because their readings are affected by solar radiation on the sensors. If fixed vertical or fixed angle deployment is used, historical information on stream flow should be assessed to determine expected low-flows and high-flows; the location of the deployment tube can then be determined accordingly. In small streams that are subject to rapid changes in flow, the retractable boom is advantageous because the position of the sensor can be readily changed. However, the sensor must be weighted to prevent hydroplaning.

Bedload and debris movement

The movement of bedload and debris are associated with high-flow conditions; both can damage the sensors. It may be expedient to remove the sensors during the high-flow periods. Another possible solution is the careful choice of a quiet pool, which is less likely to be influenced substantially by debris. Ice is a special type of debris. To obviate the problems with ice in a reasonably large river, Ryan et al. (2004) used a flow-through deployment method. Sensors can operate to below freezing temperatures in streams, but the greatest problem occurs when the sensor is removed and exposed to severe freezing temperatures.

Turbulence and bubbles

Turbulence produces bubbles, and bubbles interfere with readings from optical sensors, such as turbidity and chlorophyll *a*. Wipers remove any bubbles immediately before a reading is taken and thus reduce any problems due to bubbles. If the sensor does not have a wiper, angle deployment is preferred because it prevents accumulation of bubbles, which frequently occurs with vertical deployment. Turbulence is greatest in straight high-flow sections of the river and thus deploying the sensor in a protected side area will reduce the effects of turbulence.

C.3.2.3 Accessibility

High flows limit access to sensors deployed on the stream bottom. Accessibility may be limited by water depth and flooding, but this should be considered in the initial station design.

C.3.3.3 Power Supply

Flow-through deployment requires 110 volt AC power. None of the other types of deployment require power.

D. Field and Laboratory Procedures

"*Maintenance is the foundation of eternity*"
Isaac Aasimov

The ultimate purpose of the field and laboratory procedures is to ensure that the sampling equipment is working properly and the sampling period data represent the environmental conditions. Sampling sites differ in stream hydrology (Section C.1), the arrangement of the equipment (Section C.2), the deployment method (Section C.3), and the proximity to an office or laboratory. This means that one set of instructions is not appropriate for all combinations of hydrology, deployment, equipment, and accessibility to a stable environment. Therefore the approach used in this chapter is to outline the recommended procedures and to document the data that should be collected.

It may not always be possible to follow precisely the recommended procedures. This does not negate the value of the data. It means that the operator must recognize potential problems due to any deviations and he/she should attempt to obtain the data in a way that follows closely the recommended procedures. Before any modifications are implemented, the operator should consult with the project supervisor and/or the regional manager.

D.1 Data Collected

The sampling period data are collected on a data logger while the operator is absent. These data document the continuous record of the stream water-quality. The field and laboratory data are collected by an operator during the field visit at intervals during the sampling period (Figure D-1).

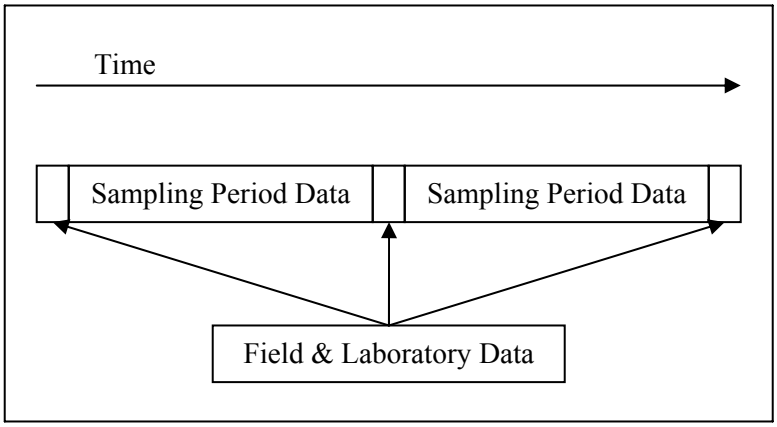

Figure D-1. The sampling period data are collected on a data logger while the operator is absent and the field and laboratory data are collected by the operator at the field site and in a stable environment.

The field and laboratory data include numerical and written information. The written information, called meta-data, summarizes the results of the site inspection (Section D.5.3.2) and the sensor inspection (Section D.5.4.3), and documents the sources of the calibration

standards (D.5.4.4). Accurate and complete metadata are necessary for data management and subsequent stages of data approval and audit. The numerical information is the data used to determine the data grade and to further validate the sampling period data (Chapter E).

D.2 Frequency of Field Visits

If the sampling period data, which are stored in a data logger, are viewed in remote real-time (Section C.2.3), unexpected data points can be recognized immediately and remedial action – an on-site visit – can be taken. However, in British Columbia, many sites are not capable of off-site real time communication and the sampling period data are downloaded and viewed only during field visits. The frequency of the field visits to all sites will depend on the stream conditions and may be changed by the operator. New sites should be visited every two to three weeks or, at least, more often than once per month. In general, at sites where there is not remote real-time communication, ***the frequency should not be greater than the longest period of data that the operator is willing or allowed to lose***.

D.3 Frequency of Separate Laboratory Samples

Historically, stream water samples have been collected during each field visit and submitted to a certified laboratory for analysis. The results are used to assess the readings of the sensors at the time of the field visit. The protocols outlined in this manual do not recommend the consistent use of these laboratory samples because the sensors are inspected and calibrated during each field visit and because readings are obtained from cleaned and calibrated portable and deployed sensors.

The variables that are sampled most commonly in British Columbia (Section C.2.1.1) - and considered in this manual - are conductivity, dissolved oxygen, pH, temperature, and turbidity. Because the measurement of chlorophyll *a* and depth and level are becoming more common, they also are included in this manual. Conductivity, dissolved oxygen, pH and temperature are field variables. Their characteristics will change during transport to a laboratory and therefore the results can not be compared to the field data. Depth and level can be checked only by other hydrometric equipment on-site. Turbidity levels measured in the field can be compared to laboratory results, but they are not required by this methods standard. Their measurement is at the discretion of the operator. Chlorophyll *a* monitoring is recommended only as a complement to more accurate laboratory analyses; therefore laboratory samples for chlorophyll *a* should be collected during every field visit.

D.4 Recommended Sampling Protocols – Background

This section has four objectives:

1. To give the purpose of the field visits.
2. To outline the sources of sensor error – the basis of the data grades - that can contribute to a decrease in accuracy of the sensor readings.
3. To identify and explain the factors considered in developing the sampling protocol.
4. To give an overview of the recommended protocol.

D.4.1 Purpose of the Field Visits

The purpose of the field and laboratory visits is to inspect the sampling site, service the sensors, and obtain the information required to determine the data grades. The data grades, which are based on the data ratings used by Wagner et al. (2006), are a measure of the accuracy of the sensors at the time of the field visit. A decrease in accuracy is called sensor error. The sensor error is measured during the field visit, but the effect of the sensor error is seen in the sampling period data collected between the field visits. After each field visit, sensor error is calculated and used to obtain the data grade.

D.4.2 Types and Sources of Sensor Error and their Effect on the Sampling Period Data

There for four main types of sensor error: fouling, calibration drift, sensor malfunction, and noise. The source of each of these errors and their effect on the sampling period data are summarized below.

D.4.2.1 Fouling

- Fouling results from sediment deposits or biological growth (bacterial, algal) on the active surface of the sensors, or vegetation, debris, or insects lodged within the sensor guard.
- The effects on different sensors are variable and should be discussed with the manufacturer. Recall that the style of deployment tube can affect accumulation biomass inside the guard.

D.4.2.2 Calibration Drift

- Calibration drift happens due to electronic drift in the equipment, and sensitivity loss. It varies among sensors and affects the life span of sensors (Section C.2.1.1).
- In general, the drift is gradual and there is a gradual change in the values of the readings of the affected sensor.
- The data recorded on millivolt differences or Nernst constants (pH sensors) and cell constants (conductivity probe) will help the operator determine potential problems with these sensors (Section D.5.4.5).

D.4.2.3 Sensor Malfunction

- Sensors may be physically damaged due to in-stream movements of debris. For example, the bulb on the pH sensor may be broken, or the Teflon membrane on the dissolved oxygen sensor may be torn. Other situations that result in malfunction are loss of power, damaged cables, and loose reference junctions. Malfunction may also result if the sensors are out of the water.
- The sensors will give erroneous or no readings.

D.4.2.4 Noise

- Noise is due to sensor sensitivity, external influences (e.g. power lines and magnetic fields), and turbulence (Quilty et al., 2004), as well as direct and reflected sunlight.
- The sampling period data will show outliers and unexpected results.

D.4.3 Factors Considered in Developing the Recommended Protocol

The following factors are important prerequisites that were considered in developing the sampling protocol.

D.4.3.1 The deployed sonde must not be disturbed excessively before cleaning

- Pre-cleaning and post-cleaning data are required to determine sensor error due to fouling. If the sonde is disturbed before the pre-cleaning data are obtained, fouling material may be dislodged from the sensors or added from the guard to the sensors. Therefore, the pre-cleaning data must be obtained with the sensor in stream water and on-site.

D.4.3.2 Cleaning and calibration checks must be done in a protected and stable environment

- The sonde and sensors must be carefully and thoroughly cleaned, and the sensors must be calibrated in conditions where the equipment and calibration standards are at a constant temperature, out of sunlight. This requires a stable and protected environment. This area should have the following features:
  - (a) A heater and thermostat for maintaining a stable temperature
  - (b) A bench or table
  - (c) Storage facilities for the calibration standards and de-ionized water
  - (d) Access to water and general cleaning facilities
  - (e) Good lighting

D.4.3.3 Post-cleaning readings must be taken in stream water in a stable environment

- After the sonde and sensors of the deployed sonde are cleaned, but before the sensors are calibrated, post-cleaning readings in stream water are required. This is done in the stable environment mentioned above. To reduce sources of error, stream water must be used for the post-cleaning measurements. This means that stream water must be brought *to* the stable environment.

D.4.3.4 Calibration standard solutions recommended by the manufacturer must be used

- This is dealt with in more detail in Section D.5.4.4.

D.4.4 Recommended Protocol – an Overview

A stable and protected environment is required for cleaning the sondes and sensors, and for calibrating the sensors. In most cases in British Columbia, the stable environment does not exist at the sampling site and thus the sondes are moved from the sampling site to a laboratory or office. The recommended protocol outlined in Figure D-2 deals with the differences in the time and location of the pre-cleaning and post-cleaning readings. The data are recorded on *RISC CWQ – 04. Field and Laboratory Data*.

Various field procedures are presently used in British Columbia, and an optimal procedure and a modified procedure, for use in rapidly changing conditions, are outlined by Wagner et al. (2006). In most cases, all of the data are collected at the field site. Two important characteristics of the recommended protocol differ from previous procedures.

1. The pre-cleaning data are collected in stream water at the field site, whereas the post-cleaning data are collected in stream water that has been transported to the stable environment, usually an office or lab away from the field site. To deal with the

change in location from the field site to a stable environment, each reading with the deployed (D) sonde is paired with a reading of the portable (P) sonde. The readings of the portable sonde (bottom of Figure D-2) are used to determine the change in the stream water during its transport from the stream to the stable environment.

2. The sensors are always re-calibrated. Even if the sensors are reading within their defined accuracy, they are re-calibrated. This means that each new sampling period starts with calibrated sensors. It also means that error will not gradually creep into the data due to a gradual calibration drift in the sensors over a series of field visits. Any shifts in the sampling period data due to this re-calibration can be adjusted in subsequent processing of the data (Section E.8)

Several additional points about the recommended protocol warrant mention.

- The sensors of the deployed and portable sondes must have the same accuracy, resolution, and range. Or at least the accuracy must be equal to or better than the accuracy of the highest data grade.

- The portable sonde must be cleaned and calibrated before each field visit.

- The series of measurements recorded for the deployed and portable sensors are recorded with a number after the letter. When the numbers after the D and P are the same it means that they are paired and the readings are taken under the same conditions. Either both sondes are in deployment tubes, in situ, or both are in a container of stream water, referred to as "in a bucket of stream water". These two conditions, in situ and “in a bucket of stream water,” represent two options for obtaining the pre-cleaning and re-deployment data. ***Both options should be included in the initial visits.*** The Excel program in Appendix 2 calculates the data grade for both options and compares the two options. The operator can use the comparisons to decide which option is most suitable for a station. The option that is used must remain consistent at a sampling location.

- There are differences in the time and location of the data acquisition during the field visit. The locations are the field site and a stable environment. The time differences depend on the relative locations of the field site and stable environment. Parts 1, 2, & 3 in Figure D-2 are the different locations.
  (a) Part 1: At the ***field site*** before the deployed sonde is cleaned. These are the pre-cleaning data (D1 &P1) and (D2 & P2).
  (b) Part 2: In a ***stable environment*** after the sondes and sensors are cleaned. These are the post-cleaning data (D3 & P3) and calibration data (C1 & C2).
  (c) Part 3: At the ***field site*** when the deployed sonde is re-deployed. These are the re-deployment data (D4 & P4) and (D5 & P5).

- The post-cleaning measurements (D3 & P3) are done in stream water that is transported to the stable environment. Because there is a time lag between the pre-cleaning measurements on site and the post-cleaning measurements in a lab, there may be some changes in the water chemistry of the stream water. However, the chemical dynamics of the stream water sample that is brought to the stable environment is most similar to the stream water sample used on-site.

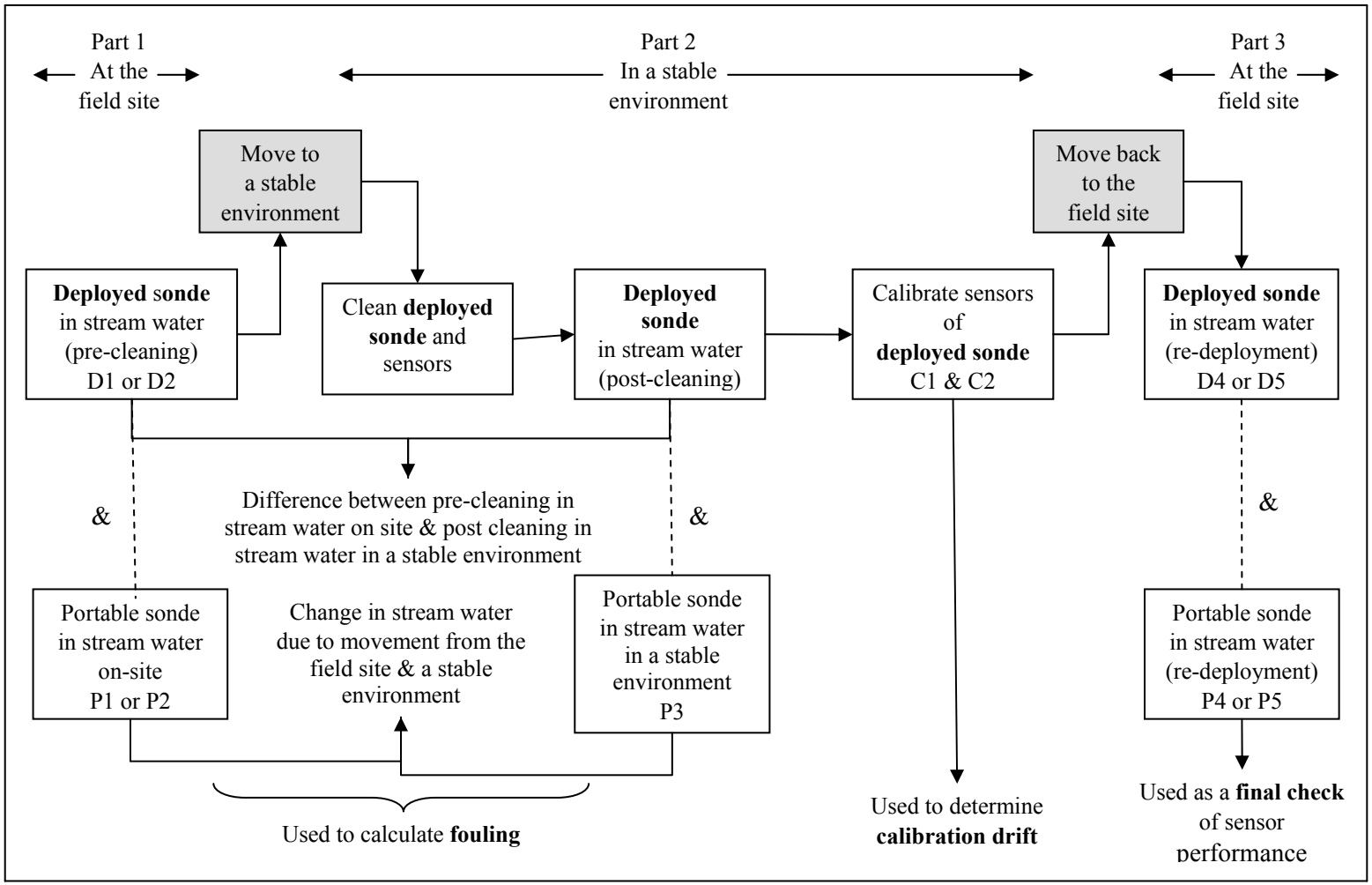

Figure D-2. Overview of the recommended protocol – data collected in pairs (deployed sonde & portable sonde) at the field site and in a stable environment

D1 & P2 = pre-cleaning, in situ
D2 & P2 = pre-cleaning, in a bucket of stream water
D3 & P3 = post-cleaning, in a bucket of stream water
C1 & C2 = pre- & post calibration readings
D4 & D5 = re-deployment, in a bucket of stream water
D5 & P5 = re-deployment, in situ

D.5 Recommended Sampling Protocols – Step-by-Step Procedures

The sampling protocols are divided into two main sections: preparing for a field visit, and collecting the field and laboratory data.

D.5.1 Prepare for a Field Visit

Recall that each field visit has an on-site and a laboratory component. Before beginning a field visit the operator must assemble the necessary field supplies, ensure that the required laboratory supplies are available, and calibrate the sensors of the portable sonde (and the sensors of the deployed sonde, if it is the first field visit). Each site will have different specific requirements, but a generic list of equipment is given below. The operator can use this list to generate his/her own.

Two sondes are required, the sonde (or sensor) that is deployed – called the deployed sonde (D), and a portable sonde (or sensor) brought to the field site – called the portable sonde (P). The only prerequisite for the two sondes is that the characteristics of the sensors (accuracy, resolution, and range) are the same. The information on the deployed sonde is added to *RISC CWQ – 01. Station Design Part 2: Data sources, sensors, and sensor parameters.* The information on the portable sonde is added to *RISC CWQ – 03. Specifications of the Parameters of the Portable Sonde.* Note that the latter has check boxes to confirm that the deployed and portable sensors have the same accuracy, resolution, and range for each parameter.

D.5.1.1 A Generic List of Field Supplies

Equipment

- ☐ Portable sonde
- ☐ Laptop computer and/or display unit
- ☐ Replacement batteries for sondes and display units
- ☐ Digital camera
- ☐ Global Positioning System (GPS) unit
- ☐ Insulated buckets or coolers for on-site measurements and for transporting water back to the lab
- ☐ Rubber gloves
- ☐ Towels for wrapping sondes
- ☐ Tools for repairs
- ☐ (If necessary) Laboratory sample bottles, preservatives, and requisition forms

Personal Gear

- ☐ Raingear
- ☐ Footwear
- ☐ Food and water
- ☐ First aid kit
- ☐ Cell phone

RISC CWQ Forms and Notes

- ☐ Station log books
- ☐ RISC CWQ – 01: Station Design
- ☐ RISC CWQ – 02: Station Log and Maintenance Form
- ☐ RISC CWQ – 03: Specifications of the Portable Sensors' Parameters
- ☐ RISC CWQ – 04: Field and Laboratory Data

Note:

- Although all of the forms are not needed, keeping a copy of the appropriate forms for each station with the station log book means that the operator can check what equipment is present and he/she can complete the forms as needed.
- Eventually the RISC forms will be computer-based.

D.5.1.2 A Generic List of Laboratory Supplies

- ☐ Calibration standard solutions (check expiry dates)
- ☐ Distilled (de-ionized) water
- ☐ Liquid-in-glass thermometer (NIST or NRC calibrated)
- ☐ Bio-degradable cleaning detergent
- ☐ Clean soft cloths for cleaning
- ☐ Sensor cleaning and maintenance equipment (brushes, rings, etc.)
- ☐ RISC CWQ Forms (see above)

Note:

- Recall that the laboratory is the stable environment and must have certain features (Section D.4.3.2).

D.5.1.3 Inspect and calibrate the sensors of the portable sonde

Before each field visit the sensors of the portable sonde must be calibrated. If this is the first field visit, it will also be necessary to inspect and calibrate the deployed sonde. The details for inspecting the sensors are given in Section D.5.4.3 and procedures for calibrating the instruments are outlined in Section D.5.4.5 and provided in detail by the manufacturer. The calibration data are recorded on *RISC CWQ- 04. Field and Laboratory Data Part 3: Sources of standard calibration solutions and the calibration data for the portable sonde.* The calibration data from the previous calibration time should be examined to assess trends in calibration data, which can help the operator recognize any potential problems.

D.5.2 The Field Visit - Introduction

The field and laboratory data are collected during the three parts of the field visit. The reader might want to refer back to Figure D-2 and the overview of the recommended protocol in Section D.4.4. Part 1 is the preliminary visit to the field site. Part 2 is in a stable environment, a lab or an office. Part 3 is the re-deployment visit to the field site. The procedures for the three parts are listed below. The numerical data recorded for both the deployed and the portable sonde are summarized in Table D-1. Detailed procedures are given in subsequent sections and the use of the data during validation is explained in Chapter E.

Part 1. At the Field Site – Preliminary Visit

1. Add the Arrival Information to *RISC CWQ – 02. Station Log and Maintenance Form*
2. Inspect the field site
3. Download the sampling period data
4. Obtain the pre-cleaning data (D1 & P1) in situ
5. Obtain pre-cleaning data (D2 & P2) "in a bucket of stream water"
6. Prepare the sondes for transport to a stable environment
7. Collect stream water samples
8. Clean the deployment tube

Part 2: In a Stable Environment (Office or Laboratory)

1. Clean the sondes and sensors
2. Obtain the post-cleaning data (D3 & P3) "in a bucket of stream water"
3. Inspect the deployed sonde and its sensors
4. Record information on calibration standards
5. Collect the calibration drift data in standards (C1 & C2) and calibrate or replace the sensors
6. Run the deployed sonde in tap water
7. Prepare the sondes for transport to the field

Part 3: At the Field Site – Re-deployment Visit

1. Obtain the re-deployment data (D4 & P4) "in a bucket of stream water."
2. Obtain the re-deployment data (D5 & P5) in situ
3. Add the departure information to *RISC CWQ – 02. Station Log and Maintenance Form*
4. Prepare the portable sonde for transport

The sampling schedule set up for completing the field and laboratory procedures may vary among operators. In some cases, the operator may complete the three parts in one day. In other cases, the operator may decide to complete part 1 for several sites on one day and complete parts 2 & 3 on subsequent days. Because the sondes and sensors are cleaned in a stable environment no sampling period data are collected during this time. The operator should therefore do her/his best *not* to remove the sondes during rainstorms or other potentially important or unstable in-stream periods.

Two options are given in Table D-1. These are the two possible conditions used to obtain the pre-cleaning and re-deployment data. In option 1, the sondes are in situ and in option 2, the sondes are "in a bucket of stream water". ***Both option 1 and option 2 should be completed for the first three or four field visits.*** The operator can then examine the results of the data grades and comparisons that are calculated in the Excel program and decide which option he/she should continue to use. This is explained in more detail in Chapter E.

Table D-1. Summary of the data recorded for the deployed sonde and the portable sonde during the field and laboratory procedures. In situ is option 1 and "in a bucket of stream water", is option 2.

Measurement conditions	Data Recorded	
	Deployed Sonde	Portable Sonde
Part 1. Arrive at the field site – obtain pre-cleaning data		
Option 1. Pre-cleaning, in-situ	D1	P1
Option 2. Pre-cleaning, "in a bucket of stream water"	D2	P2
Part 2. In a stable environment – obtain post-cleaning and calibration data		
Post-cleaning, "in a bucket of stream water"	D3	P3
Calibration information	C1 & C2	N/A
Part 3. Return to field site - obtain re-deployment data		
Option 2. Re-deployment, "in a bucket of stream water"	D4	P4
Option 1. Re-deployment, in-situ	D5	P5

D.5.3 Field and Laboratory Data Part I: At the Field Site – Preliminary Visit

The eight steps for this stage, which are listed above are explained in this section.

Note:

- Dissolved oxygen is measured in mg/l and thus a re-calibration is not necessary at the field site and is not included in the procedures. If dissolved oxygen is needed as a percentage, the operator should re-calibrate the dissolved oxygen sensor on-site, based on the barometric pressure at the site.

D.5.3.1 Add the Arrival Information to RISC CWQ – 02. Station Log and Maintenance Form

RISC CWQ – 02. Station Log and Maintenance Form is an on-going record of who visited the site, the conditions of the site at the time of arrival and departure, and the purpose of the field visit, including any required maintenance. A copy of the form is included in Appendix 1.

The operator must remember to check the time on the data logger with his/her watch and record this on the RISC CWQ – 02 form. In general all the data are collected at standard time.

D.5.3.2 Inspect the Field Site

Damage to the sampling equipment can necessitate repairs and limit the value of the sampling period data. Table D-2 provides a general list of features to inspect and the reasons for the inspection.

Table D-2. A general list of features to inspect at the field site and the reasons for their inspection

General Inspection	Reasons for Inspection
Station & Equipment	
• Damage to the enclosure, wires, junction box, and deployment tube.	• Repairs may be necessary.
• Signs that the station or sensors have shifted or moved in any way.	• The deployment tube may have been bumped and shifted orientation. • Sensor may be damaged.
• Damage to solar panels or telemetry equipment.	• Batteries will not be charged. • Transmission of data hindered.
• Field cables cracked or damaged.	• Improper information to data logger.
• If flow-through deployment is used, check the pipes and intake screen, ensure that the intake is clean, that water is flowing, and air bubbles are vented.	• Reduced flow will affect water level in the sampling chamber. • Bubbles will cause a vapour lock – particularly with gravity fed systems.
Stream Conditions	
• Signs of flooding or high flow (debris in stream, on deployment tube, or on banks).	• Fouling may be extensive. • Some equipment may be damaged.
• Signs of bedload movement.	• Changes may affect depth readings of sampling period data. • Bottom deployment sensor may be damaged or moved. • Sensors may be too close to the substrate.

Each operator should generate his/her own list because the details will depend on the equipment at the site, the deployment method, and the stream and weather conditions. Details of the inspection do not have to be recorded on RISC forms, although it is good field practice to summarize the inspection in the station log book. If unexpected values are apparent in the sampling period data, information in the station log book may help explain the values. If equipment is damaged or needs repairs, this information should be added to *RISC CWQ 02. RISC Station Log and Maintenance Form.*

D.5.3.3 Download the Sampling Period Data

Attach the interface cable from the laptop computer or display unit to the deployed sonde and download and view the sampling period data. ***If the sonde must be removed from the water to attach an interface cable between the sonde and the laptop (or display), the actions listed***

in D.5.3.4 should be completed before the data are downloaded. See Section 5.3.5 about removing the sonde.

D.5.3.4 Obtain the Pre-Cleaning Data (D1 & P1) in situ

Remember if the sonde must be removed from the water to attach an interface cable, this step should be completed before the previous step (Section D.5.3.3).

1. Connect an interface cable from the portable sonde to the laptop and deploy the portable sonde beside the deployed sonde. In some streams, it may be possible to simply put the portable sonde near the deployed sonde (Figure D-3). However, we *recommend* that the operator install a second deployment tube, for the portable sonde, parallel to, but above the existing tube (Figure D-4). This ensures that the two sondes (D & P) are in the same position, and it frees the operator to record the data.

2. Record the values of the parameters for both the deployed (D1) and portable sondes (P1) in *RISC CWQ – 04. Field and Laboratory Data Part* 1: The pre-cleaning, post-cleaning, and re-deployment data.
   Note:
   - If the deployed sonde is attached to an external data logger, it may be necessary to communicate with the data logger to check and change the operational settings.
   - The information from the two sondes should be obtained as close together in time as possible.

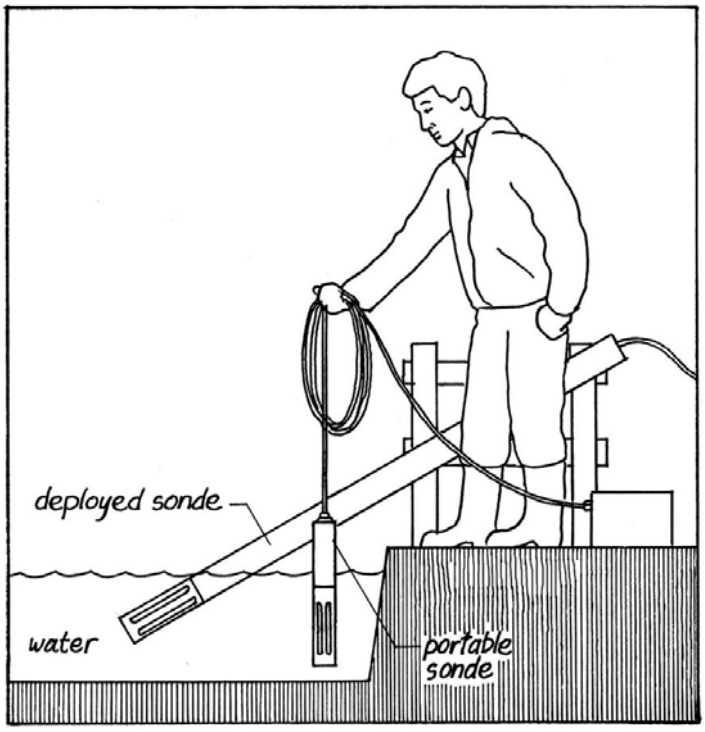

Figure D-3. The portable sonde deployed by the operator beside the deployed sonde.

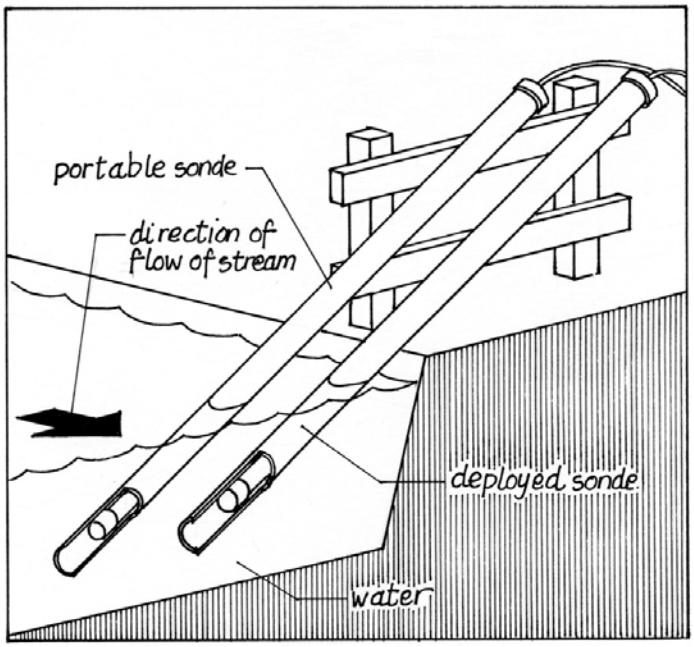

Figure D-4. A second deployment tube for the portable sonde should be installed.

D.5.3.5 Obtain the Pre-cleaning Data (D2 & P2)"in a Bucket of Stream Water"

1. Collect a sample of stream water in a cooler. A cooler is insulated and will help to maintain the water at a stable temperature. Remember to rinse the cooler with stream water.

2. Carefully remove the deployed sonde and examine the guard for attached debris.
   Note:
   - The sonde should be removed more slowly than the velocity of the stream. This should prevent any material that contributes to fouling from being dislodged.
   - It is good practice to take a picture of the sonde.

   If there is noticeable debris, this will suggest that this option for obtaining the pre-cleaning data is probably not as suitable as the in situ procedure.

3. Place the deployed sonde beside the portable sonde in a bucket of water (Figure D-5)

4. Record the values of the variables for both the deployed (D2) and portable (P2) sensors in RISC CWQ – 04. Field and Laboratory Data Part 1: Pre-cleaning, post-cleaning, and re-deployments data.

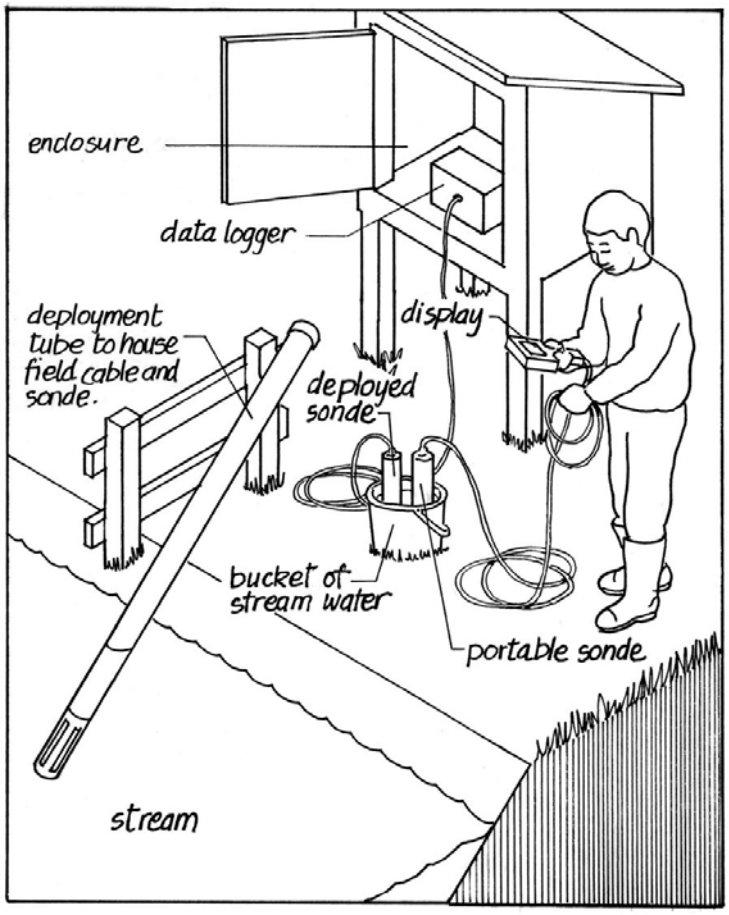

Figure D-5. The deployed sonde and the portable sonde are in a bucket of stream water. Note that the deployed sonde is connected to a data logger.

D.5.3.6 Prepare the Sondes for Transport to a Stable Environment
It is important that the sensors remain moist.

1. Carefully remove the portable sonde from the bucket and prepare it for transport back to the stable environment.
   Note:
   - Wrap the guard in a damp towel. Another option is to replace the guard with the calibration cup and place a moist sponge on the bottom of the calibration cup.
   - Remember to put the cap on the sonde to protect the electronic connections (Figure D-6).

2. Carefully remove the deployed sonde from the bucket. Carefully remove the guard and examine the sensors for fouling and debris. It is good practice to take pictures.
   Note:
   - A more thorough inspection of the sensors is done in the lab/office.

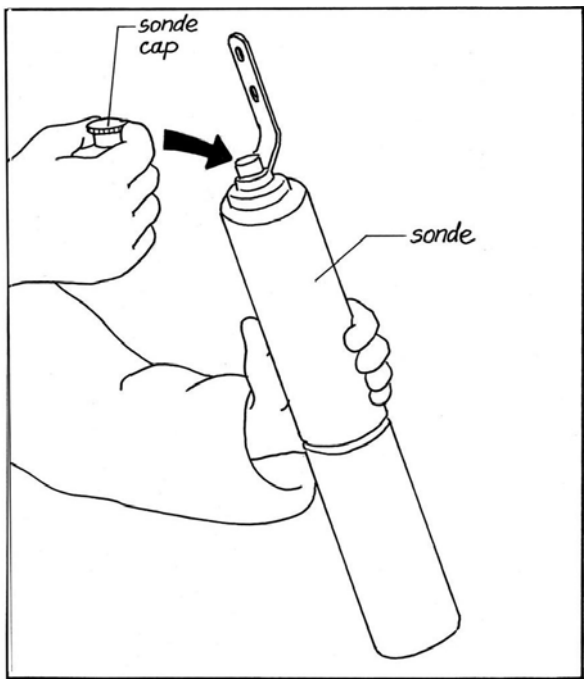

Figure D-6. Recap the sonde to prevent the entry of dirt and moisture.

4. Prepare the deployed sonde for transport to the lab or office. Use the same procedure as for the portable sonde. Remember to re-cap the sonde to protect the electronic connections.

D.5.3.7 Collect Stream Water Samples

1. Collect a stream water sample in a cooler for use in Part 2 and prepare it for transport to the lab or office. The volume must be so that the two sondes can be placed in the cooler.

2. If applicable, collect a stream water sample to submit to a certified laboratory, prepare it for transport, and complete the required forms.

D.5.3.8 Clean the Deployment Tube

Algae, debris and sediment may adhere to the inside of the deployment tube. The tube should be cleaned by sliding a mop down the inside of the tube to remove any debris (Figure D-7) and rinsed by pouring a bucket of stream water down the tube. In addition, check that there is water flowing freely across the stream-opening end of the tube.

Figure D-7. A mop is used to clean the deployment tube. The tube being cleaned is the one housing the deployed sonde. Photo: George Butcher

Go to the next field site and repeat the field steps or move to a stable environment to complete the next steps.

D.5.4 Field and Laboratory Data Part 2 - In a Stable Environment

D.5.4.1 Clean the Sondes and Sensors

The portable sonde and sensors are cleaned and calibrated before the field visit. The deployed sonde is cleaned and calibrated during this second part of the field and laboratory data collection.

The following steps outline the general procedures that should be followed; however, each operator should add to this list as necessary, using the manufacturer's recommended procedures.

1. Ensure that the waterproof cap is still tightly secured on the sonde connector.

2. Prepare the cleaning mixture in a clean bucket. The mixture is warm water and a small amount of biodegradable detergent. A soft cloth is used to do the cleaning.

3. Remove and clean the guard.
   Note:
   - Handle the instrument very carefully, particularly when the guard is removed. If the sonde is dropped and knocked against anything (e.g. the bench), the sensors could be damaged.

4. Clean the body of the sonde and then rinse it with distilled water.

5. Carefully clean all of the sensors and examine them to ensure that all of the debris and precipitated salts (e.g. Figure D-8) are removed. If there is extensive fouling, the probes might have to be removed and cleaned.

Figure D-8. A conductivity / temperature sensor before cleaning. Note the cleaned conductivity / temperature probe in Figure D-9. Photo: Linda Gregory

6. Clean the chambers on the conductivity probe. There should be a brush provided by the manufacturer. Do not use a pipe cleaner because it has a wire tip that could damage the sensor.

7. Gently wipe the face of the optics with moist lens paper (or kimwipes).

8. Inspect the pH probes and make sure that the glass bulb and platinum button are free of any foreign material.

9. For both depth and level sensors, use a syringe filled with DI to clean the pressure port. Ensure that the water comes out the other side. For level-vented sensors, ensure that the desiccant is active and regenerate it as necessary. Check the manufacture's instructions for the specific procedures required for different types of depth and level sensors.

10. Thoroughly rinse the guard and sonde in distilled water.

D.5.4.2 Determine the Post-Cleaning Values in a Bucket of Stream Water.
The stream water that was collected on-site in a bucket / cooler and brought to the lab is used in this step. Recall that stream water is used to reduce the sources of error. Some characteristics of the water will change during transport of the water, but the chemical dynamics of the water will be more similar than another source of water.

1. Place both sondes in the cooler / bucket of stream water as was done at the field site.

2. Record the results for the deployed sensors (D3) and the portable sensors (P3) in *RISC CWQ – 04. Field and Laboratory Data Part 1. Pre-cleaning, post-cleaning, and re-deployment data.*

D.5.4.3 Inspect the Deployed Sonde and its the Sensors
Several specific inspections should be completed. If there is a problem with a sensor, the information should be added to *RISC CWQ – 02. Station Log and Maintenance Form*. The details of the inspection are outlined below. The probes of one type of sonde are shown in Figure D-9.

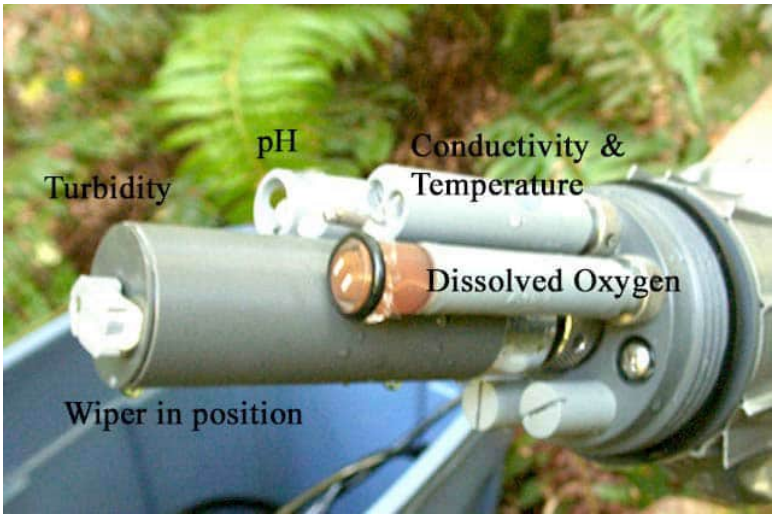

Figure D-9. Examples of some probes used in one kind of sonde. Photo: Judith Burke

The sensor maintenance should be completed AFTER the calibration drift data (C1) are added to *RISC CWQ – 04. Field and Laboratory Data Part 3*, but before the final calibration values (C2) are obtained. In most cases, the data obtained during the calibration procedures will show whether or not further cleaning or maintenance is required.

1. Check the O-rings of the battery chamber to ensure that the seal is still waterproof. If there is any suggestion of water entry, replace the O-ring seal.

2. If there is a gradual decrease in the dissolved oxygen values in the sampling period data, it may be because the Teflon membrane is damaged. Information on changing the membrane is given in Section D.5.4.5 under *Dissolved Oxygen.*

3. Check the anode surface on the dissolved oxygen probes. If there is any tarnish, the probes must be cleaned again using the specific instructions of the manufacturer. (Note the clean anodes in Figure D-9)

4. Check the faces of the optical probes (turbidity and chlorophyll *a*). They should be free of fingerprints and grease. If they are not clean, re-clean with mild detergent and rinse three times with de-ionized water. This can be done before the C1 data are obtained.

5. Check for deposits or contaminants on the glass and/or platinum surfaces of the pH probe, and for any material on the reference electrode junction. This may be the case if the response time is slow, or if the required range of millivolt reading is not obtained. The probe must be removed and cleaned according to the manufacturer's instructions, or replaced.

6. Check the wiper blades. It is highly recommended that turbidity probes with wiper blades are used if there is obvious fouling. If the wiper blades are dirty or worn, they must be replaced because this can affect parking of the wiper. In some cases, it is necessary only to replace the sponge. In other cases, the whole assembly must be replaced. Check with the manufacturer.

7. Check the voltage of the internal batteries. The expected life span of the batteries in different instruments will vary and the minimum allowable voltage will vary. The operator should record these numbers in the logbook. If it is a self-contained sonde, the batteries will have to be replaced at each field visit.

D.5.4.4 Calibration Standards

Standard calibration solutions must be used and recorded on *RISC CWQ – 04. Field and Laboratory Data Part 2*: *Sources of standard calibration solutions and the calibration data for the* ***deployed*** *sonde*. The standards should be certified by National Research Council (NRC) Canada or National Institute for Standards and Technology (NIST). Appropriate standards for conductivity and pH are available from a variety of suppliers. Distilled water is used to rinse the sensors and to calibrate zero turbidity. A liquid-in-glass thermometer is used to check temperature. At present, there are only four allowable sources of the turbidity standards.

Sources of Turbidity Standards

1. AMCO-AEPA^{R} polymer bead turbidity standard is available from GFS Chemicals and instrument manufacturers.
2. Formazin prepared as per Standard Methods for the Examination of Water and Wastewater in a certified lab.
3. Dilutions of 4000 NTU formazin concentrate that is purchased from Hach.
4. Hach Stablcal^{TM} (stabilized formazin turbidity standard) in different concentrations up to 4000 NTU.

Several important points about turbidity standards warrant mention.

1. Formazin is a polymer solution that has been the accepted primary turbidity standard for several decades. Apart from its excellent light scattering capability, it has three important limitations:
   (a) Formazin requires agitation or stirring to keep the polymer in suspension. If it is not stirred frequently, the concentration may increase as aliquots are removed.
   (b) Formazin is only stable at high concentrations. Standards above 400 NTU are stable for ≥ 1 year, standards between 20 and 400 NTU are stable for ~ 1 month, standards between 2 and 20 NTUare stable for ~ 12-24 hours, and standards < 2NTU are stable for 1 hour or less.
   (c) Formazin is hazardous to human and environmental health. Safe handling precautions are necessary as the precursor compounds are carcinogenic, mutagenic, tetratogenic, and tumorigenic (MSDS Sheets, GFS Chemicals Inc.).

2. Hach Stablcal^{TM} uses the same polymer as traditional formazin but in a different matrix to enhance stability. All Stablcal^{TM} standards (1- 4000 NTU) remain stable for a minimum of 2 years. Stablcal^{TM} standards come in varying NTU concentrations and do not require dilution or other preparation other than agitation.

3. Polymer bead turbidity standards (produced by GFS Chemicals Inc.) are non-toxic, stable and do not require agitation. Polymer bead turbidity standards are distributed by the instrument manufacturers and are instrument-specific, i.e. they are specially formulated for each sensor. ***These are recommended***. *Generic polymer bead standards are cheaper to purchase but are not calibrated for sensor type and their use is not RISC standard acceptable.*

4. Different turbidity sensors will give different readings in the same standard but accurate readings in the stream. For example, the YSI 6026 turbidity sensor should be calibrated to 100 NTU in YSI 6073 turbidity standard, but the sensor 6136 should be calibrated to 123 NTU in YSI 6073. This is one example of why it is critical that the information on turbidity standards be obtained from the manufacturer.

D.5.4.5 Collect the Calibration Data

General Comments & Instructions

The sensors should be calibrated in the sequence recommended by the manufacturer and using the procedures recommended by the manufacturer. The sequence used in the manual is as follows:

1. Temperature
2. Conductivity & specific conductivity

3. pH
4. Chlorophyll *a*
5. Turbidity
6. Dissolved oxygen
7. Depth or level (if applicable)

This sequence is used because of some of the characteristics of the parameters.

- Several parameters are temperature-dependent and temperature-compensated and thus temperature should be done first.

- The conductivity standard is 1413 µS/cm and the pH standards have conductivity values more than five times higher. Therefore conductivity should be done before pH to avoid any possible contamination of the conductivity probe by the pH standards.

- Dissolved oxygen is salinity-compensated and temperature-compensated and therefore dissolved oxygen must be done after both temperature and conductivity. Because it must be left to stand for a period of time it is usually done last.

- Chlorophyll *a* is calibrated in DI and should be done before turbidity.

- Depth or level is done in air and can be done at any time. It is given as the final calibration in the procedures.

The following general procedures should be followed:

- The sensors should be rinsed with distilled water and then with the standard solution. ***All rinses should be done three times***. For each rinse, add 3 to 4 cm of solution to the calibration cup and the rotate or swirl the instrument so that the probes are well rinsed. Discard the solution after each rinse.

- The measurement to obtain (C1) and to do the calibration (C2) is in fresh standard solution. This solution is then saved to use as the rinse standard in subsequent measurements. Saving the measurement solution will ensure that there is sufficient standard solution for subsequent rinses.

- In many cases the sondes can be calibrated either upright (Figure D-10, probes down) or upside-down (Figure D-11, probes up). The optical measurements – turbidity and chlorophyll *a* – must be done with the sonde upright. Except for dissolved oxygen, the sensor being calibrated must be immersed in the standards.

The data are recorded on *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the* ***deployed*** *sonde.* Remember that the portable sonde is calibrated before the initial field-visit and these data are recorded on *RISC CWQ – 04. Field and Laboratory Data Part 3: Sources of standard calibration solutions and the calibration data for the* ***portable*** *sonde.*

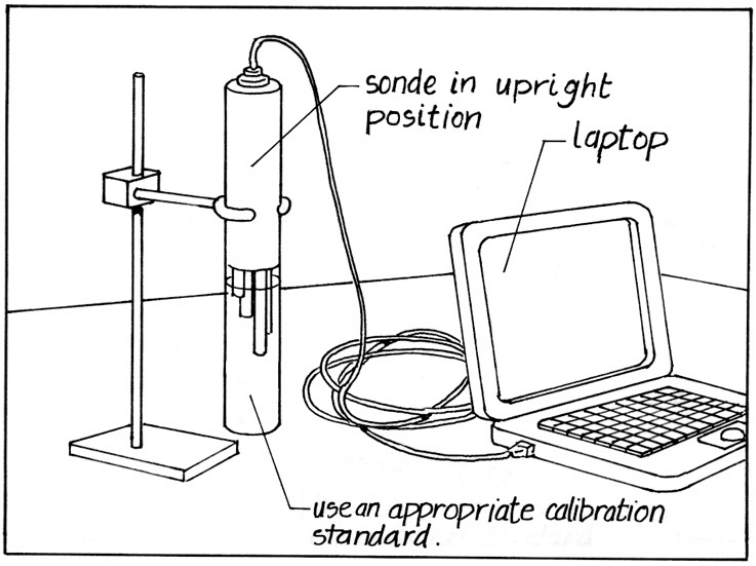

Figure D-10. An upright sonde. This is how the sonde must be positioned for the optical measurements. The volume of solution will vary depending on the sensor being calibrated.

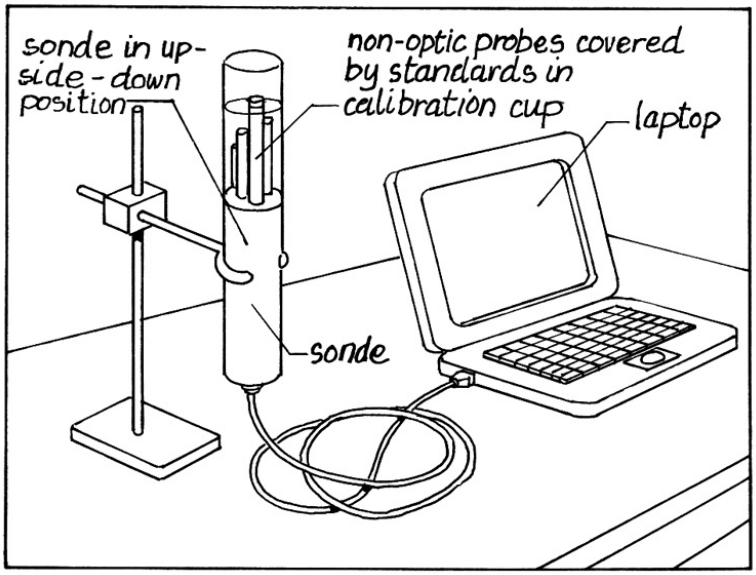

Figure D.11. An upside-down sonde. The volume of solution in the calibration cup depends on the sensor being calibrated. Because optical probes are usually the longest and these measurements must be taken with the probes down, it will not be necessary to cover these probes with the solution.

Temperature

1. Rinse the calibration cup with DI and fill it with DI to cover the temperature probe.

2. Record the temperature in column C1 in *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the* ***deployed*** *sonde.*

3. Insert the calibration thermometer (liquid-in-glass & NIST- or NRC-calibrated) in the DI and record the temperature in column C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2*.

4. If the temperature probe (C1) is not the same as C2, it is not giving the correct temperature and will have to be replaced. If the temperature probe must be replaced, do so before continuing with the calibrations.

   Note:
   - If the temperature probe is defective and is replaced, it means that the temperature dependant sensors will not have recorded realistic sampling period data. This *must be indicated in the validation report* (Chapter E).

Conductivity / Specific Conductivity

Specific conductivity is the conductivity at 25°C. These sensors are temperature-compensated and thus the result is specific conductivity. However, the temperature dictates the *expected conductivity reading as indicated on the side of the bottle* (Figure D-12). This number must be used as the expected value during the calibration.

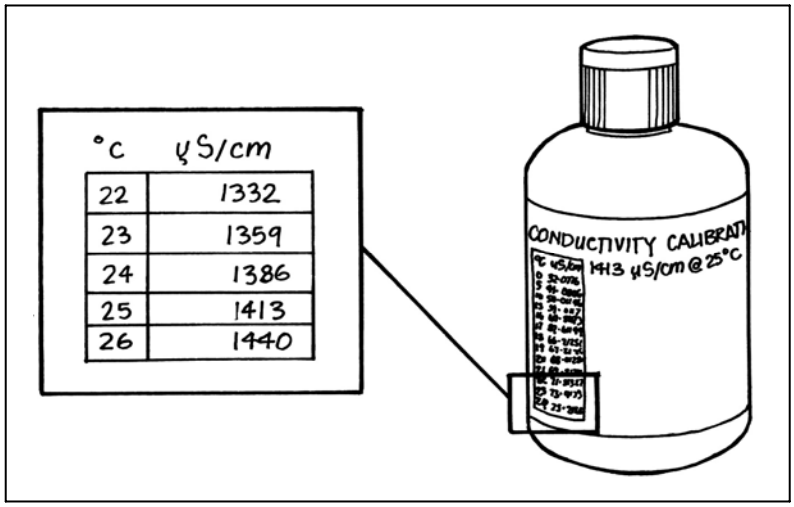

Figure D-12. The expected conductivity value depends on the temperature. Use the correct value from the bottle, based on the temperature of the standard solution.

1. Rinse the probe with DI and then dry the probe.
   Note:
   - Dry with a kimwipe or hairdryer. Do not use tissues.

- This should give zero µS/cm. If not the sensor may be malfunctioning. Check with the manufacturer.

2. Rinse with the conductivity standard (1413 µS/cm standard solution is recommended for most freshwaters in British Columbia).

3. Add the conductivity standard to the calibration cup. The vent hole on the conductivity probe and the temperature probe must be immersed.

4. Gently move the sonde to remove any bubbles.

5. Allow the values to stabilize and record the specific conductivity in column C1 of R*ISC CWQ – 04. Field and Laboratory Data Part 2*. Remember to give the expected value from the bottle containing the standard calibration solution (Figure D-12) as the correct value.

6. Re-calibrate if necessary. Record the value in column C2 of *RISC CWQ – 04.: Field and Laboratory Data Part 2*.

7. Record the cell constant in *RISC CWQ- 04. Field and laboratory Data Part 2*.

8. Save the standard solution for subsequent rinses.

pH

This is a two-point calibration. The first is always pH 7. If the values in the stream are less than pH 7, the second calibration is pH 4. If the stream values are greater than pH 7, the second standard is pH 10.

The pH depends on temperature and the expected reading at different temperatures is on the bottle of pH buffer. *Enter the expected value from the bottle as the correct pH* (Figure D-13) in the display or laptop, during the calibration procedure.

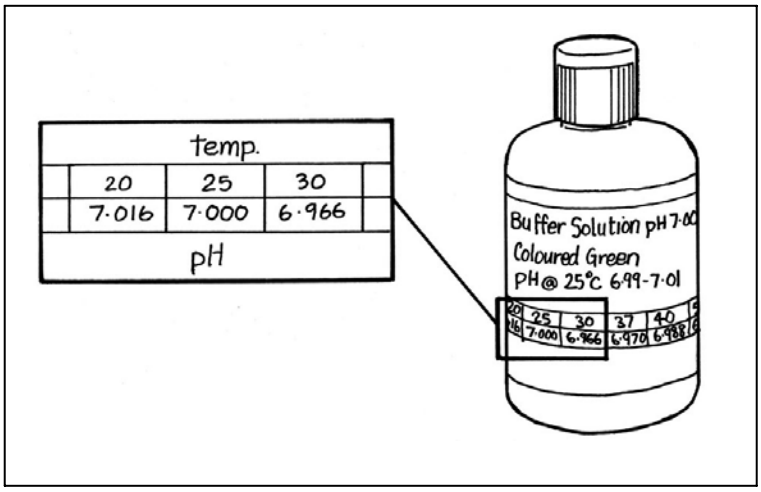

Figure D-13. Check the temperature and use the expected pH value as the correct value.

1. Rinse the probe with DI and then with pH 7 standard.

2. Add pH 7 solution to the calibration cup.

3. When the temperature and pH values stabilize record the pH in column C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde.*

4. Re-calibrate if necessary. Remember to use the value based on the temperature that is on the bottle (Figure D-13). Record the value in column C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde.* Record the millivolt reading or indicate whether KCl was added to the sensor.

5. Rinse the probe with DI and then with the second pH standard solution (e.g., pH 4)

6. Add the second pH standard solution to the calibration cup and repeat steps 3 & 4 for the second pH. Remember to use the pH value on the bottle based on the temperature of the solution (Figure D-14)

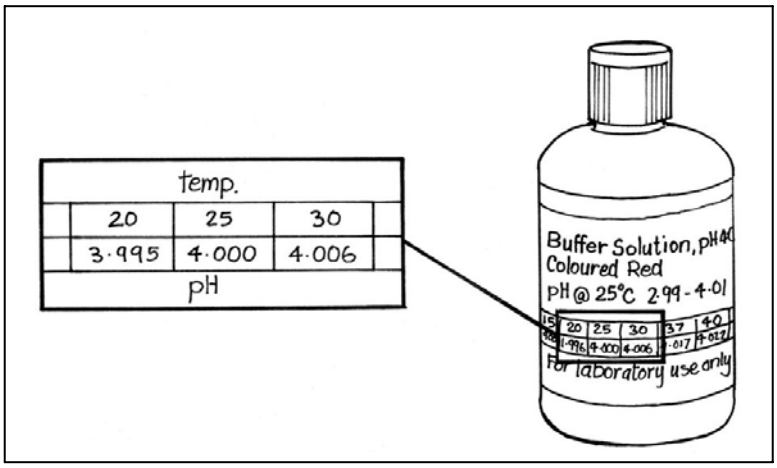

Figure D-14. Check the temperature and use the expected pH as the correct value

7. Record the millivolt reading or indicate whether KCl was added to the sensor.

8. If the mV reading is available use the values given in the RISC form (*RISC CWQ – 0. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde)* to determine if the probe is operating effectively.

Chlorophyll a

Chlorophyll *a* fluoresces when it is exposed to a particular wavelength of light. There should be no fluorescence in distilled water, an expected fluorescence in a dye, and an expected fluorescence in a pre-measured chlorophyll sample. Calibration drift is determined in distilled water. It is up to the operator to decide the best way to calibrate for the second point. The use of a pre-measured chlorophyll *a* sample is recommended.

1. Rinse the probes with DI water.

2. Add fresh DI and record the reading in C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the **deployed sonde**.*

3. Re-calibrate to zero if necessary. Record the value in C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the **deployed sonde**.*

Turbidity
This is a two-point calibration: 0 NTU using DI, and a second standard such as 100 NTU. The general recommendation is 100 NTU, but the operator can use a different concentration. In all cases the calibration for 0 NTU is done first.

It must be emphasized again that the proper standards must be used and the expected value in different standards must be known. The operator must know the appropriate standard and the expected value. The expected value for different sensors is on the bottle of the standard solution. **Please refer to point 4 in Section D.5.4.4**

Use the calibration cup provided by the manufacturer. Do not use white or opaque cups as reflection from light-coloured surfaces can cause incorrect high readings in low NTU water.

Add solutions to the calibration cup very slowly so that there are no bubbles. It helps if the calibration cup is held at an angle.

1. Rinse the probes with DI and then add DI to the calibration cup.
   Note:
   - If the probe has a turbidity wiper, ensure that the wiper is parking properly . Check with the manufacturer as to the correct parking position (Figure D-15).

Figure D-15. A turbidity probe with a wiper in the correct position. Photo: Hoskin Scientific

2. Clear the optics by activating the wiper.

3. Record the value in column C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the **deployed sonde**.*

4. Re-calibrate if necessary and record the calibrated value in C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2*.

5. Rinse the probes with DI and then with the second standard (e.g. 100 NTU).

6. Add the second standard to the calibration cup.

7. Re-calibrate if necessary. Record value in C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2*.

Dissolved Oxygen
This is a one-point calibration in a saturated environment.

1. If there is a sleep mode and warm up time when the sonde is deployed this must be modified during calibrations.

2. Rinse the calibration cup with DI water.

3. Add distilled water to the calibration cup as instructed by the manufacturer. This varies among manufacturers so be sure that the correct amount of water is added.

4. Loosely add the calibration cup to the sonde. The seal must be loose to allow ambient barometric pressure equilibration. Wait 10 to 15 minutes.

5. When the temperature stabilizes, record the temperature and the dissolved oxygen (% and mg/l) in *RISC CWQ – 04. Field and Laboratory Data Part 2*.

6. Check and record the barometric pressure (BP) in *RISC CWQ – 04. Field and Laboratory Data Part 2*.

7. Using the BP, re-calibrate the sensor. Record the calibrated values in % and in mg/l.
   Note:
   - If % dissolved oxygen is recorded the sensor must be re-calibrated for barometric pressure in the field. However, % DO is not required as a field parameter for a data grade, only mg/l is included.

   - ***If the dissolved oxygen membrane is damaged it must be replaced***. After the membrane is replaced it must be allowed to relax. In general, the membrane should be changed the day before a field visit, but new membranes can be burned in more rapidly, in some cases. The operator should check with the manufacturer on the required times and procedures.

Depth and Level (if appropriate)
The calibration for both depth and level sensors is done in air. Depth sensors are non-vented and are affected by changes in barometric pressure while they are deployed. Level sensors are vented and do not vary with changes in barometric pressure during deployment. However, in both cases, the calibration is in air (zero depth or level) at the barometric pressure at the time of calibration.

1. Determine the depth reading in air. Record the value in the field notes.

2. Calibrate the sensor to zero for the given barometric sensor.

D.5.4.6 Run the Calibrated Sensors in Tap Water

After the sensors are calibrated and the calibration drift data are recorded it is recommended that the sensors are put in tap water and data recorded for 0.5 to 1 hour (Figure D-16). The data should be examined to ensure that they are reasonable and consistent. If they are not, one or more sensors may have to be replaced.

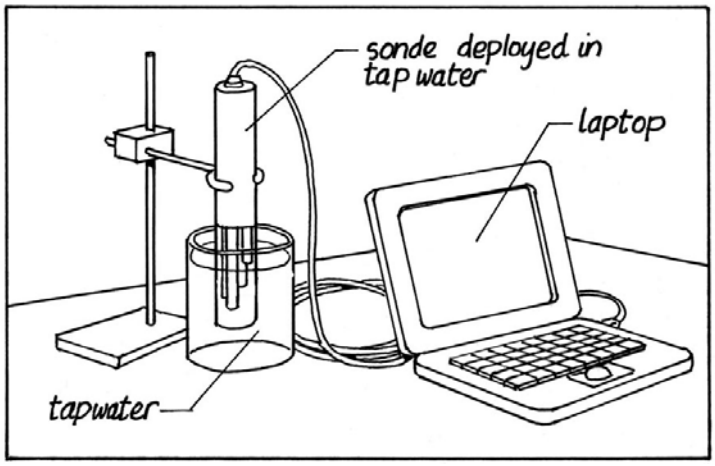

Figure D-16. Put the calibrated sensors in tap water to ensure that they are recording consistent and reasonable values.

D.5.4.7 Prepare the sondes for transport to the field site

The sondes should be transported back to the field site in the same way they were transported from the field site to a stable environment.

Return to the field site to re-deploy the sondes

D.5.5 Field and Laboratory Data, Part 3: At the Field Site – The Re-deployment Visit

There are three steps to the third stage:

1. Obtain the re-deployment data (D4 & D5) "in a bucket of stream water"
2. Re-deploy the sonde and obtain the re-deployment Data (D5 & P5) in situ
3. Prepare the portable sonde for transport

D.5.5.1 Obtain the re-deployment data (D4 & D5) "in a bucket of stream water"

These data are collected to ensure that the deployed sonde is working correctly on-site before the sondes are re-deployed.

1. Collect a stream water sample in a bucket.

2. Place the deployed sonde and portable sonde in the bucket (Figure D-17). Attach an interface cable from the sonde to the laptop or display, and record the data for both the deployed sonde (D4) and the portable sonde (P4) in *RISC CWQ – 04. Field and Laboratory Data Part 1: The pre-cleaning, post-cleaning and re-deployment data.*

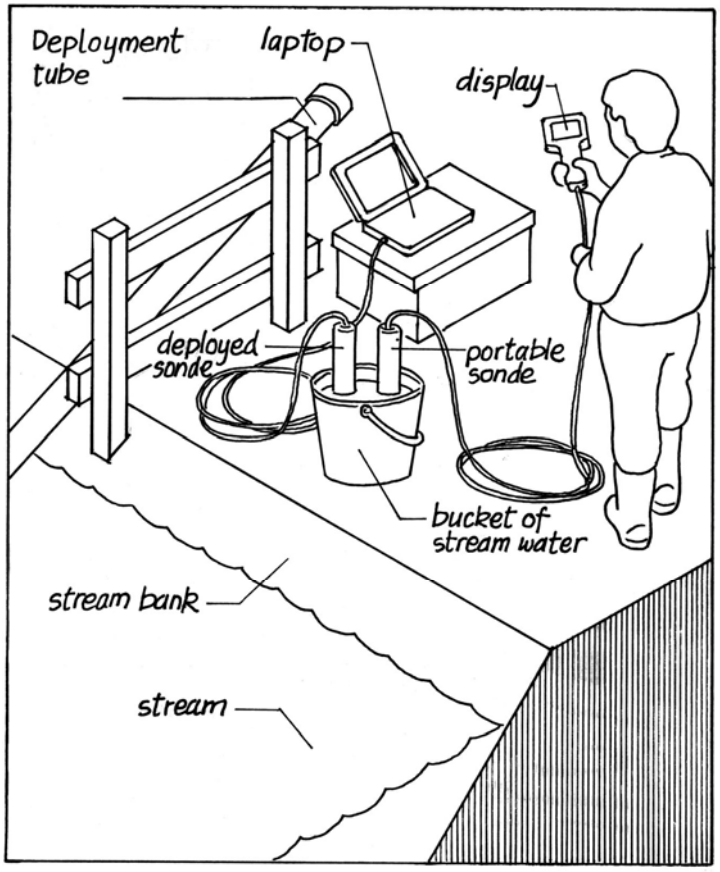

Figure D-17. The deployed sonde and the portable sonde in a bucket of stream water. Note that the deployed sonde is self contained. Also see Figure D-5.

D.5.5.2 Obtain the Re-deployment Data (D5 & P5) in situ

These are the first values for the new set of sampling period data.

1. Deploy the deployed sonde and obtain a reading. Record the readings in column D5 *RISC CWQ – 04. Field and Laboratory Data Part 1: The pre-cleaning, post-cleaning, and re-deployment data.*
   Note:
   - If the deployed sonde is attached to an external data logger (e.g. Figure D-5) it may be necessary to communicate with the data logger and check the operational settings. If this is done, make sure that the settings are returned to the deployed mode after the reading is taken.

2. Put the portable sonde in the second deployment tube (Figure D-18).
   Note:
   - As in the preliminary visit, we recommend that the portable sonde is in a deployment tube as shown in Figure D-18.
   - In cases where the water is slow moving, it may possible to put the portable sonde near the deployed sonde (Figure D-4).

3. Record the readings in P5 of *RISC CWQ – 04. Field and laboratory Data Part1: The pre-cleaning, post-cleaning, and re-deployment data.*

Figure D-18. Deploy the portable sonde in its own deployment tube. Photo: George Butcher

D.5.5.3 Prepare the Portable Sonde for Transport

Remove the portable sonde and prepare it for transport to the next site or to the stable environment. Remember to put the cap on the sonde. If the portable sonde is returned to the stable environment, the sensors must be stored as recommended by the manufacturer.

D.5.5.4 Compete the departure information on RISC CWQ – 02. Station Log and Maintenance Form

This is the same form used to add the arrival information (Section D.5.3.1).

This completes the collection of the field and laboratory data.

E. Validation

"*All things are ready, if our minds be so.*"
William Shakespeare

Validation is the set of procedures used to complete the quality assessment requirements of a continuous water-quality sampling program (Chapter B). It is a systematic evaluation of all of the data (meta and numerical) to find and deal with errors and to assign data grades. The validation process is completed by the operator after each field visit. There are five steps, each of which is explained in a section of this chapter. All of the calculations are completed in Excel programs. The Excel programs for steps 2 and 3 are in Appendix 2 and the programs for steps 4 and 5 are in Appendix 3. Appendix 4 is a check list of the validation steps. The operator should use Appendix 4 to document the completion of each step and to add comments as necessary about the validation results. Ultimately, Appendix 4 will be generated within the data repository (Section E.8).

1. Examine the RISC forms to ensure that they are complete.
2. Determine the data grade for each parameter.
3. Compare field data collected *in situ vs*. "in a bucket of stream water".
4. Examine the sampling period data for data gaps and data anomalies and flag the data, if necessary.
5. Determine the percent of the sampling period data (for each parameter) that are flagged.

Steps 1 to 3 use the field and laboratory data, and steps 4 and 5 use the sampling period data. As in all cases, the laboratory data are those obtained in a stable environment.

This chapter outlines each of the given steps. It concludes with sections on the use of the data grades and the storage of the data and subsequent analyses.

E.1 Validation Step 1 – Examine the RISC Forms

The operator or the person working for the operator completes the RISC Forms. The first step in validation is to confirm that the forms are complete for each station. There are four forms, but only two are completed during each field visit. *RISC CWQ – 01. Station Design* is completed when the station is first established and if any of the equipment is updated or replaced. Similarly, *RISC CWQ – 03. Specifications of the Portable Sensors* is completed initially and then if the sonde or sensors are replaced. Data are added to *RISC CWQ – 02. Station Log and Maintenance Form* and to *RISC – CWQ – 04. Field and Laboratory Data* during each field visit.

The operator should review forms to ensure that they are complete and then check the appropriate boxes and add comments as necessary in the validation summary (Appendix 4).

E.2 Validation Step 2 - Determine the Data Grades

Data grades rate the sensor performance. They are based on sensor error due to fouling and calibration drift. During the laboratory procedures in a stable environment, sensor malfunction will be detected and will be incorporated into the measure of calibration drift.

E.2.1 Criteria for Data Grades

The data grades are based on the accuracies of the sensors, similar to the ratings used by Wagner et al. (2006). Four important points about the data grades are given below.

1. There are *five* levels in Table E-1 (excellent, very good, good, fair, and poor). Each level is a multiple of the accuracy – to the nearest tenth, when applicable – of the sensors commonly used in British Columbia.
   - As sensor technology improves, the grades may be modified. For example, new turbidity sensors have a better accuracy at low turbidity values. These sensors are not yet common in British Columbia so the new accuracy level is not used for the data grade.

2. The accuracy used for specific conductivity is *not* the accuracy given for the conductivity sensors.
   - The accuracy specification for the conductivity probe is ± 0.5% of the reading + 1 µS/cm (e.g. http://www.hydrolab.com; http://www.YSI.com. The criteria chosen for the highest data grade for specific conductivity are ± 3 µS/cm for values ≤ 100 µS/cm and ± 3 % of the reading for values > 100 µS/cm . These criteria exceed the calculated criteria specified by the manufacturers for conductivity, but several factors were considered.
     (a) At low conductivity values 3 % of the reading is less than the resolution and accuracy of the sensors, therefore 3 µS/cm is used.
     (b) Specific conductivity depends on temperature and the ions present. The temperature is measured, but the ions present are not known and thus the algorithm used to determine specific conductivity from conductivity is an approximation.
     (c) Specific conductivity is used as an indication of total dissolved solids. It is not generally a water-quality objective.

3. In cases where the accuracy is specified as a set value or a percent of the reading, whichever is greater, the dividing point where the accuracy goes from the set amount to a percent is given.
   - This applies to dissolved oxygen (0.2 mg/l or 5% of reading, whichever is greater), turbidity (2 NTU or 5% of reading, whichever is greater), and specific conductivity (see above). At levels ≤ 4 mg/l dissolved oxygen, ± 2 mg/l is greater than 5% of the reading. Above 4 mg/l, 5% of the reading is greater than 2 mg/l. Similarly, for turbidity levels ≤ 40 NTU, ± 2 NTU is greater than 5% of the reading and > 40 NTU, 5% of the reading is greater than 2 NTU.

4. No data grades are given for chlorophyll *a* or depth and level.
   - YSI does not give the accuracy for chlorophyll *a*. Hydrolab says ± 3% for signal level equivalents of 1ppb rhodamine WT dye. The operator should develop her/his curve for known levels of chlorophyll *a*.
   - The accuracy of depth and level sensors depends on the sensor type and depth. The operator can develop his/her own data grades. See point number 1.

Table E-1. Data grades are based on sensor error. See text for criteria used to obtain the grades.

Parameter	Data Grade Criteria				
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**
Temperature	≤ ± 0.2 °C	> ± 0.2 to 0.4 °C	> ± 0.4 to 0.6 °C	> ± 0.6 to 0.8 °C	> ± 0.8 °C
Specific conductance (≤ 100 µS/cm)	≤ ± 3µS/cm	> ± 3 to 6 µS/cm	> ± 6 to 9 µS/cm	> ± 9 to 12 µS/cm	> ± 12 µS/cm
Specific conductance (> 100 µS/cm)	≤ ± 3% of reading	> ± 3 to 6% of reading	> ± 6 to 9 % of reading	> ± 9 to 12 % of reading	> ± 12 % of reading
pH	≤ ± 0.2 pH units	> ± 0.2 to 0.4 pH units	> ± 0.4 to 0.6 pH units	> ± 0.6 to 0.8 pH units	> ± 0.8 pH units
Turbidity (≤ 40 NTU)	≤ ± 2 NTU	> ± 2 to 4 NTU	> ± 4 to 6 NTU	> ± 6 to 8 NTU	> ± 8 NTU
Turbidity (> 40 NTU)	≤ ± 5 % of reading	> ± 5 to 10% of reading	> ± 10 to 15% of reading	> ± 15 to 20% of reading	> ± 20% of reading
Dissolved oxygen (≤ 4 mg/l)	≤ ± 0.2 mg/L	> ± 0.2 to 0.4 mg/L	> ± 0.4 to 0.6 mg/L	> ± 0.6 to 0.8 mg/L	> ± 0.8 mg/L
Dissolved oxygen (> 4 mg/l)*	≤ ± 5 % of reading	> ± 5 to 10% of reading	> ± 10 to 15% of reading	> ± 15 to 20% of reading	> ± 20% of reading

* The sensors may be less accurate for values > 20 mg/l.

E.2.2 Calculate and Record the Data Grade

Five steps are required to determine the data grade for each sensor. These are explained below, *but* ***all of the calculations and the assignment of the data grade are completed in the Excel program (Appendix 2)***. The final data grade can be added to the validation summary table (Appendix 4).

1. Calculate fouling.
2. Calculate calibration drift.
3. Change the fouling and calibration drift to a percent of the reading, if required.
4. Use the fouling and the calibration drift values to determine sensor error.
5. Determine and record the data grade.

E.2.2.1 Calculate Fouling

The data that are used to complete the calculations are in *RISC CWQ – 04. Field and Laboratory Data*. These should be transferred to page 1 of the Excel program in Appendix 2. Eventually, this will be completed in the data repository. The reader might want to refer to Figure D-2 and Table D-1 to review the data that are collected.

Option 1: The pre-cleaning data for both sondes (D1 & P1) are collected in situ. The post-cleaning data (D3 and P3) are collected "in a bucket of stream water" that is transported to the stable environment (lab).

(D1 – D3) = *fouling of deployed sensor plus changes in the stream water due to transport to the stable environment*. Although stream water is used for both measurements, the pre-cleaning data are collected in situ and the post-cleaning data are collected "in a bucket of stream water" that is transported to the lab.

(P1 – P3) = *Change in stream water due to transport to the stable environment*.

(D1 – D3) – (P1 – P3) = *fouling* (**F**). The change in stream water due to transport to the stable environment is subtracted from the fouling plus the change in the stream water.

Option 2: The pre-cleaning data for both sondes (D2 & P2) are collected "in a bucket of stream water". The post-cleaning data (D3 and P3) are collected "in a bucket of stream water" that is transported to the stable environment.

(D2 – D3) = f*ouling of deployed sensor plus changes in stream water due to transport to the stable environment*. The explanation is the same as for (D1 – D3), except that the pre-cleaning data are obtained with the sonde "in a bucket of stream water".

(P2 – P3) = *Change in stream water due to transport to the stable environment*.

(D2 – D3) – (P2 – P3) = *fouling* (**F**). The change in stream water due to transport to the stable environment is subtracted from the fouling plus the change in the stream water.

E.2.2.2 Calculate Calibration Drift

(C1 – C2) = *calibration drift* (**CD**) in standard calibration solutions.

Note:

- (D3 – P3) is the difference between the cleaned deployed sensor and the cleaned and calibrated portable sensor. Therefore it is a measure of calibration drift in stream water plus differences between sensors. This calculation is not included in Appendix 2, but the operator might want to compare the difference to (C1 – C2).

E.2.2.3 Change the total amount to a percent of the reading, if required.

The data grades are expressed either as a set value or as a percentage of the reading (Table E-1). The grades for temperature and pH are always a set value, whereas those for specific conductivity, turbidity, and dissolved oxygen are a percentage of the reading, except at the low end of the range. The difference - specific amount *vs*. percentage of the reading - is a result of the type of relationship between the observed and the expected values as the concentration increases (Figure E-1). In cases where the observed value is a consistent percent greater or less than the expected value, the actual deviation increases as the concentration of the parameter increases (Figure E.1a). In other cases, the observed value is a consistent amount less or greater than the expected value (Figure E.1b).

In cases where there is both a set value and a percent, the set value is used at the lower concentrations due to the decreased accuracy (increased possible electrical noise) of the sensors at the extremes (e.g. low end) of the measurement range (Section C.2.1).

Determine fouling as a percent of the reading

Fouling as a percentage of the reading is the observed value minus the expected value divided by the observed value, converted to a percent. The observed value minus the expected value is the arithmetical difference. It is the fouling (F) that is calculated as shown in Section E.2.2.1. The observed value is D1 (pre-cleaning value in situ) in option 1 and D2 (pre-cleaning value "in a bucket of stream water" in option 2. The calculation for options 1 and options 2 are given below.

Option 1

Fouling as a % of the reading = 100 (F / D1)

Where:

F = (D1 – D3) – (P1 – P3) from Section E.2.2.1

D1 = pre-cleaning value of the parameter *in situ*

Option 2

Fouling as a % of the reading = 100 (F / D2)

Where:

F = (D2 – D3) – (P2 – P3) from Section E.2.2.1

D2 = pre-cleaning "in a bucket of stream water"

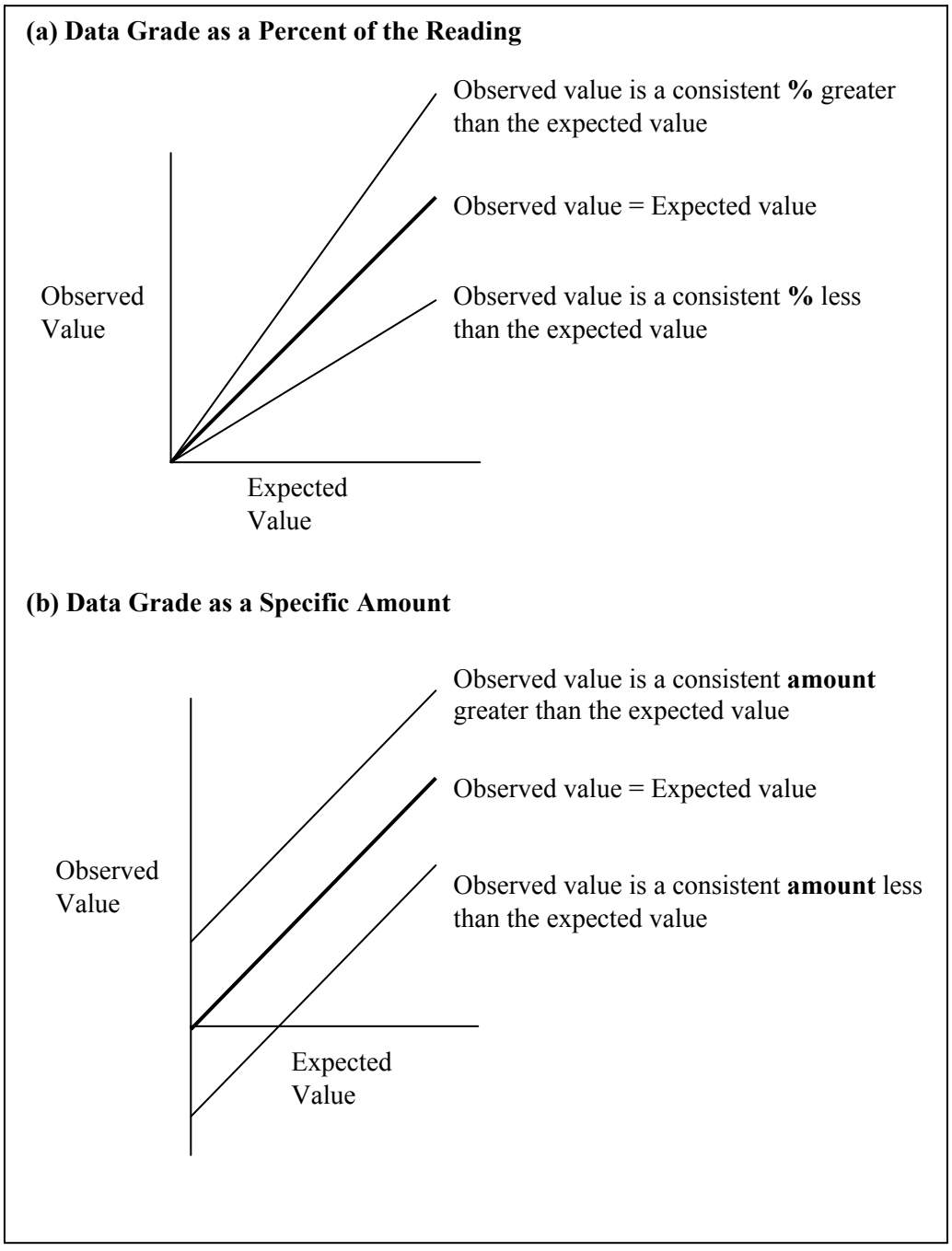

Figure E-1. The relationship between the observed values and expected values when for parameters for which the data grade is (a)a percentage of the reading and (b) a specific amount. See text for details.

Determine calibration drift as a percentage of the reading

Calibration drift as a percentage of the reading = 100 (CD / C1)

Where:
CD = calibration drift from Section E.2.2.2
C1 = value from cleaned sensor before calibration

E.2.2.4 Use the fouling and the calibration drift values to determine sensor error.
Sensor error is used to obtain the data grade. It is either a set amount or as a percentage of the reading. In both cases (set amount and % of reading), it is the sum of the absolute values of the two sources of error. The absolute values are used so that the two errors are not artificially reduced or cancelled. Separation of the sources of error is important in assessing how the data should be corrected.

Sensor error as a set value
Sensor error = |F| + |CD|

Where:
F is from option 1 or 2 in Section E.2.2.1
CD is from Section E.2.2.2

Sensor error as a percentage of the reading
Sensor error = |F as a % of the reading| + |CD as a % of the reading|

Where
F as a % of the reading is from option 1 or 2 in Section E.2.2.3
CD as a % of the reading is from Section E.2.2.3

E. 2.2.5 Determine and record the data grade.
The sensor error is compared to values for the different grades in Table E-1. The data grade is recorded in Appendix 4.

E.3 Validation Step 3 - Compare data obtained in situ with those obtained "in a bucket of stream water".

There are two times that the measurements are made both in situ and "in a bucket of stream water". These two sets of data are collected during the visits to the field site to obtain the pre-cleaning data and the re-deployment data.

The comparisons are completed by the Excel program in Appendix 2. In all cases, the difference between the two readings is divided by the accuracy of the sensor. This is the value given for the "excellent" data grade. If the resulting value is ≤ 2, the comparison is acceptable. This means that the difference is equal to or less than two time times the accuracy of the sensor. The two is used because the data are from two sensors (portable and deployed). The differences between the two sensors should cancel out in the calculations, but 2 times the accuracy is used to ensure that positive (acceptable) results are not rejected.

Both the in situ and "in a bucket of stream water" measurements are taken for the first three or four visits to the site. If the differences are acceptable for the data collected during these three to four visits, the operator can use the procedure he/she finds most appropriate for a given site. If the comparisons are not acceptable, the operator should use her/his knowledge of the equipment and the site to determine why the comparisons are different. Some reasons for an unacceptable comparison are listed below.

- A malfunctioning sensor in either the deployed or the portable sonde
- Rapidly changing in-stream conditions
- Bubbles on the sensor
- A dirty deployment tube
  - Recall that the deployment tube must be cleaned at the end of the preliminary field visit. Debris in the tube may be added to the sonde as it is removed. This would affect the pre-cleaning values "in a bucket of stream water"
  - If the tube is not properly cleaned, the sonde and sensors may collect debris during the re-deployment and this would affect the *in situ* readings
- Improper flow across the bottom of the deployment tube(s)
  - This may be due to sediment deposition, some upstream blockage of water flow, or a poorly designed deployment tube (Figure E-2)

Both options should be continued until the operator can reasonably explain the differences.

Figure E-2. A poorly designed deployment tube. The section of the tube that covers the guard of the sonde is a heavy metal with slots that are easily clogged with debris, preventing a good flow of water across the tube. Photo: George Butcher.

E.3.1 Comparison of pre-cleaning data obtained in situ *vs*. "in a bucket of stream water"

As a set value

((D1 – P1) – (D2 – P2)) / accuracy of the sensor

As a percent of the reading

((100(D1 – P1) / D1) – (100(D2 – P2) / D2)) / accuracy of the sensor

Where:
(D1 – P1) = the difference between the pre-cleaning value of the deployed sensor and the portable sensor measured *in situ*
(D2 – P2) = difference between the pre-cleaning value of the deployed sensor and the portable sensor measured "in a bucket of stream water".

E.3.1 Comparison of re-deployment data obtained in situ *vs.* "in a bucket of stream water"

As a set value
((D4 – P4) – (D5 – P5)) / accuracy of the sensor

As a percent of the reading
((100(D4 – P4) / D4) – (100(D5 – P5) / D5)) / accuracy of the sensor

Where:
(D4 – P4) = the difference between the re-deployment value of the deployed sensor and the portable sensor measured *in situ.*

(D5 – P5) = difference between the re-deployment value of the deployed sensor and the portable sensor measured "in a bucket of stream water".

This is a final check that the sensors are functioning properly and that there is no effect due to re-deploying the sonde. ***The D5 values are the start of a new set of sampling period data***.

E.4 Validation Step 4– Examine the Sampling Period Data

The sampling period data are the data collected on a data logger while the operator is absent. These data provide information about the water chemistry of the stream. If there is minimal sensor error and the data grade for the sensors is excellent, the sampling period data should be excellent. However, the sampling period data should be plotted and examined for unreasonable values, abrupt changes, prolonged changes, and data gaps. These are discussed below.

E.4.1 Unreasonable (Suspect) Values

Some sampling period data may be unreasonable or suspect and should be flagged and removed from subsequent analyses. Four categories used to identify unreasonable values. The abbreviations used in the tables and the Excel program are the check (✓) statements.

- Values that exceed the range of a sensor. This is called ✓range.
- Values that are truncated. This is called ✓truncation.
- Cases in which adjacent values exceed the accuracy of the sensor. This is called ✓accuracy.
- Values that are negative - except for temperature.

The criteria and calculations for each of these categories are discussed in the following four sections. The sampling period data are added to the Excel program in Appendix 3. These are done after each field visit and thus the sampling period data should be easily accommodated

in the Excel spreadsheet. Note that there is one sheet for each parameter. After the data are flagged, ***it is the responsibility of the operator to accept or reject the flagged data.***

The criteria used to check for unreasonable (suspect) data are based on the information for the sensors commonly used in British Columbia. The accuracy and range of the sensors is given in RISC CWQ – 01. Station Design. If any of these criteria differ from the ones used in the Excel programs, they can be modified, but *only after consultation with Ministry of Environment staff*.

E.4.1.1 Values exceed the range of the sensors
The Excel program given in Appendix 3 uses the heading ✓range to flag values that exceed the range of each sensor. The criteria for the main sensors that are incorporated into the Excel program are summarized in Table E.2.

E.4.1.2 Truncated values
The Excel program in Appendix 3 uses the column heading ✓truncation to determine if values are truncated. This occurs when the sampling period data values exceed the range of the sensors. If a spike stays at the upper or lower range of the sensor, the values may be truncated. The criteria used in the Excel program are summarized in Table E-3.

E.4.1.3 Adjacent measurements exceed accuracy range of the sensor.
The Excel program in Appendix 3 uses the column heading ✓accuracy for this test. The criteria incorporated into the Excel program are based on the sensors commonly used in British Columbia. These are summarized in Table E-4.

E.4.1.4 Negative Values (except temperature)
This will be apparent in the ✓range test below, because the low range is zero, except for temperature. If the turbidity is very low negative values may result; it should be checked by the operator.

Table E-2. Criteria used to flag sampling period data that are off scale (✓range)

Parameter	Units	✓range
Temperature	° C	If temperature = < -5 or > 45°C, flag the value. If not, use the given value.
Specific Conductivity	µS/cm	If spec. cond. < 0 or > 100 000, flag the value. If not, use the given value.
pH	pH units	If pH < 0 or > 14, flag the value. If not, use the given value.
Turbidity	NTU	If turbidity < 0 NTU or > 1000 NTU, flag the value. If not, use the given value.
Dissolved Oxygen	mg/l	If DO < 0 mg/L or > 50 mg/L, flag the data If not, use the given value.

Table E-3. Criteria used in ✓ truncation to determine if the values are truncated.

Parameter	Units	✓truncation
Temperature	° C	If temperature = -5 or 45°C, flag the value. If not, use the given value.
Specific Conductivity	µS/cm	If spec. cond. = 0 or 100 000, flag the value. If not, use the given value.
pH	pH units	If pH = 0 or 14, flag the value. If not, use the given value.
Turbidity	NTU	If turbidity = NTU or 1000 NTU, flag the value. If not, use the given value.
Dissolved Oxygen	mg/l	If DO = 0 mg/L or 50 mg/L, flag the data If not, use the given value.

Table E-4. Criteria used in ✓ accuracy (Appendix 3) to determine if adjacent measurements exceed the accuracy range of the sensors.

Parameter	Units	✓accuracy
Temperature	° C	If the difference in temperature between adjacent values is > 0.2, flag the first value. If not, use the given value.
Specific Conductivity	≤100 µS/cm	It the difference in spec. cond. between adjacent values, is > 3, flag the value. If not, use the given value.
	> 100 µS/cm	It the difference between adjacent spec. cond. values, divided by the first of the two values, is > 0.03, flag the value. If not, use the given value.
pH	pH units	If the difference in pH between adjacent values is > 0.2, flag the first value. If not, use the given value.
Turbidity	≤ 40 NTU	If the difference in turbidity between adjacent values is > 2, flag the value. If not, use the given value.
	> 40 NTU	If the difference between adjacent turbidity values, divided by the first (of the two) values, is > 0.05, flag the value. If not, use the given value.
Dissolved Oxygen*	mg/l	If the difference between adjacent dissolved oxygen values, divided by the first (of the two) values, is > 0.05, flag the value. If not, use the given value.

* ✓accuracy for dissolve oxygen is checked only for the accuracy of 5% of the reading.

E.4.2 Abrupt Changes

Abrupt changes in the levels of different parameters are frequently related to changes in flow, but may also be affected by groundwater input and biological activity. If possible, the reason for the abrupt change should be documented. If there is no apparent reason for the abrupt change, the value(s) should be flagged. This should be apparent from the flags in ✓accuracy.

E.4.3 Prolonged Changes

Prolonged changes may be due to an in-stream event that damaged the sensor, fouled the sensor, or to a malfunctioning sensor. This may be apparent in a sudden and continued increase (e.g. turbidity), a gradual decrease (e.g. dissolved oxygen), or inconsistent (unstable) readings (e.g. pH or specific conductivity). This should be apparent from the data grade. It can be used to assist in correcting the data because the starting point of the change can be identified.

E.4.4 Data Gaps

Missing data may prevent reliable calculations of the daily mean, mean minimum or mean maximum, which is particularly important if these daily results are published on-line as they are frequently done for data collected by the United States Geological Survey (Wagner et al. (2006). Therefore Wagener et al. (2006) provide criteria for allowable missing data. In British Columbia, there is not yet any protocol for the on-line publication of water-quality data. However, data gaps may also prevent accurate calculations of more long term data summaries – monthly mean, mean minimum, mean maximum – and should be considered before the data are released.

Data gaps may be due to malfunctioning or damaged equipment, which should be reflected in the data grades, and may be apparent from the station log and maintenance record and the field notes. However, the data gaps should be flagged and quantified. This is done in the Excel program in Appendix 3.

The importance of the cumulative effect on the monitoring data due to unreasonable values, abrupt changes, prolonged changes, and data gaps is considered in the following section.

E.5 Validation Step 5 – Determine the Percentage of the Sampling Period Data (for each parameter) that are Flagged

The data grade represents the sensor performance at the time of the field visit. A high data grade does not obviate the presence of unreasonable values in the sampling period data (Section E.4). For example, the sensor may be out of water, or unexpected high values that exceed the range of the sensors may occur even though the sensor is functioning accurately. In all cases, these values must be flagged and not used in subsequent calculations. This is completed in the Excel program in Appendix 3. The Excel program in Appendix 3 also identifies data gaps, gives the number of flags per parameter per sample point, and indicates whether the parameter at the end of each sampling period is flagged. The percentage of the sampling period data that is flagged is simply the number of flags divided by the number of data points.

E.6 Validation Report & Release of Sampling Period Data

The results of the five validation steps must be summarized in Appendix 4. This step is completed by the operator, although it should ultimately be generated within the data repository. Once the data are validated, they are available for release to the public. The data grades are released with the data. *Flagged data that are confirmed by the operator as unreasonable should not be released*.

E.7 Use of the Data Grades and Data Comparisons

The data grades and data comparisons provide quantitative information on the length of the sampling period, the quality of the sampling period data, and the accuracy of the re-deployed sensors. Each of these is explained below.

Length of the sampling Period

The data grades are calculated *after each field visit*. If the grades for one or more of the parameters are consistently low, the operator can identify the error and modify the sampling schedule accordingly. For example, if the data grade is low due to extensive fouling, the operator should decrease the time between field visits. If the grade is consistently high, the operator may increase the time between field visits.

Quality of the sampling period data

The data grades measure sensor error at the end of the sampling period. An excellent or very good data grade indicates that the sensors are operating correctly and the sampling period data are not affected by sensor malfunction, calibration drift, or fouling. This does not obviate some event during the sampling period that may have produced unexpected results, but it does mean the operator can be *confident about the quality of the data.*

Accuracy of the re-deployed sensors

The procedures and calculations in this manual give *quantitative* information on the performance of the sensors when they are re-deployed. In all cases they are re-calibrated. This means that the sampling period data obtained at the beginning of the sampling period – when the sensors are re-deployed – have no sensor error.

E.8 Data Storage and Subsequent Analyses

The RISC forms in Appendix 1 will be contained in a data storage system (currently WIDM). The calculations that are presently completed in Excel (Appendices 2 & 3) will be stored in this database, as will subsequent calculations. The components of this storage system as they relate to the information collected during these standards operating procedures are summarized in Figure E-3.

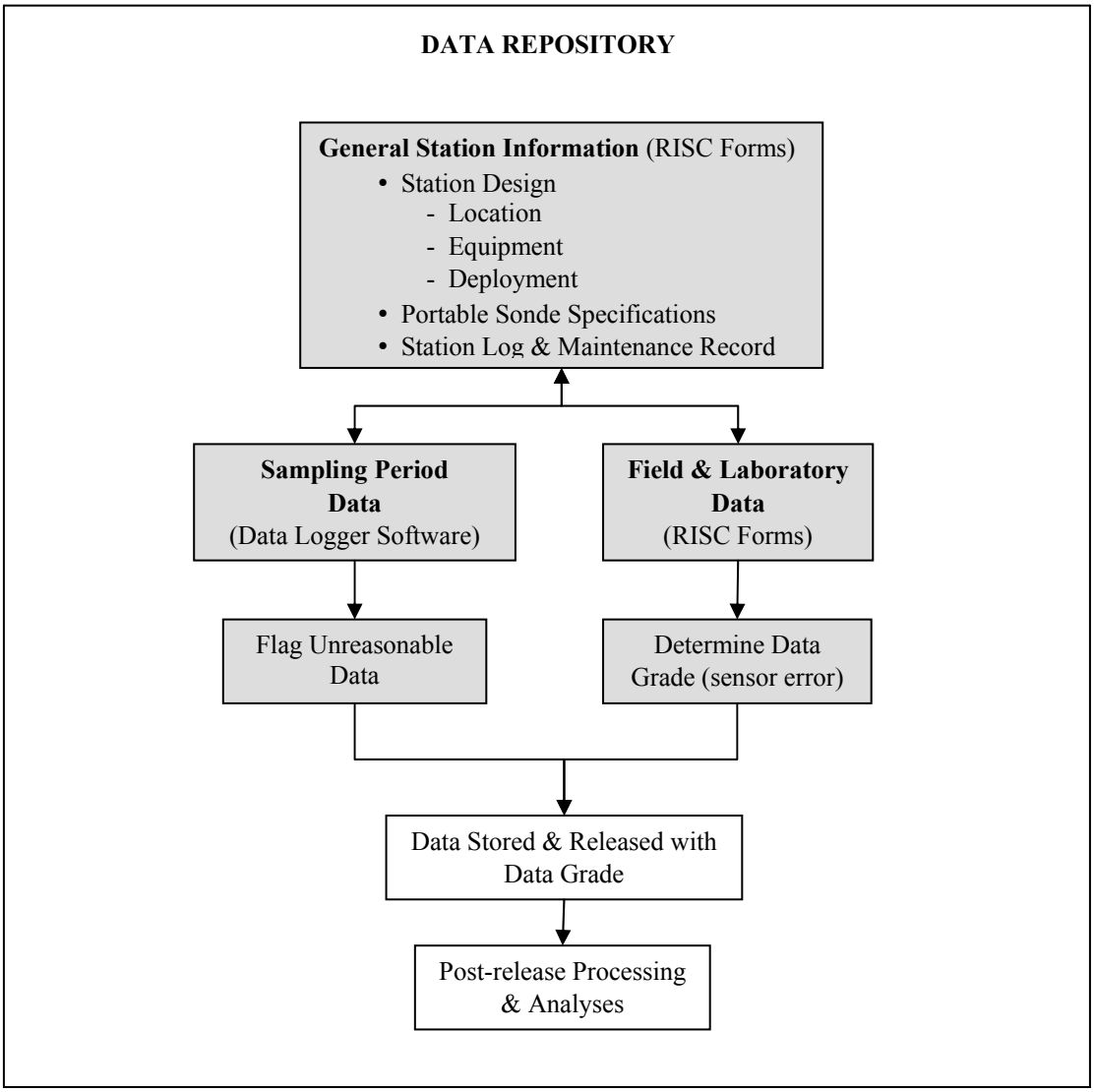

Figure E-3. An outline of the storage and flow of the meta data, sampling period data and field and laboratory data in a data storage system. The shaded boxes represent the data collected, recorded and/or analyzed according to the procedures given in this manual.

**** The laboratory is the stable environment.***

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G. Glossary of Terms

"*Words are tools which automatically carve concepts out of experience*."
Julian S. Huxley

Accuracy: The difference between the reading in a standard solution and the true value.

Calibration drift: The change in the response of the sensors over time. It may be due to electronic drift in the equipment or sensitivity loss.

Data grades: Quantitative ranking of sensor performance based on the extent of sensor error at the time of the field visit.

Data logger: An instrument used to record the monitoring data. It may be internal or external.

Deployed sonde: The sonde that is deployed at the sampling site. It collects the monitoring data.

Deployment: The way in which the stream water comes in contact with the sensors. Deployment method is the way that the sensors are placed in the stream.

Deployment tube: A tube used to house and thus protect the deployed sonde and flexible cable.

Field and laboratory data: Data collected on-site and in a stable environment, respectively, at intervals during the monitoring period.

Fouling: The accumulation of sediment or algal deposits on the active surface of the sensors or the presence of vegetation, debris or insects within the sensor guard.

Laboratory samples: Discrete water-quality samples collected and submitted to a certified laboratory.

Life span (of a sensor): The expected time period that a sensor will operate effectively.

Meta-data: The written non-quantitative information recorded during the field and laboratory procedures. They include the results of the site and sensor inspections, the sources of calibration standards, and any photographs taken during the field visits.

Operating environment (of a sensor): The medium, temperature, and depth in which a sensor can operate effectively.

Operator: The person in charge of the sampling site. He or she may not be the one who collects the data but he / she is ultimately responsible for ensuring that the data are recorded, validated and corrected.

Pool: Areas in a stream that are deeper and have a slower velocity than other areas, and have a concave shaped bottom, a near-zero gradient on top, and relative fine sediment.

Portable sonde: A sonde that has sensors with the same accuracy, resolution and range as the deployed sonde. It is moved from site to site during each filed visit.

Quality assessment: The system of activities used to ensure that the quality assurance procedures are implemented and the quality control elements are evaluated.

Quality assurance: All of the procedures used to *control* the components of a water-quality sampling program.

Quality control: All of the data collected and used to measure bias and variability.

Range: The lowest to the highest values that a sensor can detect with the same resolution and accuracy.

Resources Inventory Standards Committee (RISC): A committee that ensures that required standard method are developed and used in environmental sampling.

Resolution: The smallest interval that a sensor can detect.

Sampling period: The time between field visits.

Sampling period data: The data that are collected on-site while the operator is absent and stored in an internal or external data logger.

Sensor: An instrument used to measure one or more water-quality parameter.

Sensor error: Incorrect readings due to fouling, calibration drift, noise, or malfunction of the sensor.

Sensor malfunction: Inaccurate sensor readings due to physical damage to the sensor or to the connections between the sensor and the data logger. Sensor malfunction can also occur if the sensors are out of water.

Sensor noise: Changes in the response of a sensor due to external influences (e.g. power lines and magnetic fields), sensor sensitivity, and direct and reflected sunlight.

Sonde: An instrument that contains ports for several sensors.

Standard calibration solutions: Solutions supplied by the manufacturer that have known and consistent characteristics.

Stable environment: A laboratory or office with appropriate facilities to clean, calibrate and inspect the sampling equipment and with a controlled temperature and good lighting.

Validation: The set of procedures used to complete the quality assessment requirements of a continuous water-quality sampling program. It is a systematic evaluation of all of the data (meta and numerical) to find and deal with errors and to assign data grades.

Conversion Relationship between Nephelometric Turbidity Units (NTU) into mg/l for Alberta Transportations' Turbidity specification

Conversion of Nephelometric Turbidity Units (NTU) into mg/l for Alberta Transportations turbidity specification is required since NTU is used as a surrogate for Total Suspended Solids (TSS) because it can be measured immediately in the field. NTU can then be converted into TSS once the relationship is formed.

TSS has the most impact on fish and fish habitat. An NTU instrument measures the particles of matter that are naturally suspended in water and these particles can be clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Turbidity is a measurement of how light scatters when it is aimed at water and bounces off the suspended particles. It is not a measurement of the particles themselves.

Basically the NTU /TSS relationship is interpreted by linear regression analysis.
The relationship between suspended solids and turbidity is unique to each instrument and each construction site, so instruments must be calibrated prior to field deployment.

Procedure:

Step 1

Calibrate the turbidity meter according to manufacturer's instructions. Preferably a 3-point calibration is conducted with fresh calibration standards of known value, typically 0, 40 and 400 NTU. Calibration standards are available from laboratory suppliers, or the calibration can be done by laboratories that typically conduct turbidity tests.

Step 2

Obtain two 20 litre pails of water from the waterbody being worked in. The samples should be allowed to settle for approximately 1 hour or until all suspended sediment is removed from the water column.

Step 3

Prepare a 1 kg slurry of fine material that is expected to be introduced to the waterbody by construction activities. Depending upon the monitoring distance downstream of the activity this may vary from fine sand to just silt and clay sizes. The slurry can be an amalgam of fines from the bed, bank and borrow.

Step 4

In one of the 20 litre pails measure and record the turbidity of the settled water. Extract a water sample for laboratory testing of TSS.

Step 5

Increase the level of suspended solids by introducing a small amount of the prepared slurry to the pail. Stir vigorously to ensure a homogeneous mixture. Measure and record

the turbidity, then extract a water sample for laboratory testing. Continuous stirring may be necessary to keep sand size particles in suspension during this step.

Repeat Step 5 to obtain sufficient points to derive the NTU-TSS relationship similar to Figure 1. Ideally five points should be obtained with readings below 15 NTU and at least five additional points below 500 NTU. At least 20 samples (or more if needed) should be used in total to develop the linear relationship within an R^2 correlation coefficient of at least 85%. .

The second pail of water can be used to temper the solution so a particular NTU reading can be obtained. Most instruments fail to respond, or 'blind', above a certain level, typically 1000 NTU for those intended for use in natural water bodies.

Turbid water samples should be sent to a qualified laboratory for total suspended solids testing (ASTM D3977 or similar). Once laboratory results have been obtained, the data can be plotted and an interpolated equation derived. This relationship is a simple straight line fit with a zero intercept unless the native waterbody has high background turbidity from chemical staining or dissolved solids, in which case the relationship will have a turbidity offset.

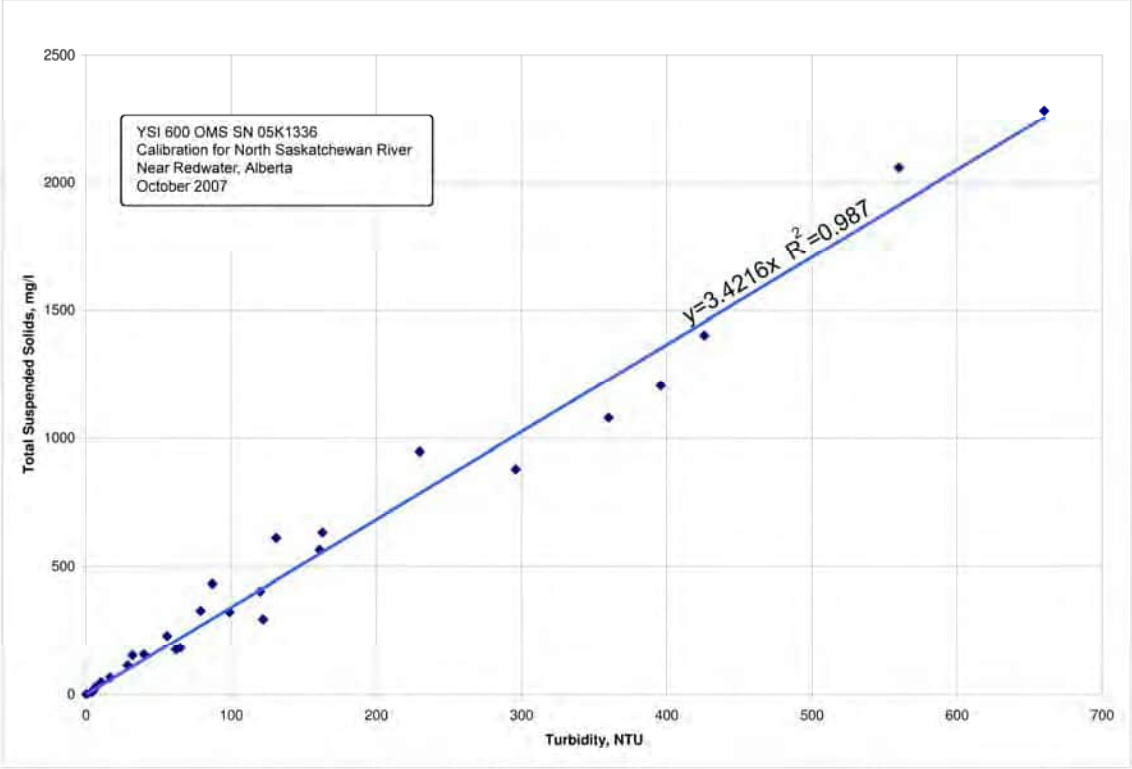

Figure 1 The TSS-NTU Relationship

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.

Link to Part D3

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.

[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.

[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.

[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).

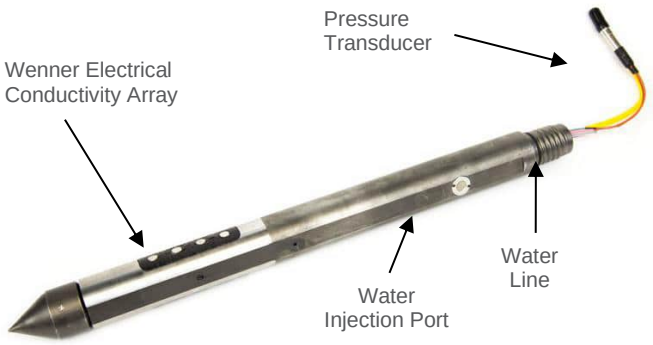

Figure 2.1: Components of an HPT probe.
(Courtesy Geoprobe® https://geoprobe.com/hpt-hydraulic-profiling-tool)

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).

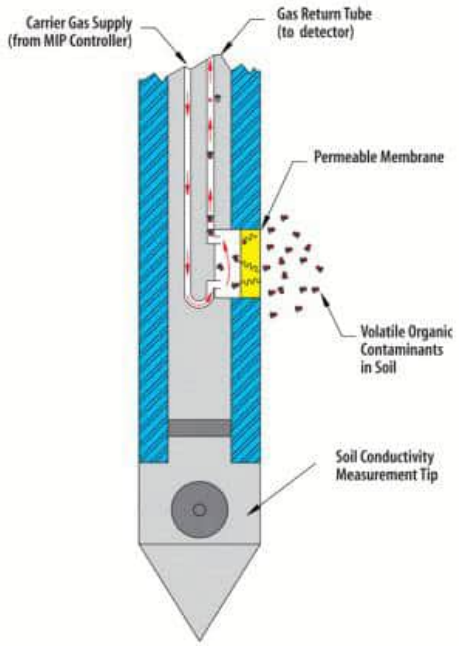

Figure 2.2: The components and operation of a membrane interface probe (Courtesy Geoprobe®).

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

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).

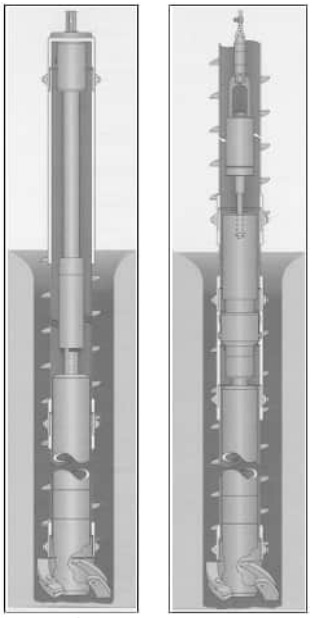

Figure 3.1: Hollow Stem Augers a) Rod and, b) Wire line (US Bureau of Reclamation,1998).

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.

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.

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

3.1.3.3 ODEX – Percussion Down-the-Hole Hammer

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.

Figure 3.3: ODEX drill bit.

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;

[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

[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").

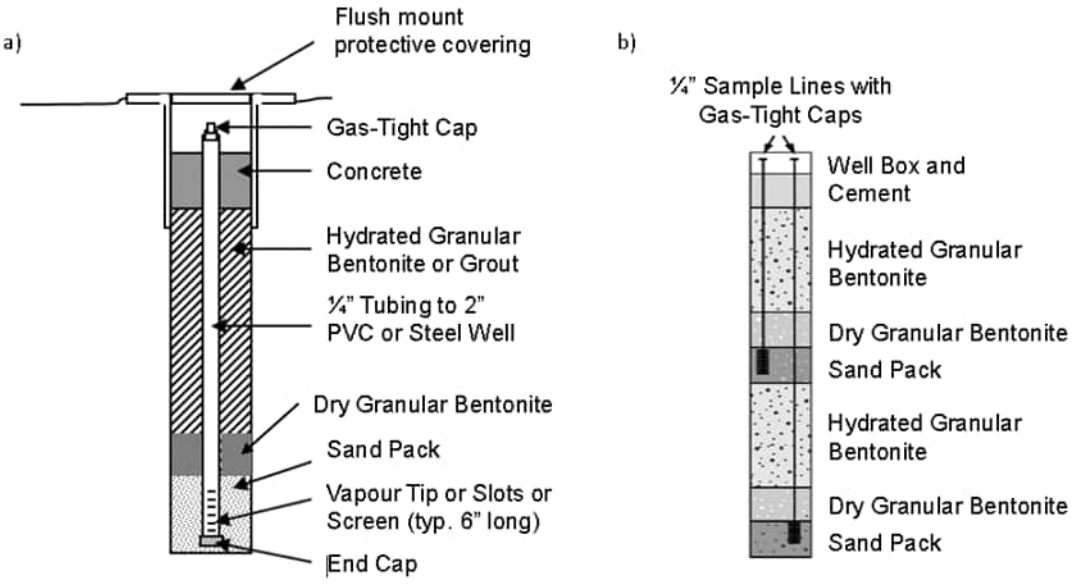

Figure 4.1: Typical drilled vapour well completion details: a) Single well, and b) Multi-well (ASTM D7663, 2012).

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.

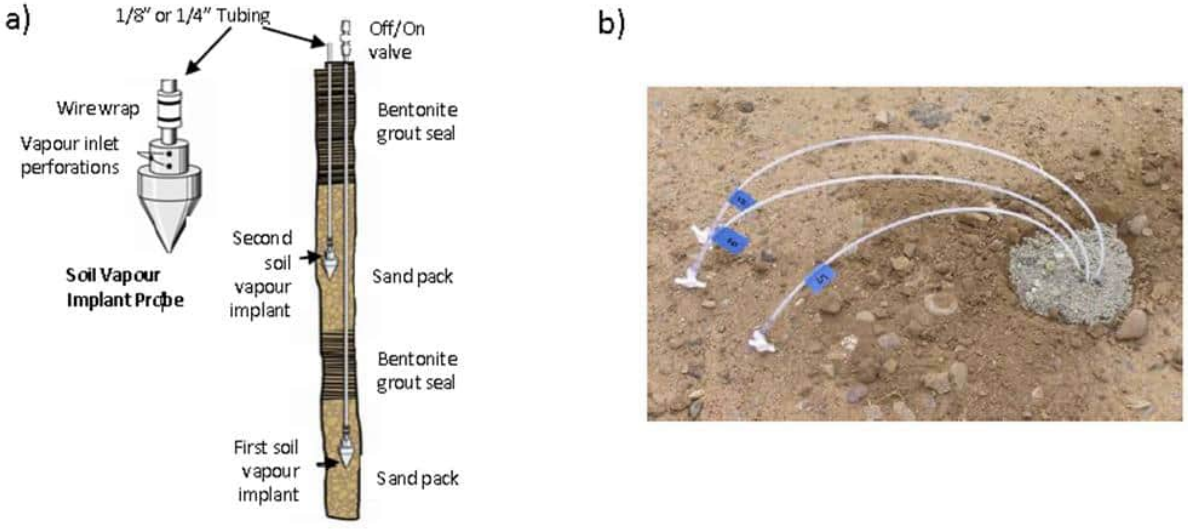

Figure 4.2: Example of multi-level soil vapour well installations (adapted from IRTC, 2014), a) Schematic of tip and tubing system; and, b) Surface completion of a temporary multi-level installation.

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.

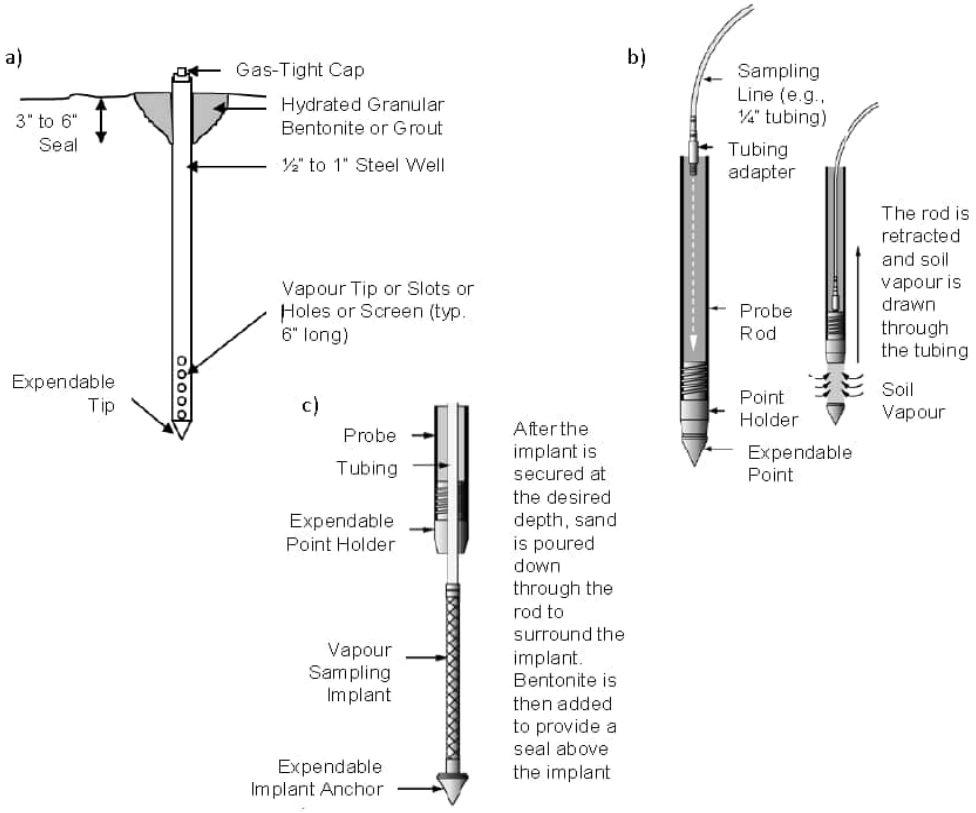

Figure 4.3: Direct-push and hand-driven Soil Vapour Well schematics (Figure adapted from ASTM D7663, 2012) a) Vapour tip and tubing installation; and, b) Drive point installation.

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 or 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.

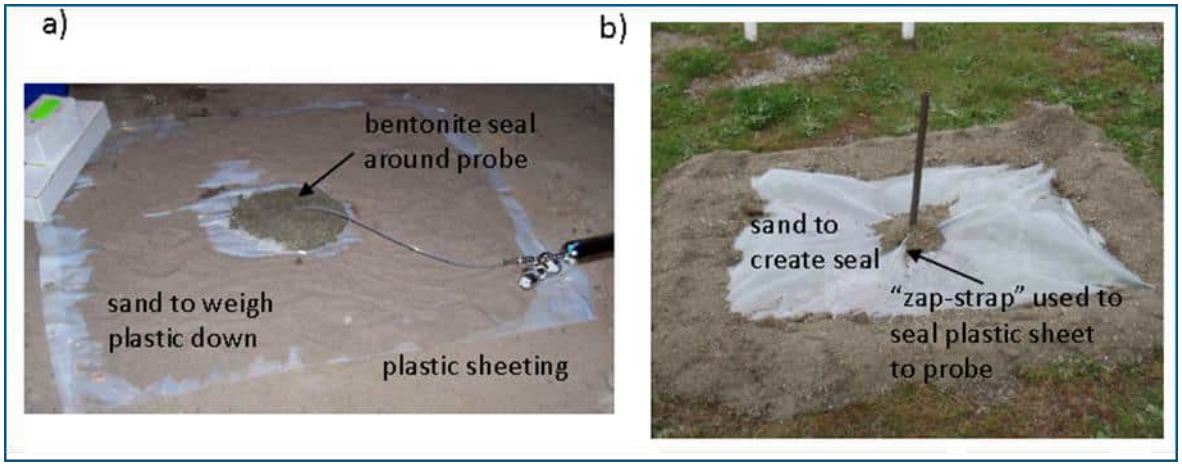

Figure 4.4: Temporary soil vapour well surface seals a) Hand-driven, b) Direct-push, and c) Direct-push screened interval. (Figure adapted from NY DOH, 2005).

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).

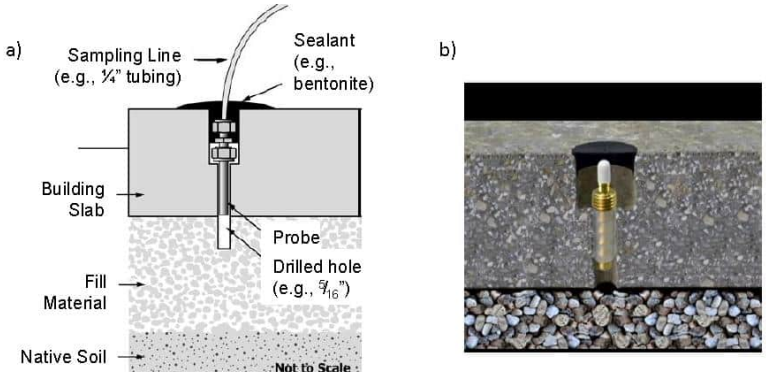

Figure 4.5: Soil vapour probe sub-slab installations: a) sub-slab probe (adapted from ASTM D7663, 2012), and; b) Vapour Pin® (Cox Colvin).

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.

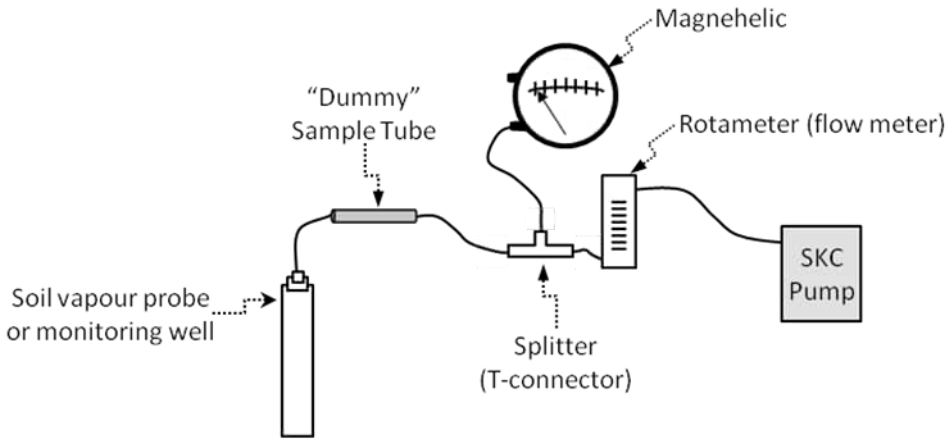

Figure 4.6: Schematic / Configuration of apparatus for a flow and vacuum test.

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.

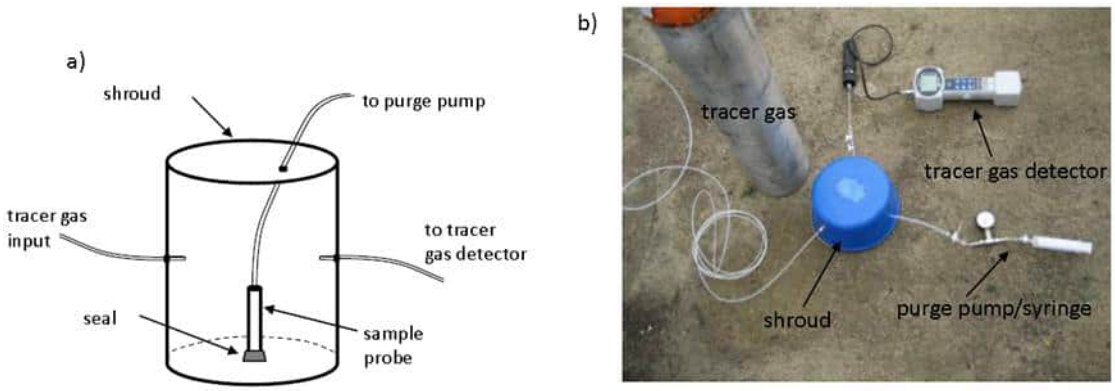

Figure 4.7: Example of a typical leak test set-up using a tracer gas. (Figure adapted from H&P Mobile Chemistry) a) schematic and b) example of tracer gas shroud over vapour probe

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).

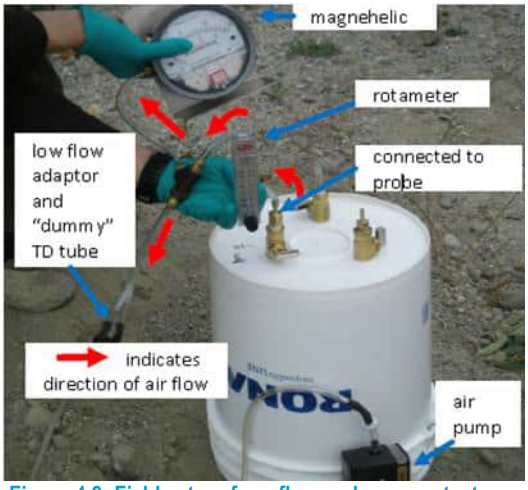

Figure 4.8: Field set-up for a flow and vacuum test.

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.

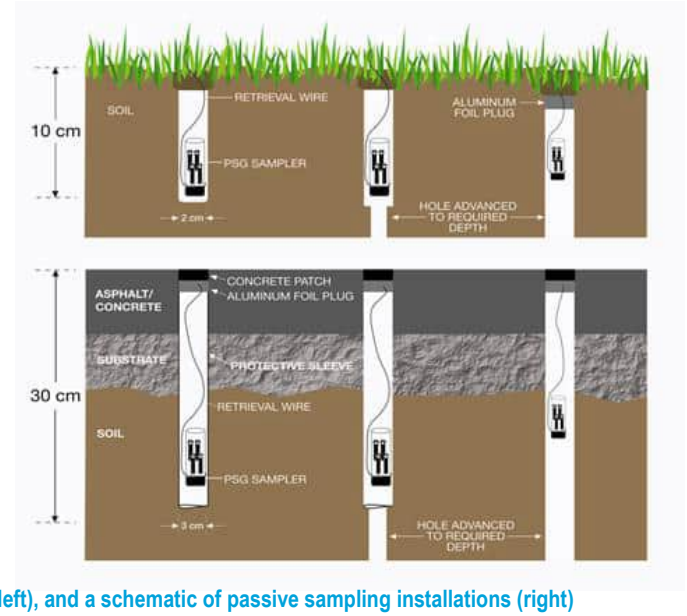

Figure 4.9: Example of a passive soil gas (PSG) sampler (left), and a schematic of passive sampling installations (right) (Figure adapted from: O’Neill, Harry, (2018) Passive Soil Gas Testing: Standard for Site Characterization).

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

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.

Figure 1. Surficial soil sample collection for soil classification.

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:

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.

Figure 1. Chip tray used for sample storage.

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)

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.

Figure 2. RKI MiniRae 3000 PID

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 before 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

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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:

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 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™, Easy Draw Syringe™, Power Stop Handle™) and immediately placed into methanol pre-preserved vials; or with a disposable sampler (e.g., EnCore™). 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™ 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™ 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).

Figure 3. Vibrasonic drill bit.

Field Equipment provided by personnel:

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

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.

Figure 8. Direct push track-mounted drilling rig.

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:

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™ 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.

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

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.


Figure 4. Check methanol fill line.

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.

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.


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

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.

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°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.

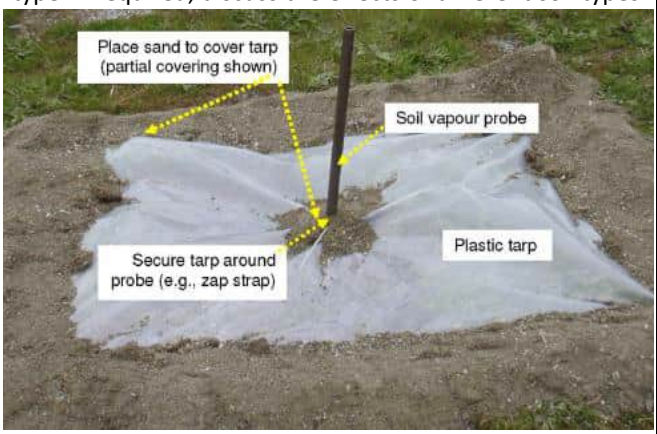

Figure 1. Secured surface seal around soil vapour probe.

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.

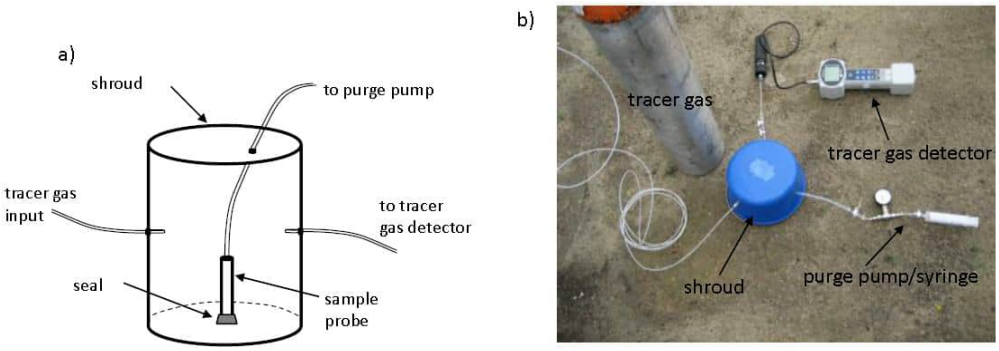

Figure 2. Typical pre-test set-ups: a) schematic and b) example of a shroud over a vapour probe (adapted from H&P Mobile Geochemistry. 2018).

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).

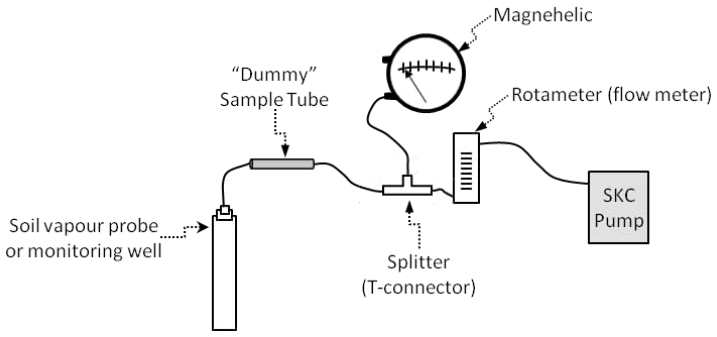

Figure 3. Configuration of a flow and vacuum test apparatus.

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).

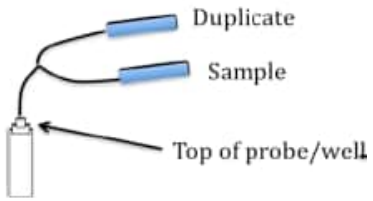

Figure 4: Schematic of duplicate sampling.

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.

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Revision History: 0.0 (New document)

Approval

The British Columbia Field Sampling Manual

Part D2

Sediment Sampling

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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.

[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.

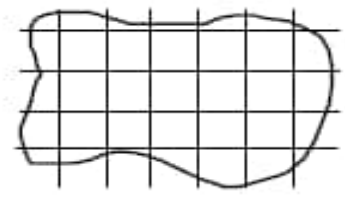
1.1.1.3 Probability-Based Sampling

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.

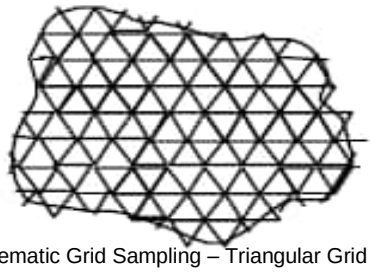
1.1.1.3.1 Gridded Sampling

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.

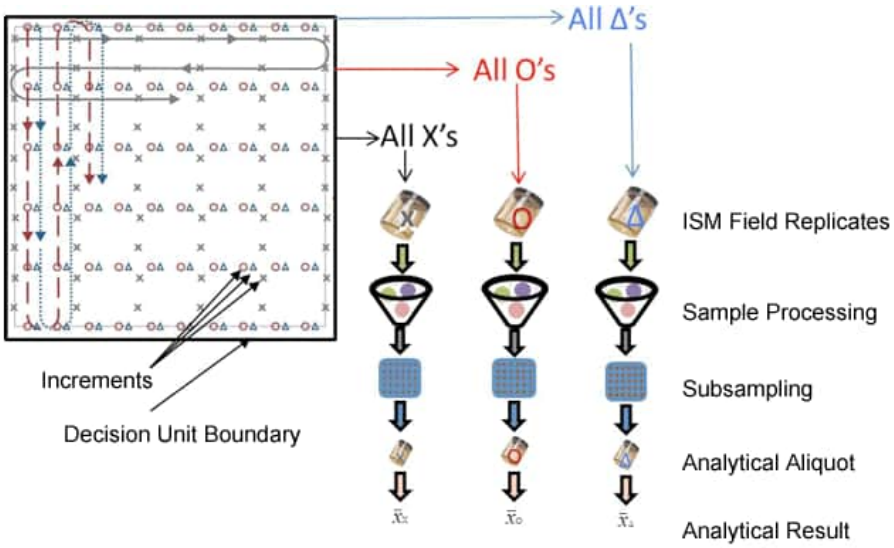


Figure 1.2: ISM Sampling Design Overview

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.

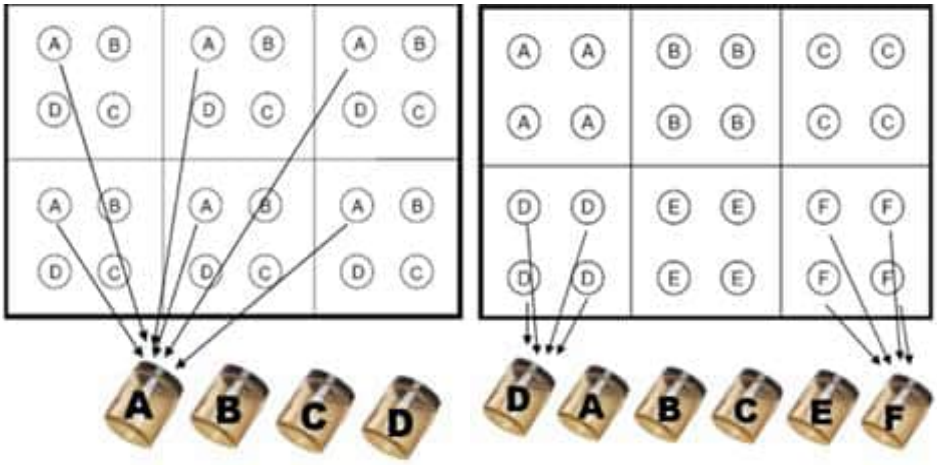


Figure 1.3: Examples of Composite Sampling Designs

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™ or Liquinox™). 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.

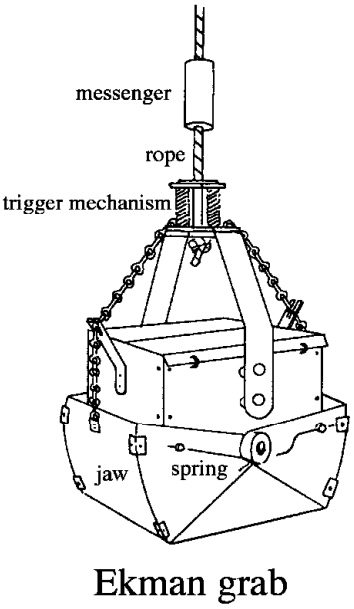


Figure 3.1: Schematic diagram of an Ekman Grab Sampler

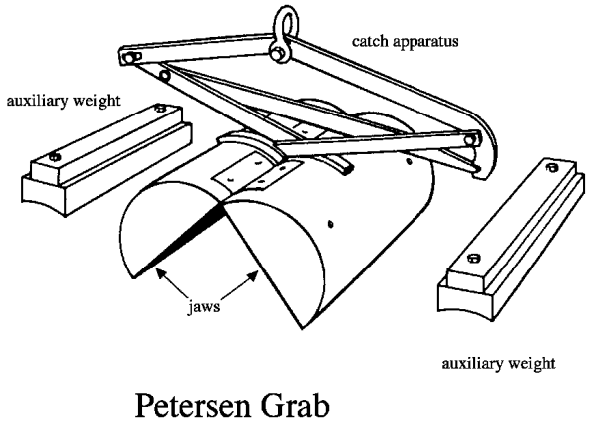


Figure 3.2: Schematic Diagram of a Peterson Grab Sampler

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.

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.

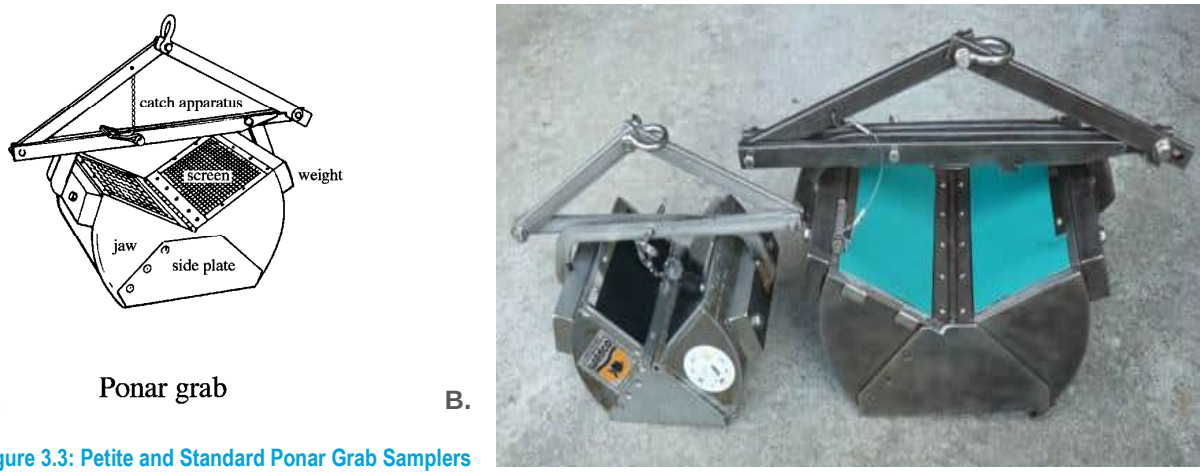


Figure 3.3: Petite and Standard Ponar Grab Samplers
A. Schematic Diagram of a Ponar Grab Sampler; and, B. The two sizes of the Ponar Grab; the Petite (left) and the Standard (right).

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.

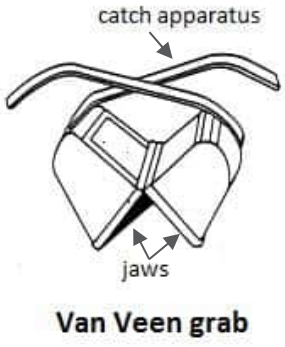


Figure 3.4: Schematic Diagram of a Van Veen Grab Sampler

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.

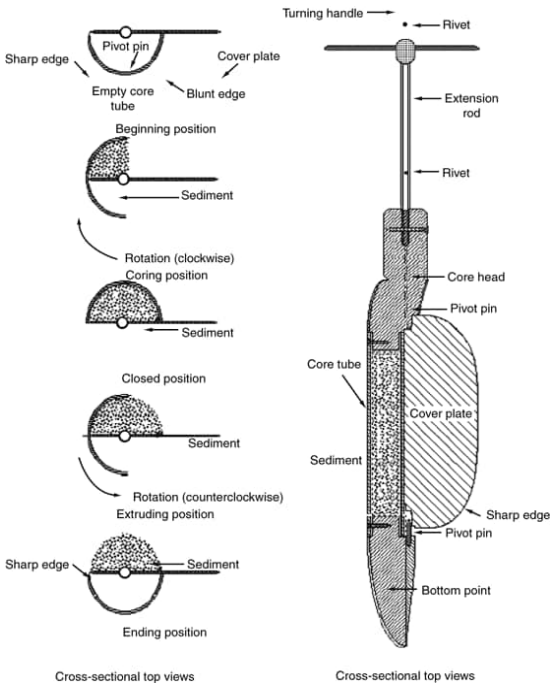


Figure 3.5: Schematic Diagram of a Russian Peat Borer

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.

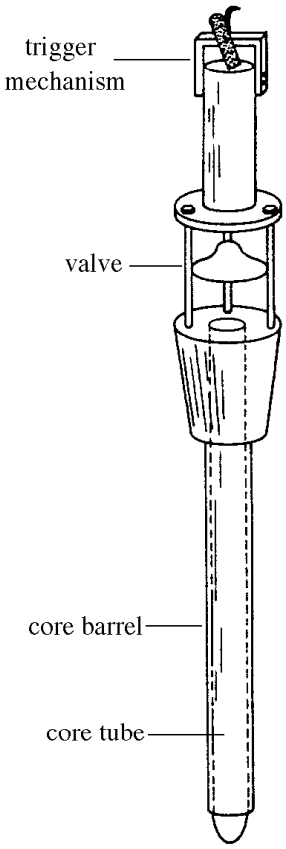


Figure 3.6: Schematic Diagram of a Kajak-Brinkhurst Core Sampler

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.

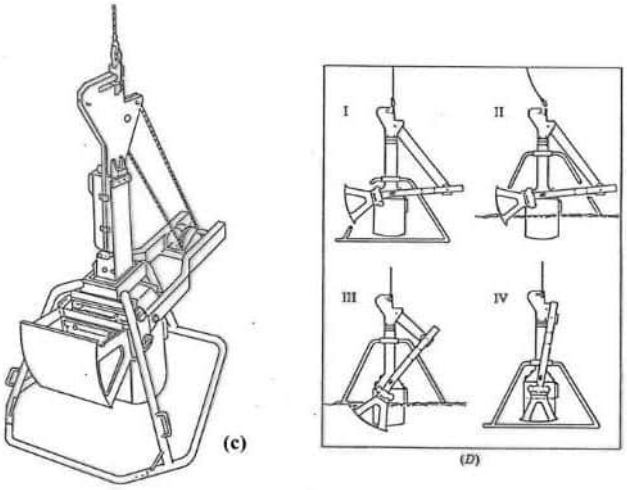


Figure 3.7: Schematic Diagram of a Reineck designed Box Core Sampler

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).

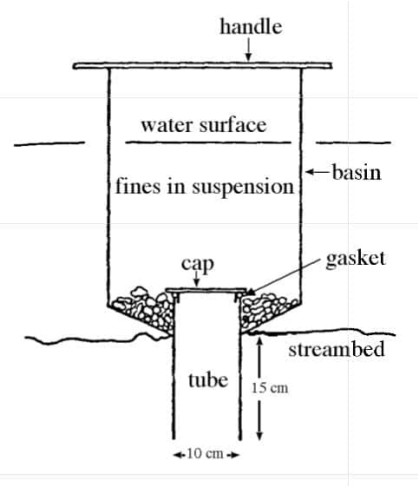


Figure 3.9: McNeil Particle Size Sampler

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.

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.

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.*

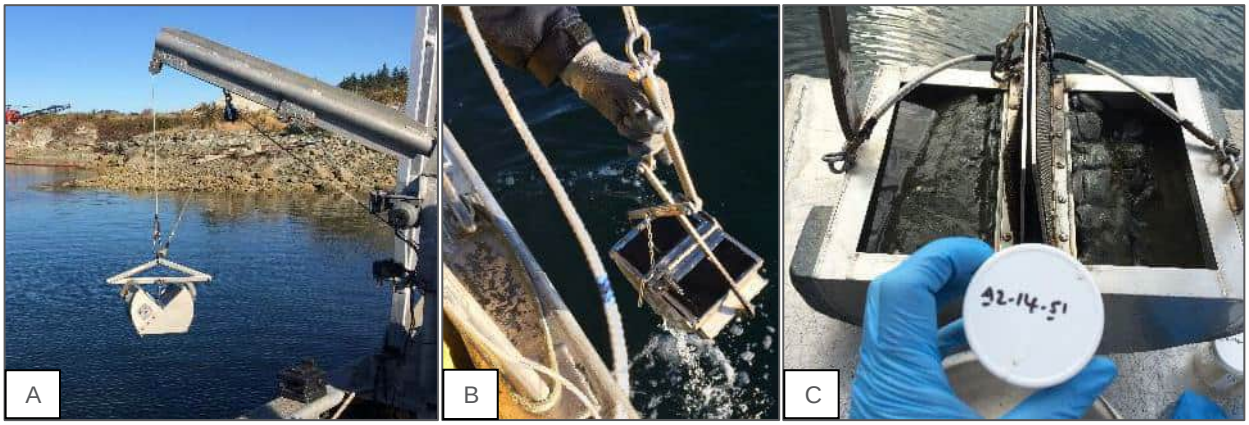


Figure 4.2: Ponar Grab Sampler Configurations (A) Standard Ponar grab sampler attached to winch/crane secured to a boat; (B) Petite Ponar grab sampler retrieval by hand; and, (C) Inspecting sediment through top flaps of a Ponar grab sampler.

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.

6 Sources of Further Information

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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™, 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.

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

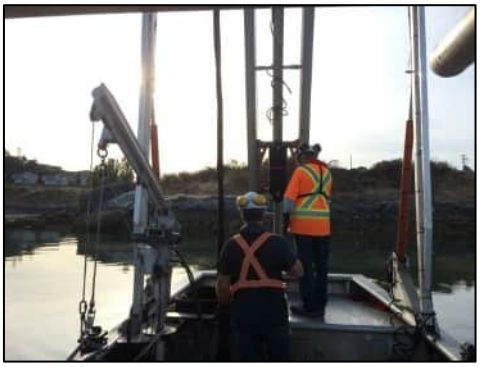

Figure 2: Vibracore sampling in marine environment

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:

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.

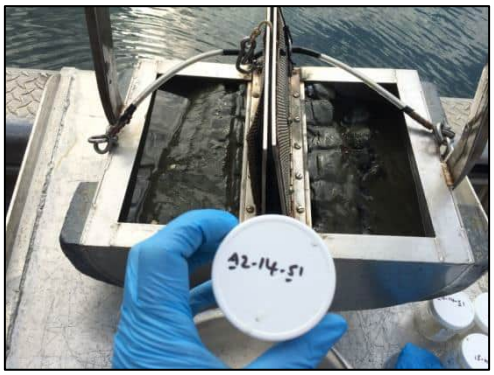

Figure 4: Ponar grab sampler full of sediment following retrieval.

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:

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

Figure 5: Retrieved sediment core in a stainless steel liner, ready for processing on shore.

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

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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:

$$\% \textit{ Reduction} = \left[1 - \frac{\%A\ (100 - \%B)}{\%B\ (100 - \%A)}\right] \times 100$$

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.

PART E
WATER AND WASTEWATER SAMPLING

AMBIENT FRESHWATER AND EFFLUENT SAMPLING

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1. Introduction

This section covers the minimum requirements to ensure quality and consistency of the field aspects of ambient water and effluent data collection. The essential tasks in water sampling are to obtain a sample that meets the requirements of the program, in terms of location and frequency, and to prevent deterioration and contamination of the sample before analysis. The procedures outlined in this section are oriented primarily towards BC Environment employees, consultants, or those under a legal requirement to undertake a sampling program for the Ministry. The protocols outlined in this section will aid field staff in collecting reliable, representative water samples.

The protocols presented here are the most acceptable ones used at present. It should be emphasized that in unusual circumstances, or with development of new methods, experienced professional judgment is a necessary component of method choice and application. It is intended that this document will be updated as the need arises to reflect new knowledge.

This section does not address the collection of samples for the purpose of providing legal evidence. For information regarding legal sampling, refer to *Guidelines for the Collection and Analyses of Water and Wastewater Samples for Legal Evidence* (Lynch and van Aggelen, 1994).

This section also does not address project design (site locations, frequency of sampling, duration, quality assurance program, etc.) or data interpretation. It also does not address the collection of groundwater samples. The protocols for the collection of ambient groundwater are documented in the Groundwater Sampling chapter of this manual.

The sample containers, preservatives and sampling procedures described in this section reflect those most widely used by BC Environment. Shipping procedures and safety measures are also outlined. Different agencies or laboratories may have specifications which differ from those described here.

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2. General Considerations

2.1 Preparing to Go to the Field

Preparation for each sampling trip is critical since oversights are not usually noticed until staffs reach the 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:

- Type and number of (labeled) bottles, including extras
- Field equipment such as meters (with adequate trouble-shooting equipment for small repairs), sampling tools (multiple samplers, through ice samplers, Van Dorns, automatic composite samplers) and filtration apparatus
- Preservatives
- Appropriate quantity of ice packs and coolers
- Log books
- Personal gear (for all possible weather conditions, e.g., survival suits, raincoats, protective footwear, waders, gloves, etc.)
- First aid kit
- Equipment (checked and calibrated, properly loaded to avoid damage during transport, batteries charged, probes not damaged or dried, etc.)
- Camera or video equipment as required
- Laboratory requisition forms (partially filled out)

Before going to the field:

- Contact a qualified laboratory to arrange for the required analyses

A recommended operating procedure is to have the key equipment in a box or plastic "tote" which is dedicated to this activity. Appendix 1 of this chapter presents an example of a generic checklist.

2.2 Locating the Site in the Field

It is the responsibility of the field staff to locate all sampling stations accurately. Only if the same location is consistently sampled can temporal changes in the water quality be interpreted with confidence. Therefore, accurately written station location descriptions (that identify key landmarks and give the site a simple and unambiguous name) must be prepared on the first visit to every sampling site (see Appendix 2.1 for an example of a site identification guide sheet). Good photographic documentation is the best way of ensuring that each site is easily recognized.

A map that labels the sample sites should accompany the **site identification log book**. This can be in the form of a 3-ring binder with a 1:50 000 map. The basic site location data (see Appendix 2.1 - latitudes, longitudes, map sheet #, site identification #, etc.) should be incorporated into the Water Quality database (EMS in the case of BC Environment). In many cases, a detailed site map may be helpful in describing the station location. Global Positioning Systems (GPS) are becoming common tools for locating position of sites and are recommended for this purpose.

2.3 Field Notes/Observations

Good sampling practice always involves the use of detailed field notes. Specific information about seemingly unimportant facts such as the time of day or weather conditions are often important when interpreting data. A **field log book** (3-ring binder with water proof paper) for each project is mandatory (see Appendices 2 and 3 of this chapter for examples of data sheets). All field measurements should be entered directly into this field log book while in the field. All information recorded in the log book should be entered into the database immediately upon return from the field.

In addition to documenting standard conditions and measurements, field staff are responsible for noting any unusual occurrences. Any deviations from standard protocols (e.g., samples taken from a different location due to safety or access considerations or procedures used that differ from those outlined here) must be recorded in the database. Upon observing an anomalous condition, such as an unusual colour or odour of the water, excessive algal growth, indications that foreign substances have entered the system (oil slicks, surface films, etc.), or fish kills, the field investigator should take samples in addition to those required by the project design. The type of samples and their preservation should be consistent with the type of analyses that the investigator thinks are warranted by the prevailing conditions. If additional samples are collected, but not exactly at an established station, a new site location description should be accurately recorded and transferred to the database (EMS) as soon as possible. This information and additional samples will prove useful during the interpretive aspects of the study. The field books are important documents and efforts should be made to ensure they are properly archived.

3. Quality Assurance/Quality Control (QA/QC)

3.1 Field Quality Assurance

The field quality assurance 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 collected for an environmental 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 sources of contamination; the following are some basic precautions to heed:

- Field measurements should always be made using a separate sub-sample which is then discarded once the measurements have been made. They should never be made on a water sample which is returned to the analytical laboratory for further chemical analyses. For example, specific conductance should never be measured in sample water that was first used for pH measurements. Potassium chloride diffusing from the pH probe alters the conductivity of the sample. Similarly, pH should not be measured from a sample that will be analyzed for phosphorus, as some pH buffers contain phosphorus. Use a separate bottle for water temperature if not *in-situ.* **Dissolved oxygen measurements (by DO probe) should be made *in-situ* rather than in a separate container.**

- Sample bottles, including bottle caps, must be cleaned according to the recommended methods and certified by the issuing laboratory as 'contamination free' (if pre-cleaned by the laboratory), for the intended analysis. Sample bottles which are pre-cleaned by the laboratory must **not** be rinsed with the sample water being collected. Bottles must be supplied with cap in place. Note that cleaned re-used bottles are not suitable for some trace constituents. If you are using a mixture of pre-cleaned, not pre-cleaned, and/or re-used bottles, label each bottle type to avoid confusion.

- Use only the recommended type of sample bottle for each analysis (see Appendix 4 of this chapter).

- Reagents and preservatives must be analytical grade and certified by the issuing laboratory to be contamination free (see Appendix 4). Containers holding chemical reagents and preservatives should be clearly labeled both as to contents and as to expiry date. No reagent or preservative should be used after the expiry date. Return expired reagents to the laboratory for proper disposal.

- If conditions dictate that samples from multiple sites be preserved at the same time (such as when returning to shore after sampling several deep stations), the possibility of adding the wrong preservative to a sample or cross-contaminating the preservative stocks should be minimized by preserving all the samples for a particular group of variables together. Colour-coded bottles and matching preservatives prevent mix-ups.

- The inner portion of sample (and preservative) bottles and caps must not be touched with anything (e.g., bare hands, gloves, thermometers, probes, preservative dispensers, etc.) other than the sample water and preservative. Remove caps only just before sampling and re-cap right away.

- 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, resealable plastic bag, not in pockets, etc.

- Petroleum products (gasoline, oil, exhaust fumes) are prime sources of contamination. Spills or drippings (which are apt to occur in boats) must be 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.

- Filter units and related apparatus must be kept clean, using routine procedures such as acid washes and soakings in de-ionized water (see section 9). Store cleaned filter units in labelled, sealed plastic bags.

- Samples must never be permitted to get warm; they should be stored in a cool, dark place. Coolers packed with ice packs are recommended (most samples must be cooled to 4°C during transit to the laboratory). Conversely, samples must not be permitted to freeze unless freezing is part of the preservation protocol (Appendix 4). Cool samples as quickly as possible. A common mistake is to forget that a large volume of warm water soon melts a small amount of ice.

- 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 set out in Appendix 4.

- Sample collectors should keep their hands clean and refrain from eating or smoking while working with water samples.

- Sample equipment and shipping coolers must be cleaned after each sampling round (see Section 9). Field cleaning is often not as effective as cleaning equipment at a support facility. Depending upon the analyte and concentration (i.e., metals or organics), it may only be possible to conduct effective cleaning procedures at a support facility, rather than in the field. Avoid using bleaches and strong detergents; specialty cleaning compounds are available.

- De-ionized water should not be used after 6 months (shelf-life period), and the containers should be clearly labeled with both the filling date and disposal date.

Note: Bottle cap liners of composite materials such as Bakelite must not be used due to high potential for contamination.

3.2 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 blank samples to test: **1)** the purity of chemical preservatives; **2)** to check for contamination of sample containers, filter papers, filtering equipment or any other equipment that is used in sample collection, handling or transportation; and **3)** to detect other systematic and random errors occurring from the time of the sampling to the time of analysis. Replicate samples must also be collected to check that the sample is reproducible. Replicate samples allow the precision of the sampling and measurement process to be estimated, and are an additional check on sample contamination. The timing and the frequency of blank and replicate samples are established in the project design and will vary with each project. A minimum level of effort would be the use of blanks and replicates consisting of 10% of the samples. Another aspect of quality control is the use of certified or standard reference materials (CRM's or SRM's) and of spiked samples to assess laboratory process.

3.2.1 Blanks

Blanks are samples that do not contain the variable to be analyzed and are used to assess and control sample contamination. They are most often used to assess contamination of the trace measurements (metals and

nutrients) but should also be used on occasion to test potential contamination of the other analyses (such as general ions). Most blanks are carried through the entire sample collection and handling process so that the blank is exposed to the same potential sources of contamination as actual samples. Ideally, blanks should be prepared by the analytical laboratory in the appropriate sample bottles under clean conditions. Some of the blanks remain in the laboratory for analysis (laboratory blanks), while the remainder travel to the field for use as trip, field, equipment, and filtration blanks. Alternatively, blanks may be prepared in the field as outlined below.

3.2.1.1 Trip Blanks

Trip blanks are meant to detect any widespread contamination resulting from the container (including caps) and preservative during transport and storage. The recommended practice for organic parameters is to use carbon free de-ionized water for trip blanks.

PROTOCOL

(a) Prior to a field sampling trip, one or more sample bottles for each type being used during the trip are selected at random, filled with de-ionized water that is provided by an analytical lab (preferably one different from the one samples are being sent to) and preserved in the field in the same manner as field samples (see section 7.2).

(b) These bottles are capped and remain **unopened** throughout the sampling trip. They are transported to the field with the regular sample bottles and submitted with the field samples for the analysis of interest.

3.2.1.2 Field Blanks

Field blanks mimic the extra sampling and preservative process but do not come in contact with ambient water. Field blanks are exposed to the sampling environment at the sample site. Consequently, they provide information on contamination resulting from the handling technique and through exposure to the atmosphere. They are processed in the same manner as the associate samples (i.e., they are exposed to **all** the same potential sources of contamination as the sample). This includes handling and, in some cases, filtration and/or preservation.

PROTOCOL
(field blanks)

(a) If the blank was prepared by the lab, then open the bottle to expose the de-ionized water to the air for as long as the sample was exposed when it was collected. Otherwise, when the blank is prepared in the field, pour de-ionized water into the pre-labeled field blank bottle and recap it (this simulates sample collection). Document whether it was a lab prepared or a field prepared blank.

(b) Filter the sample as per the protocol outlined in section 7.1 (only if the associate sample requires filtration).

(c) Add preservative as per section 7.2 (only if the associated sample requires preservation).

(d) Ship to the lab with the remaining samples.

3.2.1.3 Equipment Blanks (prepared prior to the field trip)

A field equipment blank is a sample of de-ionized water that has been used to rinse sampling equipment. This blank (perhaps more properly described as a rinsate) is useful in documenting adequate decontamination of equipment. It is collected after completion of the decontamination process (washing) and prior to sampling.

PROTOCOL

(a) Pour the rinse (de-ionized) water that was used for the last rinsing into a pre-labeled bottle that identifies the piece of equipment that was cleaned.

(b) Submit the blank with the regular samples for analysis.

3.2.1.4 Filtration Blanks

Filtration blanks (or rinsate blanks) are de-ionized water that is passed through the filtration apparatus in the same manner as the sample. Analysis of the filtrate provides an indication of the types of contaminants that may have been introduced through contact with the filtration apparatus. Filtration blanks are also used as a check for potential cross-contamination through inadequate field cleaning techniques (rinsing of the apparatus with de-ionized water between samples). It should be done both at the start and again at some point between samples (after the apparatus has been cleaned

and immediately before the next 'real' sample is filtered). Each of these blanks is preserved in the same fashion as the associate samples.

PROTOCOL

(a) Follow procedure outlined in section 7.1 (filtration).

3.2.2 Replicate Samples

3.2.2.1 Co-located Samples (field duplicate, triplicate, etc.)

Co-located samples are independent samples collected as close as possible to the same point in space and time and are intended to be identical. These samples are essential in documenting the precision of the entire sampling and analytical (laboratory) process.

For this procedure, simply follow (and repeat) the protocol outlined in section 4 (sample collection).

Note: Replicate samples have more information than either blanks or split samples, and are particularly recommended for QC studies.

3.2.2.2 Split Samples

Split samples are aliquots taken from the same container and analyzed independently by one or more laboratories. They are used to obtain the magnitude of errors owing to contamination, random and systematic errors, and any other variability, which are introduced after the time of sampling through analysis at the laboratory(ies). Split samples are commonly used to compare two or more laboratories. Care must be taken to ensure that the samples are split in a way to ensure homogeneity (a sample splitter must be used for samples containing suspended solids or effluents).

3.2.3 Spiked Samples (Field)

Spiked samples for each variable being tested are prepared by spiking aliquots of a single water sample with known amounts of the variable of interest. The information gained from spiked samples is used to reveal any systematic errors (or bias) in the analytical method. The spike solution is prepared by an analytical laboratory (preferably) or it can be prepared by the field staff (far less desirable) prior to the sampling trip.

PROTOCOL
(spiked samples)

(a) Collect the sample in a pre-labeled bottle as per section 4.

(b) Add the aliquot of spike solution, recap the bottle, mix and then treat the sample as if it were a regular sample (i.e., preserve and filter if required).

3.2.4 Reference Samples

Reference samples are used to document the bias of the analytical (laboratory) process. There are two types of reference samples. The first, and simplest, is when an independent laboratory prepares a water sample with the addition of a known quantity of a variable of interest. In this case, the independent laboratory should provide calculated and measured concentrations on the variable.

The second type of reference material is a certified reference sample. It is obtained from a recognized national scientific body such as the National Research Council. The sample itself is an aliquot of a very large stabilized (may be preserved) batch sample that was collected from one place at one time. The batch sample has been subjected to a large number of analyses performed by independent laboratories using several different analytical techniques, but some reference materials are analyzed by different labs using the same methodology. Consequently, the distributing agency can provide a mean value and confidence interval for the variable of concern.

These samples are submitted blind to the analyzing laboratory along with the samples collected during a field trip. There is the option of submitting them blind (labeled as a regular sample) or non-blind with labeling that it is a certified reference material. The former is a more desirable QA tool.

4. Collecting Samples

Water samples are often obtained by filling a container held just beneath the surface of the water, commonly referred to as a dip or **grab sample**. Through the use of special depth samplers (such as a Van Dorn bottle), grab samples can also be obtained from deep waters. This is important as distinct thermal and chemical differences can occur throughout the water column. **Composite samples** are obtained by mixing equal volumes of discrete grab samples (collected at one point at regular time intervals or, collected from multiple points such as varying depths). A composite sample provides an estimate of average water quality conditions.

Note: If sample bottles have not been pre-cleaned by the laboratory, then they must be rinsed 3 times with either de-ionized water or sample water. The exceptions to this is when a sample is to be analyzed for suspended sediments, for contaminants likely associated with the suspended solids, or for oil and grease. In these cases, the bottles should not be rinsed with sample water as suspended particles or grease-like materials are retained on the interior surface of each bottle with each rinsing. For specialized analyses (trace metal, organics) and pre-cleaned bottles, containers should <u>not</u> be rinsed. Rinsing is not a recommended practice. Use of pre-cleaned bottles is recommended, where practical. Where bottles are rinsed, the rinsate should be discarded.

Special sampling and handling techniques known as “clean” and “ultra clean” methods are needed to achieve accurate results when measuring low-level trace metals in ambient waters. Clean methods are needed to quantify trace metals accurately when the concentrations are less than about 20 mg/L and down to 0.1 mg/L. Ultra clean methods are needed when the metal concentrations are less than 0.1 mg/L, as might be required for trace metals such as mercury, cadmium, or silver (Hunt et al., 1995). These methods are not in general use in British Columbia at this time, and detailed guidance on the methods has only recently become available. We expect that guidance on clean and ultra clean techniques will be added to the next edition of this field manual. In the interim, sample collectors should refer to the recent US Environmental Protection Agency report of the subject (USEPA, 1995).

4.1 Lake

Sample stations can be located either near-shore or in deeper waters (deeper sites are typically located over the deepest point of the lake). In general, the near-shore sites detect those effects that are associated with influences such as groundwater and run-off. Deep stations provide information about the water column, such as conditions associated with stratification (depth profiles). Additionally, near-shore sites tend to provide information on a relatively short time scale (days or weeks). The deeper sites allow for documentation on a seasonal or longer time frame.

4.1.1 Shore Sample

Sample collection at near-shore stations generally consists of grab samples at a specified location. It is critical that there be no deviation in location unless conditions at the site (e.g., severe weather, physical changes of the site, etc.) pose a threat to the sampler's safety. **If safety is threatened, then search for an alternative location nearby, or simply do not attempt to take the sample**. If an alternative location is found, then all details regarding the new site and the reasons why the alternative was necessary must be recorded in the field log book. This information should be entered into the database as soon as possible after returning from the field.

To avoid contamination from suspended sediments, the sample collector should preferably sample from a boat or a dock or, if that is not possible, should wade out past the point where wave action affects the lake bottom. In most cases, this distance is not far from shore. But, in any case, **the sampler should not exceed a depth where there exists a reasonable possibility that water might enter the gum-boot or hip-wader**. This is particularly important during colder periods of the year when getting wet poses a health risk (such as hypothermia).

PROTOCOL
(for collecting shore samples)

(a) Obtain labeled bottles and wade into the lake at the most accessible point.

(b) Once you reach a sufficient depth (where bottom material will not interfere with the sample), stop and orient yourself towards the center of the lake.

If rinsing is required (see section 4, Collecting Samples), proceed from step (c), otherwise start at step (h).

(c) Remove the lid and hold it aside without touching the inner surface.

(d) With your other hand, grasp the bottle well below the neck. Lean out towards the center of the lake and, in one continuous motion, plunge the bottle beneath the surface and slowly force it through the water until it is partly full. This motion creates a current over the mouth of the bottle (such that water entering the bottle has not come in contact with your hand).

(e) Replace the lid and shake the bottle vigorously.

(f) Remove the lid and reach back towards shore to pour the water out.

(g) Repeat steps (c) through (f) twice more before collecting the sample.

(h) Remove the lid (without touching the inner surface) and grasp the bottle well below the neck. Lean out towards the center of the lake and, in one continuous motion, plunge the bottle beneath the surface and slowly force it through the water until it is full.

(j) Return to shore and pack the sample(s) in a cooler until time and conditions permit for other necessary procedures (filtration and/or preservation, which should be done as soon as possible after the samples are collected).

4.1.2 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, then the weather forecast or marine conditions should be obtained prior to departure from home. If conditions are poor, then the sampling trip should be postponed.**

4.1.2.1 Site Identification

Deep water sampling sites are marked with a buoy or referenced by easily identifiable features (preferably two) on shore. Reference points should be described (both in writing and with photographs) in the site identification log book. Once at the site, and if it is not too deep, anchor the boat (or tie it to the buoy) and wait until it settles with the bow (front) facing into the current (wind) before collecting the sample. If the water is too deep to anchor, then one person will have to maintain the location (with either the motor or with paddles) while the other person collects the samples and takes the field measurements.

4.1.2.2 Surface Water

PROTOCOL
(for collecting surface water)

(a) The person at the bow (front) should always collect the samples. This is because the bow is the anchor point and, even in a slow moving water, the boat will drift so that the bow is upstream. In quiescent water the samples should be collected prior to anchoring and while the boat is slowly moving forward. These precautions reduce the potential of

contamination from the boat or motor. The person in the stern (rear) can be responsible for holding the boat's position (when not anchored), taking the field measurements (see section 6) and field notes. Contamination is not as much of a concern for field measurements.

(b) Obtain a labeled sample bottle and remove the lid without touching the inside of the lid (or bottle!). If rinsing is required for the type of bottle, fill and rinse three times [see 4.1.1 (c) to (g)].

(c) Reach out an arm length from the boat to take the sample. Ensure that the person in the stern is providing counterbalance (working over the opposite side of the boat).

(d) Plunge the bottle under the surface and move it slowly towards the current (the direction the boat is facing). This should be done at a depth of approximately 0.5 meters.

(e) Recap the bottle immediately and proceed with the next sample.

(f) Samples requiring filtration and/or preservation (see sections 7.1 and 7.2) should be dealt with as soon as possible after returning to shore.

4.1.2.3 Deep Water

Lake water samples may be collected from any desired depth through the use of a **Van Dorn** (or similar) sampler (Figure 1). The Van Dorn bottle is designed for sampling at a depth of 2 metres or greater. A drain valve is provided for sample removal. Note that Van Dorn samplers are available in both horizontal and vertical configurations. The advantage of the vertical configuration is that the water within the open bottle is flushed out as the bottle is lowered, so one can be guaranteed the water collected was collected from the indicated depth. The advantage of the horizontal configuration is that a very narrow depth range is sampled. Vertical configurations are most commonly used. The horizontal configuration should be used when samples are taken near bottom at the sediment-water interface, or when samples are required from a narrow band of the depth profile (i.e., chemocline, thermocline).

The sampling sequence recommended is to obtain the field measurements first (temperature, DO, conductivity - see section 6). These are often necessary prerequisite for locating the depths from which the water samples should be taken (i.e., if three deep samples are required at a site then it might be necessary to know the depths of the major stratified zones - epilimnion, thermocline, hypolimnion).

Although operation of the Van Dorn bottle varies slightly depending on its size and style, the basic procedure is the same.

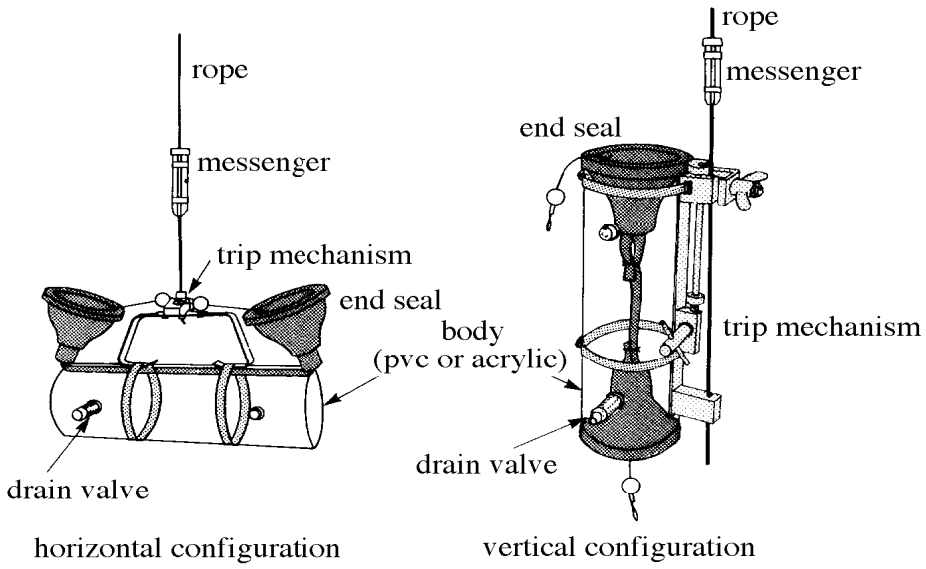

Figure 1. Van Dorn sampler

PROTOCOL

(for collecting deep water)

(a) Ensure the sampling bottle is clean.

(b) Open the sampler by raising the end seals.

(c) Set the trip mechanism.

(d) Lower the sampler to the desired depth.

(e) Send the messenger down to “trip” the mechanism that closes the end seals.

(f) Raise the sampler to the surface.

(g) Transfer the water sample from the Van Dorn bottle to individual sample containers via the drain valve. Take care to avoid contact with the drain spout as contamination at this stage often occurs.

(h) Rinse bottles 3 times (if they have not been pre-washed), and collect sample (see section 4.1.1).

(i) Filter and/or preserve the samples as required once at shore.

4.1.3 Winter Sampling

Sampling in winter presents extra elements of danger. **Always proceed with caution over ice and do not jeopardize your safety**. Check the ice for thickness with a rod or ice chisel every few steps (ice should be a minimum of 3 to 4 inches thick). Ice over moving water can be of varying thickness, and the strength of the ice cannot be estimated from its apparent thickness near the shore. **Always have someone accompany (follow) you, wear a life jacket, and carry a length of rope (tied around your waist) to use as a life line. If the ice is unsafe, do not take a sample. Never take unnecessary risks.**

Note: Ice near the outlet of a lake is often thin, therefore, caution should be used when sampling this area of a lake. Additionally, ice thickness on reservoirs, where water levels fluctuate, can be variable.

In springtime, ice can be thick, but not strong enough to walk on (often called "Frazzle" or "corded" ice).

PROTOCOL
(for sampling through ice)

(a) 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 and to ensure that there is water movement under the ice at your selected spot. It is preferable to select a site where the ice is sagging rather than bulging.

(b) 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**.

(c) Remove all ice chips and slush from the hole, using a plastic sieve.

(d) Use a Van Dorn (or similar) sampler to collect the sample (see section 4.1.2.3).

(e) Do not allow samples to freeze.

Note: An alternative to this method would be to use the Through-Ice sampler described in section 4.2.4 - Winter Sampling on rivers (this technique does not allow the collection of samples that are deeper than 2 metres). Any deviations from the above protocol must be noted in the field log book.

4.2 River/Stream

The majority of samples collected from streams and rivers in British Columbia are grab samples taken near the surface at one point in the cross section of the flow. On rare, special occasions, more sophisticated multi-point sampling techniques known as equal-discharge-increment (EDI) or equal-width-increment (EWI) methods are used. Since these techniques are infrequently used they will not be discussed here, but further information about the protocols can be obtained from Clark and Shera, 1985.

Note: The collection of samples for the purpose of assessing the suspended sediment load in fast flowing waters requires specialized techniques/equipment. The equipment is not readily available, therefore, the protocols will not be discussed here. For information regarding the equipment and techniques, refer to Guy and Norman (1970) or Stichling and Smith (1968).

4.2.1 Access from the Stream Bank

Wherever practical, samples should be collected at mid-stream rather than near-shore. Samples collected from mid-stream reduce the possibilities of contamination (i.e., shore effects - back eddies, seepage from near shore soils, atmospheric components such as pollen concentrating in slow moving water, etc.). Samples should not be taken in back eddies or brackish waters unless required by the monitoring program objectives. The most important issue to consider when deciding where the sample should be collected from is **SAFETY**. If the flow is sufficiently slow that the collector can wade into the stream without risk, then the sample can be

collected at a depth that does not pose a threat (discretion is the key - **never wade into water that appears deep or fast flowing**). When conditions dictate that the sample be taken from the stream bank, deviations from the standard protocol should be accurately documented in the field log book and transferred to the database as soon as possible. **Samplers must be wary of non-visible bottom under turbid conditions.**

PROTOCOL
(for wading into flow)

(a) Obtain labeled bottles and wade into the river downstream from the point at which you will collect the samples, then wade upstream to the sample site. This ensures that you will not disturb sediments upstream of the sample point. Attach safety line if conditions have any significant risk.

(b) Stand perpendicular to the flow and face upstream.

(c) Remove the lid and hold it aside without touching the inner surface. If rinsing is required for the type of bottle, fill and rinse three times (see section 4).

(d) With your other hand, grasp the bottle well below the neck. Plunge it beneath the surface in front of you with the opening facing directly down, then immediately orient the bottle into the current. Avoid collecting surface scum and film.

(e) Once the bottle is full, remove it from the water by forcing it forward (into the current) and upwards.

(f) Replace the cap immediately.

PROTOCOL
(for sampling from the stream bank)
(when the current is too strong, water is too deep, or ice is too thin)

(a) Secure yourself to a solid object on shore (with a safety harness and line if necessary). As a safety precaution, the second person must remain nearby while the first is collecting the samples.

(b) Remove lid from a labeled bottle and place into a clean resealable bag (e.g., Zip Lock) so both hands can be used to take sample. If rinsing is required for the type of bottle, rinse three times.

(c) Hold the bottle well below the neck or secure it to a pole sampler.

(d) Reach out (arm length only) and plunge the bottle under the water with the opening facing directly down and immediately orient it into the current.

(e) When the bottle is full, pull it up through the water while forcing into the current.

(f) Immediately recap the bottle.

4.2.2 Access from a Bridge

Some sample stations are designed to be sampled from a bridge. This allows the collection of samples from the central flow of rivers where wading is not an option. The samples can be collected using an apparatus called a **multiple sampler** (Figure 2) that is lowered over the side of the bridge. Since the multiple sampler holds more than one bottle, it has the advantage of allowing all containers (therefore, all variables) to be sampled at the same time and at the same place. This allows for more precise cross-referencing among the variables. Other pieces of equipment for single bottles are also available and can be used in situations that are appropriate.

The precise location at which the sampling device is lowered from the bridge should be marked to ensure that the same section of the river is sampled each time.

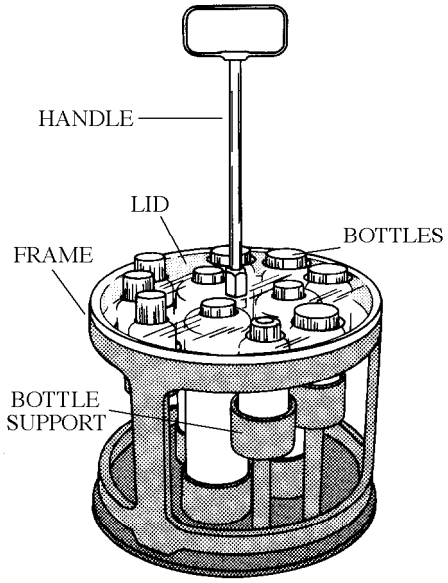

Figure 2. Generalized multiple sampler

PROTOCOL
(from bridge with multiple sampler)

(a) Remove the lid (with handle) from the multiple sampler.

(b) Secure all sample bottles (lids on) into the multiple sampler (as in Figure 2).

(c) Refit the lid to the sampler.

(d) Secure the free end of the sampler's rope to bridge before attempting to take the sample.

(e) Remove lids from the sample bottles and place in a clean resealable bag (e.g., Zip Lock).

(f) Whenever possible lower the multiple sampler over the upstream side of the bridge (side the that the water reaches first), being careful not to disturb bridge surfaces with the rope or sampler. This avoids

contamination of the sample from the bridge itself or substances falling into the water or into the open bottles from the bridge (e.g., fuel, oil, dust, wood chips, etc.).

(g) Allow the sampler to submerge to the point that all the bottle openings are below the surface.

(h) After a sufficient period has elapsed to fill all bottles, haul the sampler up, add preservatives where required, and recap each bottle before disassembling the sampler.

4.2.3 Sampling from a Boat

Due to the fact that fast-flowing waters pose a serious threat, it is essential that the person operating the boat be very experienced with river boating. Ideally, there should be three people along on 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.

Sampling trips should start at the site that is most downstream and work upstream. If mechanical problems should arise then the current will work to your advantage and assist you to return to the vehicle.

PROTOCOL
(in flowing waters)

(a) When a sample site is reached the boat operator idles into the current so as to maintain the boat in one location. Use a reference point on shore to do this.

(b) The person in the bow is responsible for collecting the water samples (see section 4.1.2).

(c) The third person is responsible for the field measurements (see section 6).

4.2.4 Winter Sampling

Due to the fact that 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. At least two people must proceed onto the ice, one ahead of the other. The person in the rear should carry a rope and each must wear a life jacket.

Generally, winter sampling on rivers follows a similar protocol as for sampling lakes in winter (see section 4.1.3). 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.

When the ice is safe, there are two tools that are commonly used for the collection of water samples, the **Through Ice Sampler** (Figure 3) and the **Flip Sampler/Duncan Sampler** (Figure 4).

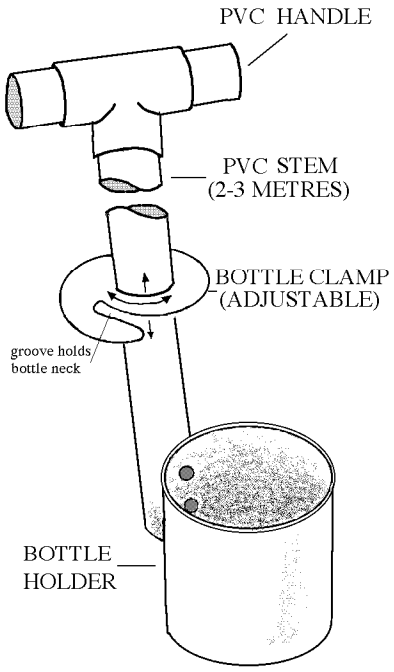

Figure 3. Through ice sampler

PROTOCOL
(Through Ice Sampler)

(a) 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**.

(b) Remove all ice chips and slush from the hole, using a plastic sieve.

(c) Load a pre-labeled bottle into the bottle holder of the **Through Ice Sampler** (Figure 3). Remove the bottle cap and insert stopper (with attached cord) into the bottle opening.

(d) Lower the sampler and bottle through the hole until it is clear of the bottom of the ice surface, and into freely moving water.

(e) Remove the stopper by pulling the cord, and allow the bottle to fill. For the bottle to fill in fast flowing water the sampler may have to be held at different angles.

(f) Bring bottle back up and decant water into the appropriate sample bottles (rinsing if required). For low-level metals analysis, a separate pre-cleaned (acid-washed) collection bottle must be used in the through ice sampler.

There are a variety of unusual conditions that may be encountered in sampling through ice. There may be meltwater below the snow on the ice surface, or there may be a slushy stratum within the ice itself. If these or other conditions occur, they should be noted in the field book and a judgment made as to whether the sample is worth taking.

Note: In streams where the ice is not too thick (20 -50 cm), it may be possible to sample with shoulder length gloves and reach below the ice into the flowing water.

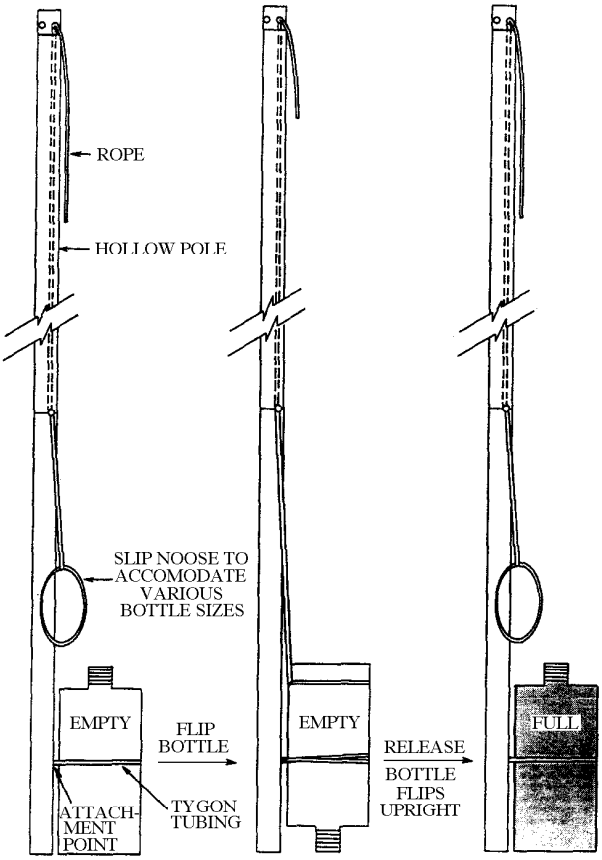

Figure 4. Flip sampler (Duncan sampler)

PROTOCOL
(Flip/Duncan sampler)

(a) 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**.

(b) Remove all ice chips and slush from the hole, using a plastic sieve.

(c) Load a pre-labeled bottle upright into the bottle holder (tygontubing) and rotate it so the mouth is facing down (Figure 4). Slip the noose over the bottom of the bottle.

(d) Hold the rope and pole at the top while you lower the sampler through the hole to the desired depth.

(e) Pull the rope to pivot the bottle so that the mouth faces upwards. Allow the bottle to fill and return it to the surface. Cap it immediately.

PROTOCOL
(from a bridge when ice is dangerous)

(a) When river ice is thin, a hole of sufficient size to collect a sample may be produced by dropping a weight attached to a hand line.

(b) Once the current has cleared the hole of debris, the protocol for sampling from a bridge (see section 4.2.2) should be followed.

Note: Extra care must be taken to avoid contamination in winter. De-icing agents such as salt can be easily transferred to the sample (particularly when working from a bridge).

5. Collecting Effluent and Receiving Water Samples

Effluent sampling has a particular series of protocols associated with it and this type of sampling is usually conducted by the waste discharge permittees. The conditions of sampling (frequency, site locations, etc.) are determined through consultation between BC Environment and the permit holder. These conditions are then outlined in the permit itself. **The sampling site must conform to Workers' Compensation Board Regulations and other applicable safety requirements, and be readily accessible under all expected weather conditions**.

An overview of the types of sampling and flow measurement procedures are presented in "Field Criteria for Sampling Effluents and Receiving Waters" (Bollans, et. al., 1989). The following protocols outline the steps required to ensure that the samples that arrive at the laboratory are representative of the true conditions in both the effluent and the receiving waters.

Blanks, as discussed in section 3.2.1, also apply to effluent sampling programs.

Appendix 4 of this chapter lists the container size and type, and preservation technique required for the individual parameters.

5.1 Effluent Stream

The sample must always be collected at the same location within the effluent stream to ensure that each is representative. Representative sampling locations occur where the effluent is well mixed in the river or stream (i.e., typically near the centre of the effluent stream in order to avoid boundary effects and biasing due to material which has a strong tendency to sink or float). Grab samples are generally specified when the concentration of a parameter under consideration is not expected to vary significantly with time; or when values associated with extreme events are desired or when the analyte is such that the procedure of compositing would destroy the sample integrity or representativeness (VOC's, oil and grease) where the sample must be shipped for the lab in the original sample bottles. Composite samples are generally specified when the concentration of the parameter under consideration is expected to vary with time (or location). The individual samples that make up the composite may be of equal volume or be proportional to the flow at the time of sampling. The compositing period is defined according to the terms of the Permit (i.e., daily, over a four-hour period, etc.).

Note: When sampling effluents or receiving waters, the collector must wear protective gear (gloves, goggles, waders, etc.).

When variability in effluent flow rates exists, flow proportional composite sampling is a technique that must be used. In order to accomplish this, accurate (preferably continuous) flow measurements must be made. Automatic sampling devices (to collect grab or composite samples) are acceptable providing that the sample is in contact with only components made of acceptable materials (stainless steel, glass, plastic or Teflon). Plastic is acceptable except where samples are taken for organic analyses. **Automatic** sampling devices must be equipped with a purge mechanism to enable the sample line to be evacuated prior to sample extraction. The velocity in the sampling line should be a minimum of 0.75 m/s to prevent the settling of solid material.

PROTOCOL
(grab samples)

(a) Obtain a pre-labeled sample bottle and remove the lid without touching the inner surface of either.

(b) Grasp the bottle well below the neck and plunge it into the effluent. Ensure that your hand is always downstream of the bottle opening.

(c) Recap the bottle and place it in a cooler containing a sufficient quantity of ice packs (twice the volume of ice to sample in the summer, one to one in the winter).

(d) Once all the samples have been collected, process accordingly (see Appendix 3 of this chapter) and ship to the laboratory without delay (see section 8).

PROTOCOL
(composite sampling - flow proportional)

Note: Flow proportional composite sampling is necessary when effluent flow rates vary significantly (variations exceeding +15% of the daily mean more than 10% of the time) and will normally be specified as a condition of the Permit.

Follow the protocol outlined above for the actual acquisition of the sample. The only variable will be the quantity collected each time. The following is a hypothetical example of calculations for quantity collected:

If you are required to collect 1% of the effluent discharge (expressed per second) and the discharge is 10 L/sec then you would collect 100 mL. If the discharge doubles to 20 L/sec then in order to collect the required 1% you would have to collect a 200 mL sample.

It will be necessary to store component samples in an interim storage container over the prescribed composite period. This container must be made of acceptable materials, and the procedures for cleaning and re-use must conform to the protocols outlined in section 9. The sample must be kept cool (4°C) throughout the collection process.

Interim discrete samples should be preserved if required after they are taken, rather than waiting until the end of the composite period for adding preservative.

It is important to maintain a record or the volume and time of collection of the discrete subsample.

5.2 Receiving Waters

The sampling of receiving waters consists primarily of the same protocols and safety considerations as those discussed for ambient water sampling (see section 4). **The possibility of elevated levels of contaminants at some locations warrants further safety practices (see WHMIS and Workers' Compensation Board Regulations)**.

The ambient conditions at each effluent discharge location dictate which sites are ideal as sampling stations. These sites, for testing the impacts of effluents on the receiving waters, are determined through consultation with the permittee. They will include the following considerations:

- A control site (receiving water in a location not affected by the discharge);
- A site intended to monitor discharge impacts after complete mixing with the receiving water;
- A site intended to monitor outside a defined initial dilution zone.

Refer to Bollans et al., (1989) for a description of dilution zones.

Refer to section 4 (Collecting Samples) for the protocols required for the acquisition of receiving water samples. Samples can be collected as either grab or composites. The rationale for composite sampling provided for effluents also applies to receiving waters. Receiving water flow variations are not usually significant over the sampling period, therefore, a flow proportional composite is not necessary.

6. Field Measurements

Field measurements involve the use of specialized equipment. Since different models are available for each variable, this section will discuss their use from a general perspective only. Field staffs are directed to the reference documentation provided by the instrument manufacturers. An equipment log book that documents instrument calibration, operation, and maintenance (yearly, at a service shop) records must be carried by the sampling staff at all times. This log book must contain information about each instrument available to the sampling group.

All field data are to be recorded in the field log book and entered into the database (e.g., EMS for BC Environment) as soon as possible upon return from the field.

6.1 Temperature

Temperature can be measured with an alcohol-filled thermometer or with an electronic thermometer that has been calibrated against a certified thermometer. All thermometers must be checked against a reference thermometer by a laboratory before use and annually thereafter. Thermometers that do not meet the data quality objective of the project (e.g., ± 0.5°C of the true temperature) must be discarded.

PROTOCOL
(thermometer)

(a) Measure surface water temperatures directly in the water, allowing the thermometer to come to equilibrium before recording the value.

(b) For deep waters, collect a grab sample (e.g., with a Van Dorn - section 4.1.2.3) and decant some water into a 1 litre "field bottle" (never measure the temperature in a sample bottle that is being submitted to the laboratory for other analysis). Measure the temperature immediately, allowing the thermometer to come to equilibrium before recording the value.

Note: Ensure that the corresponding depth is identified for each temperature recorded in the field log book.

PROTOCOL
(temperature using meters)

Note: Many meters have the capacity to measure temperature. Typically, though, temperature is measured with a combined temperature-dissolved oxygen meter. Temperature changes that occur with depth strongly influence the solubility of oxygen and therefore, the two need to be correlated (% saturation of dissolved oxygen).

(a) Calibrate the meter as per the operating instructions issued for each model.

(b) Check meter temperature readings, both in air and in water, against a thermometer of known accuracy as a quality control measure. If the measures do not agree, the meter can be adjusted to the thermometer reading. This check should be repeated throughout the day to determine if the meter is "wandering". All adjustments must be recorded in the field log book. Temperature data are typically recorded to the nearest 0.5 degree.

(c) For depth profiles, record readings for increments of 1 - 2 metres. As a quality control measure, record the readings twice, once as the probe descends, and then again as it ascends.

6.2 Dissolved Oxygen (DO)

Dissolved oxygen can be measured by either chemical titration (Winkler method) or the membrane electrode method. Both have the potential of being accurate and reliable, but both methods require some training so that accurate measurements can be made. Meters provide a convenient and inexpensive way of measurement and are the most commonly used method. A well-calibrated oxygen meter membrane electrode system is preferred for obtaining a depth-profile of DO in a

lake or deep river. Sampling for DO measurements requires particular care, since any contact between the sample and the air will modify the results. If percent saturation is to be determined, then the water temperature must be measured at the same time and location. Additionally, barometric pressure or altitude are required to accurately determine percent saturation.

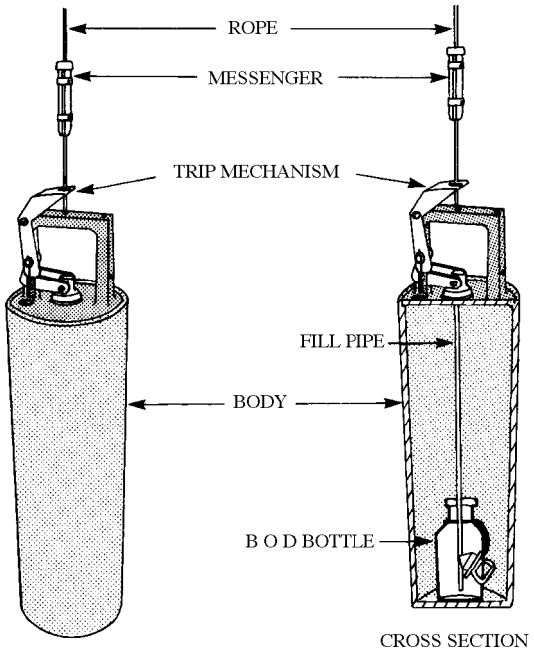

Figure 5. Dissolved Oxygen sampler

PROTOCOL
(Winkler method)

(a) If a DO sampler (Figure 5) is available the sample can be collected directly into a BOD (biochemical oxygen demand) bottle which is used for DO sampling. This sampler flushes 3 volumes of water through the bottle before it is filled (minimizing air-water contact). If this sampler is used, then proceed directly to step (c) after acquisition of the sample. Otherwise, a Van Dorn bottle can be used to collect water samples for DO analysis. In shallow waters (where a water-bottle sampler cannot be used), use a hand pump or a bucket with a clamped drain tube installed at the bottom.

(b) When the sample has been collected with a Van Dorn bottle or into a bucket, then transfer the sample to a 250 or 300 mL BOD bottle immediately. Allow the water to flow continuously through a delivery tube placed to the bottom of the bottle, taking care to prevent turbulence and bubble formation. Wait until at least 3 times the capacity of the sample bottle has overflowed before gently removing the tube (count the number of seconds for the bottle to fill initially then repeat twice).

(c) Immediately and gently add the flocculating agent (typically a pre-measured powder pillow containing manganous sulfate and alkali-iodide-azide, available from HACH*). Insert stopper, being sure that no air becomes trapped in the bottle. Mix vigorously by inversion. Allow the precipitate to settle and shake vigorously again. At this point analysis can be suspended for up to 8 hours (when samples from all sites can be processed at the same time). Care must be taken to ensure that the samples are not exposed to light during the interim. Place in a cooler for transport to shore or laboratory.
* If pre-packaged chemicals are not available, directions for preparation of the chemicals are given in *Standard Methods*.

(d) Add 1 mL of concentrated sulfuric acid (H_2SO_4) with an automatic pipette by inserting the tip just below the surface of the sample. Carefully insert the stopper and shake the bottle until all of the precipitate has dissolved.

(e) Measure 100 mL of the sample with a volumetric pipette and then transfer to a 250 mL Erlenmeyer flask. Touch the tip of the pipette to the side of the flask during delivery.

(f) Titrate with 0.005M standardized sodium thiosulfate solution. Mix the sample during titration until a very pale yellow is observed.

(g) Add 2 drops of stabilized starch solution, mix to get a uniform blue color, and titrate carefully but rapidly to a colourless end point. Record the volume of the titrant used in mL to two decimal places.

(h) Calculate the concentration of dissolved oxygen in the sample as follows:

$$mgO_2/L = \frac{(\text{mL titrant})(\text{molarity of thiosulfate})(8000)}{(\text{mL sample titrated})(\text{mL of bottle} - 2/\text{mL of bottle})}$$

PROTOCOL
(DO meter - most common model YSI 57)

(a) Follow instructions as per the manufacturer directions for storage, transportation, calibration, and use.

(b) Obtain DO readings for increments of 1 - 2 metres both during the descent and the ascent of the probe. Allow probe to equilibrate (a steady reading on the meter) at each depth before recording the value. When passing through a zone of rapid temperature or DO change (a lake thermocline for instance), two to five minutes may be required for equilibration.

Notes:

1. **When membrane function deteriorates, it should be changed to avoid contamination of the sensing element. Air bubbles must not be trapped under the membrane.**
2. **When measuring DO in lake hypolimnia, do not allow the probe to remain in waters of low DO (<0.5 mg/L) as the probe will become damaged.**

Use high sensitivity membranes where possible. Service meters annually. Meters should never be stored for long periods with batteries inside. Probes need cleaning too. Attach tag indicating service date and battery change date. Always carry spare parts, including batteries.

A simplified but thorough set of instructions for operating and calibrating a DO meter should accompany the meter - preferably laminated in plastic.

6.3 Conductivity/Salinity

Conductivity and salinity can be measured with a specific conductance meter or a multi-purpose meter (e.g., a Hydrolab).

PROTOCOL

(a) Follow instructions as per the manufacturer directions for storage, transportation, and use. Check the accuracy of the meter against a conductivity standard.

(b) Obtain readings for increments of 1 - 2 metres both during the descent and the ascent of the probe. Allow probe to equilibrate at each depth before recording value.

(c) Check readings periodically by having water samples measured in a laboratory.

Notes:

1. **Conductivity is a numerical expression of the ability of matter to carry an electric current. If the matter is an aqueous solution the term conductance is synonymous with conductivity. Either term is correct.**
2. **Since the conductance of solutions changes with temperature, a correction is made (usually an internal automatic correction by the instrument) to estimate the conductance at 25 C, called the 'specific conductance.' Note that not all meters have temperature compensation. Also meters having temperature compensation can be damaged such that the temperature compensation is not working. Therefore instrument maintenance checks should include evaluation of the temperature compensation.**

6.4 pH

Either an electronic pH meter or a multi-purpose meter is used to measure pH. Most pH meters require that the sample be brought to the surface, while the Hydrolab can be lowered through the water column. This measurement is accurate for the current conditions only in a fresh sample. Rapid pH changes that occur as a result of gas diffusion, biological activity, and chemical reactions dictate that the measurements be performed immediately.

pH electrodes are available for specific measurement of pH in waters of low ionic strength and high ionic strength. It is imperative when measuring pH in water of low ionic strength that an electrode designed for measurement in solutions of low conductivity or dissolved solids be used. Caution should also be taken that the pH electrodes are functioning correctly - ones in long term use or storage can lose the internal electrolyte and provide inaccurate data.

pH is a deceptively easy measurement to make but without understanding of how to use the equipment correctly, the risk of inaccurate data is very high.

PROTOCOL
(pH meter)

(a) Follow the pH meter manufacturer's instructions for storage and preparation of the electrodes.

(b) Remove electrodes from the storage solution and rinse with distilled water. Electrode fill plug, if present, should be removed before taking readings.

(c) In the field, calibrate the pH meter using two buffer solutions which will bracket the pH range of the samples [one at pH 7, one at acidic pH (4.0 or 5.0), or one at alkaline pH (8.0 or 9.0)]. Place the electrode in each solution

for at least 1 minute (rinse well with distilled water between buffer solutions). If the reading does not correspond to the value of the buffer solution, adjust the meter and record the discrepancy in the field log book. Repeat this process before the end of the sampling day. Samples should be at or near the temperature of the buffers used for calibration or the meter be equipped with a temperature compensation probe.

Note: Never calibrate with just a single buffer solution.

d) Immerse the electrode directly into the surface water or into the field bottle (for samples collected from depth). Allow it to equilibrate before recording the value. Values are typically recorded to the nearest 0.1 pH unit.

(e) Check the field readings by having water samples measured periodically in a laboratory.

PROTOCOL
(pH using a multi-purpose meter)

Note: These meters have automated internal calibration mechanisms that must be checked at time of overhaul maintenance, and the probes must be calibrated for each parameter.

(a) Follow instructions as per the manufacturer's directions for calibration, storage, transportation, and use.

(b) Obtain readings for increments of 1 - 2 metres both during the descent and the ascent of the probe. Allow probe to equilibrate at each depth before recording value.

6.5 Clarity

Water clarity in lakes is most commonly measured with a Secchi disc. The Secchi disc is a weighted disc, 20 cm in diameter, that is divided into black and white quadrants. The measurement is called the 'extinction depth'.

PROTOCOL

(a) Lower the Secchi disc over the shaded side of the boat.

(b) Record the depth at which the pattern of the disc is no longer observable. The disc should then be lowered beyond this depth to determine, when it ascends, the depth at which it reappears. Average the two depth readings to calculate the extinction depth.

(c) Record the value in the field log book along with the weather and water surface conditions (e.g., cloudy, sunny, windy, surface chop, etc.). Measurements should be to the nearest 0.1 meter.

Note: Secchi disc readings should only be taken from 2 hours after dawn to 2 hours before dusk. During winter months, readings should only be taken between 10 A.M. and 2 P.M. Sunglasses should not be worn while taking the measurement.

6.6 ORP

Oxidation-Reduction potential (ORP) is most commonly measured with a multi-purpose meter (e.g., Hydrolab).

PROTOCOL

(a) Follow instructions as per the manufacturer's directions for storage, transportation, calibration and use.

(b) Obtain readings for increments of 1 - 2 metres both during the descent and the ascent of the probe. Allow probe to equilibrate at each depth before recording value.

(c) As the meter approaches the lake bottom (use bathymetric maps or a depth sounder to assess depth), the readings may drop rapidly. At this point, take care that the probe does not contact the sediment.

6.7 Stream Flow

The most accurate measure of stream flow is achieved with a current meter used at multiple points along the cross section of the stream. However, simpler methods may be used if the flow estimates need only be approximate (cross-sectional area, a roughness factor, and floating object provide a very gross estimate of flow).

PROTOCOL
(current meter)

(a) Follow flow meter instructions as per the manufacturer's directions for storage, transportation, calibration, and use.

(b) Extend a measuring tape at right angles to the direction of flow and measure the width of the cross section. Record measurements on a data sheet. Leave the tape strung across the stream.

(c) Divide the width into segments using at least 20 points of measurement. If previous flow measurements have shown uniform depth and velocity, fewer points may be used. Smaller streams may also require fewer points. Measuring points should be closer together where depths or velocities are more variable. Cross sections with uniform depth and velocity can have equal spacing.

(d) Record the distance (from the initial starting bank) and the depth of each point.

(e) Record the current velocity at each measuring point.

Note: Horizontal and vertical variation of stream velocity may influence stream-flow measurements. To correct for vertical differences, hydrologists have determined depths that can yield acceptable estimates of the mean velocity over a vertical profile. If the depth exceeds 0.8 m, it is recommended that velocities be measured at 20 percent and 80 percent of full depth and averaged to estimate mean velocity. In the depth range 0.1-0.8 m, take the velocity at 60 percent of the full depth (measured from the surface) as an estimate of the mean over the profile.

(f) Calculate flow as a summation of flows in partial areas using the following equation:

$$q_n = \frac{v_n \, d_n \, (b_{n+1} + b_{n-1})}{2}$$

where:

q = discharge in partial area n (m^3/sec)
v = average current velocity in partial area n (m/sec)
d = mean depth of partial area n (m)
b_{n+1} = distance from point to the following point (m)
b_{n-1} = distance from point to the preceding point (m)

PROTOCOL
(floating object)

(a) Measure stream width (*w* in meters) and average depth (*d* in meters). Width is width of the water exclusive of dry stream bed. The average depth must be estimated, but is typically 0.4 - 0.6 of maximum depth (for shallow streams and deep streams respectively).

(b) Measure a three meter strip (*l*) along the stream bank that bisects the area measured in step (a) (very fast streams will require a strip longer than 3 m).

Choose a location where both flow and substrate are fairly uniform and representative of the stream reach. Curved areas should be avoided.

(c) Toss a floating object (e.g., cork, twig, etc.) into the flow upstream of the three meter measure area. Time the float as it travels the three meter segment. Repeat this step five times to obtain a mean of the time interval (*t* expressed in seconds). It is recommended that you re-measure until you get 3 measurements very nearly the same.

(d) Discharge is then calculated as follows:

$$q = wdla/t$$

where:

q = discharge (in m^3/second)
a = roughness coefficient (0.8 if rough [boulders], 0.9 if smooth [mud, sand])

7. Field Filtration and Preservation

When the sampling objective is to determine concentrations of dissolved metals, low-level nutrients (e.g., phosphorus), or chlorophyll *a* in a water system, the sample must be filtered through a non-metallic 0.45 µm membrane immediately after collection. The guiding principle is to filter and preserve as soon as possible.

7.1 Filtration

The field filtration apparatus recommended is a portable vacuum system designed for ease of use in the field, thereby minimizing the time between sample collection and filtration (Figure 6). When filtering more than one sample, always filter the samples in the order of lowest expected variable levels to the highest. This minimizes the risk of cross-contamination between samples.

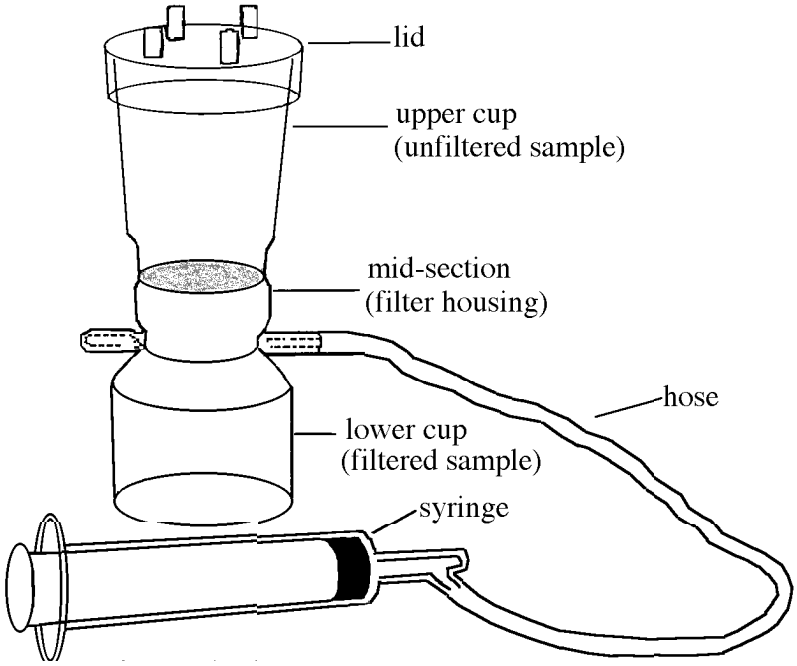

Figure 6. Filtration apparatus

PROTOCOL

(a) Rinse filtration apparatus with de-ionized water.

(b) With a pair of clean, non-metallic tweezers, place a filter paper on the surface of the mid-section of the filter apparatus. Assemble the apparatus as per Figure 6.

(c) Pour 250 mL of de-ionized water in the top section of the apparatus.

(d) Generate a partial vacuum by withdrawing the plunger of the syringe. Reject the initial filtrate (50 mL), then filter the remaining water through to the lower section of the apparatus.

(e) Disassemble the apparatus and pour the filtrate into a labeled sample bottle. This is the first filter blank.

(f) Reassemble the apparatus and filter first sample (as per instruction [d]) and pour the filtrate into a <u>new</u> labeled bottle. Always use standard amount of sample water (i.e., 250 mL) unless otherwise noted.

(g) Rinse the entire apparatus twice with de-ionized water and proceed to next sample. **Always rinse the apparatus thoroughly between sites**.

(h) At some point between samples (or after the last sample - if not filtering many samples), rinse the apparatus twice, change the filter paper, and filter 250 mL of de-ionized water. Transfer the filtrate to a labeled 'blank' bottle (e.g., 2nd filter blank or final filter blank).

Note: Other filtration techniques are also available and acceptable (e.g., Nalgene hand operated vacuum pump, disposable luer-lok syringes, etc.). Dedicate different sets of filtering apparatus for ambient, receiving water and effluent.

Note: The apparatus should be cleaned in a lab between field uses by soaking in dilute nitric acid solution followed by de-ionized water rinse and placing the dry and clean apparatus in a resealable bag (e.g., Zip Lock) for transportation.

7.2 Preservation

Many preservatives are considered hazardous materials and, therefore, the regulations outlined by WHMIS (Workplace Hazardous Materials Information System) must be adhered to. Read safety instructions and WHMIS material safety data sheets supplied for each preservative.

Deteriorated samples negate all the efforts and cost expended in obtaining representative samples. In general, the shorter the elapsed time between collection and analysis, the more reliable the analytical results.

Bulk dispensers for preservatives are <u>not</u> recommended due to the risk of contamination and deterioration over time. Preservatives should be pre-packaged in the laboratory in single-sample vials or ampoules to reduce the risk of contamination. Each of these ampoules should be labeled and have an expiry date beyond which they must be discarded in accordance with WHMIS regulations.

Note: Never use vials having Bakelite, or like material, as filler behind the cap liner of the lid.

Refer to Appendix 4 of this chapter for the quantity and type of preservative required for each individual analysis. Avoid pouring preservative down inside surface of sample bottle.

PROTOCOL

(a) Before beginning, put on latex gloves and safety glasses or goggles.

(b) Add preservatives to those samples which need preservation, being sure to match each preservative with its similarly labeled sample bottle. Preservative containers must not come in contact with the sample or inside of the sample bottle/lid. Minimize the length of time that the sample or preservative is exposed to the atmosphere.

(c) Recap sample bottles tightly and invert twice to mix.

(d) Recap the preservative bottles/vials tightly and place into a protective container. Ship these and latex gloves back to the lab with the samples for disposal.

Note: Consult WHMIS for recommended procedures for spill cleanup. Samplers should become familiar with WHMIS procedures before going into the field.

8. Shipping

The day's sampling schedule must be designed to ensure that the samples arrive at the shipping agency's terminal well before the end of business hours. Since some variables have very limited hold times (see Appendix 4), every effort must be made to avoid delays in shipping. The following is the procedure to be followed to maintain the integrity of the samples during transit.

PROTOCOL

Note: Ice packs should be used as opposed to loose ice or bagged ice. When loose ice melts, the contents of the cooler are free to shift, potentially allowing contamination of samples with melted ice water and/or breakage of glass bottles.

(a) Pack the samples upright in the cooler with at least 1 (winter) to 2 (spring, summer, fall) times as much ice as the total volume of the samples. Ensure that the samples that are most likely to deteriorate are closest to the ice packs (i.e., those that are not chemically preserved). Also, ensure that the glass bottles are separated from each other by ice packs, plastic bottles, or clean packing material to prevent them from shifting, falling over and/or breaking.

(b) Complete the laboratory requisition forms, enclose them in a sealed plastic bag, and then tape them to the inside lid of the cooler or place them in the cooler on top of the samples. The recommended minimum information that should accompany samples to the laboratory (on each requisition form) includes:

- Name of the source
- Site name
- EMS site numbers
- Date and time of collection
- Name of collector
- Field measurements
- Comments on sample appearance, weather conditions, and any other observations that may assist in interpreting water quality data

Additionally, a request should be made to the laboratory that they record the time and temperature of the samples at arrival (whenever samples requiring preservation by cooling to 4°C are shipped).

(c) Seal the cooler with heavy duty packing tape to reduce the possibility of it accidentally opening and to prevent tampering with the samples. Coolers arriving at the laboratory with torn or absent tape alert the lab staff that tampering might have occurred during transit.

(d) Attach a label prominently displaying the destination.

Note: If data on temperature on arrival is requested (to document that samples arrived at the laboratory at proper temperatures), a separate labeled bottle with water in it should be shipped in each cooler.

9. Cleaning Equipment

Equipment cleanness is an essential factor in ensuring that samples remain contaminant-free. All sampling devices (Van Dorn, multiple sampler, through ice sampler, tow nets, etc.) must be thoroughly cleaned and scrubbed with de-ionized water after each sampling trip. This process should be followed by two or three rinses with de-ionized water. The last rinsate should be collected and shipped for analysis as an equipment blank (see section 3.2.1.3).

Note: The Van Dorn sampler should be stored in the open position to prevent moisture from being trapped (might promote fungal or bacterial growth).

General cleanliness considerations include:

- Shipping containers (coolers) wiped free of dirt and rinsed with de-ionized water
- Vehicle neat and tidy
- Trailer, boat and motor free of aquatic plants before use on another body of water

The filtration apparatus must be soaked in an acid bath (10% HCl) and rinsed three times with de-ionized water. The final rinsate should be submitted periodically as an equipment blank.

Equipment used for ambient sampling should not be used for effluent sampling. Each type of sampling should have equipment dedicated to that use.

10. Sources of Further Information

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11. Revision History

October 10, 2013: This section republished without change. Notes added to Appendix 4: Sample Container, Preservation, and Hold Times for Water and Effluent Samples updated.

Appendix 1 Generic Field Checklist

(including water, sediments, biota and effluents)

General:

Log Books____ Pencils____
Cooler (with ice packs)____ Felt Markers (waterproof)____
Rope____ Tape____
Camera (film)____ Requisition forms____
Way bills____ Shipping labels____
De-ionized water (4L)____ Squirt bottle____
Resealable bags____ maps____

Labeled Sample Bottles:

General chemistry (1 L) #____ General chemistry (2 L) #____
Dissolved Metals #____ Total Metals #____
Total Organic Carbon #____ Low-level nutrients #____
Coliforms #____ Sediments #____
Zooplankton #____ Phytoplankton #____
Periphyton #____ Invertebrates #____
Tissue cups #____ Macrophytes____
Extras - two of each

Sampling Equipment (clean, in working order, batteries charged):

DO Sampler (BOD bottle, Winkler reagents)____
Thermometer____DO meter____
pH meter____ Conductivity meter____
Hydrolab____ Secchi disc____
Van Dorn, rope____ Through Ice Sampler____
Auger (bit sharpened, skimmer)____ Spare probe membranes (repair kit)____
Sediment grab____ 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:

Filter Pots____ Syringe(s), Hose____
Tweezers____ 0.45/1.0 µ membrane filters____
Preservative Vials with acid____ Disposal Container (for used vials)____
70% ethanol____ Formalin_____
Lugol's solution____ Magnesium carbonate____
Boat Equipment:
Canoe (or boat)____ Paddles____
Motor____ Fuel____
Life jackets____ Rope____
Anchor____ Tool kit____

Personal Gear:

Lunch____ Survival suit____
Rain gear____ Gum boots____
Waders (hip, chest)____ Sun screen____

Safety:

WHMIS guidelines____ First Aid Kit____
Goggles (or safety glasses)____ Rubber gloves____
Hard Hat (for industrial sites)_____

Appendix 2 Site Identification

Appendix 2.1 Site Identification Guide

Appendix 2.2 Site Data Sheet (Lake)

Appendix 2.3 Site Data Sheet (River)

Appendix 2.4 Site Data Sheet (Effluent)

Appendix 2.1 Site Identification Guide

Lake / river name _____

EMS site number _____

Latitude _____

Longitude _____

Map sheet number _____ Elevation _____

Access road names or numbers _____

NOTES:

Distinguishing features

_____
_____
_____
_____

Best access point to water

_____
_____

Photograph/Access map

Appendix 2.2 Site Data Sheet (Lake)

EMS site number _____
Date _____
Time _____
Weather _____
Air temperature _____

Field Measurements:

Secchi depth _____

Depth (m)	Temp		D.O.		pH	Cond	ORP
	down	up	down	up			
0							
2							
4							
6							
8							
10							
12							
14							
16							
18							
20							
22							
24							
26							
28							
30 (or depths appr. to lake)							

Appendix 2.3 Site Data Sheet (River)

Site number _____

Date _____

Time _____

Weather _____

Air temperature _____

Field Measurements:

Water temperature _____

D.O. _____

pH _____

Conductivity _____

Flow / discharge _____

Stage (rising / falling) _____

Substrate type _____

Flow Data Measurements for Cross-Sections:

Appendix 2.4 Site Data Sheet (Effluent)

Site number_____

Date_____

Time_____

Weather_____

Site Observations

Effluent description_____

Site observation_____

Maintenance/process considerations_____

Appendix 3 Sampling For The Most Common Variables

Appendix 3.1 General Chemistry (including nutrients)

Appendix 3.2 Metals

Appendix 3.3 Carbon

Appendix 3.4 Chlorophyll *a*

Appendix 3.1 General Chemistry (including nutrients)

3.1.1 General chemistry (including acidity, alkalinity, chloride, colour, fluoride, hardness, nitrogen, pH, phosphorus, potassium, silica, sodium, specific conductance, sulfate and turbidity)

PROTOCOL

(a) Collect sample for all nutrients (as per sections 4 & 5) in a pre-labeled, plastic bottle (250mL to 2L depending on how many tests needed).

(b) Secure lid tightly and place in cooler with ice packs immediately.

(c) Do not field filter or preserve.

3.1.2 Low-level nutrients (phosphorus and nitrogen)

PROTOCOL

(a) Collect sample (as per sections 4 & 5) in a pre-cleaned (do not rinse), pre-labeled 250 mL brown glass bottle.

(b) Field filter all low-level nutrient samples. Always return filtered sample to a new (clean) pre-labeled bottle.

(c) Secure lid tightly and place in cooler immediately.

(d) Do not field preserve.

Appendix 3.2 Metals

3.2.1 Total metals

PROTOCOL

(a) Collect sample (as per sections 4 & 5) in a pre-cleaned (do not rinse), pre-labeled 500 mL plastic bottle.

(b) Preserve the total metals samples with nitric acid (HNO_3 provided by the analytical laboratory in individual ampules).

(c) Secure lid tightly and place in cooler immediately.

(d) Do not field filter.

3.2.2 Dissolved metals

PROTOCOL

(a) Collect sample (as per sections 4 & 5) in a pre-cleaned (do not rinse), pre-labeled 500 mL plastic bottle.

(b) Field filter all dissolved metal samples. Always transfer the filtered sample to a new (clean) pre-labeled bottle. Field filtration is a procedure where contamination often occurs. Extreme caution should be exercised.

(c) Once the sample has been field filtered and transferred to a new bottle, then preserve with nitric acid (HNO_3 provided by the analytical laboratory in individual ampules).

Secure lid tightly and place in cooler immediately.

Appendix 3.3 Carbon

3.3.1 Total organic/inorganic carbon

PROTOCOL

(a) Collect sample (as per sections 4 & 5) in a pre-labeled 250 mL plastic bottle.

(b) Secure lid tightly, ensuring that no air is trapped in the bottle, and place in cooler with ice packs immediately.

(c) Do not field filter or preserve.

3.3.2 Dissolved organic/inorganic carbon

(a) Collect sample (as per sections 4 & 5) in a pre-labeled 250 mL plastic bottle.

(b) Field filter each dissolved carbon sample. Always transfer filtered sample to a new (clean) pre-labeled bottle.

(c) Secure lid tightly, ensuring that no air is trapped in the bottle, and place in cooler with ice packs immediately.

(d) Do not field preserve.

Appendix 3.4 Chlorophyll *a*

PROTOCOL

(a) Collect sample (as per section 4) into a pre-labeled plastic bottle.

(b) Secure lid tightly and immediately place in cooler with ice packs.

(c) When all samples for the day are collected, filter (using a .45 micron membrane filter) an appropriate portion of the chlorophyll *a* sample. This can be done in the field or in the lab within a few hours of collection if the samples are kept dark and cool. The filtration should be done in cool temperature and subdued light (not on the tailgate at the boat ramp!). The amount of sample filtered depends on the density of the algae present (productive lakes may require only 50 mL, unproductive lakes may require 1 L to be filtered). **Always record the volume of sample that was filtered (both in the field log book and on the Laboratory Requisition Form)**.

(d) As the water sample is filtered, observe the filtration pressure or vacuum (<5psi) and the water level. When all but the last few mLs of water are drawn through the filter, rinse the top holding cup with de-ionized water and continue to filter. Before the rinse water is fully filtered, add 2-3 drops of $MgCO_3$ suspension (1g magnesium carbonate / 100 mL de-ionized water) and gently swirl the apparatus to distribute the $MgCO_3$. Magnesium carbonate is a buffer to stabilize the pH of the algal cells above 7. The cells are very sensitive to acid pH as the chlorophyll will then be degraded to other pigments like phaeophytins.

(e) With clean tweezers, carefully remove the filter and place it in the center of a larger (9 cm) 'Whatman' filter paper. Fold the two papers in half and then in half again (with the smaller filter paper inside the larger). Secure the filter papers shut with a plastic paper clip. With a **pencil**, label the 'Whatman' filter paper as a chlorophyll sample. Also, for each sample, identify the date, site number and the volume of water filtered directly onto the 'Whatman' filter paper.

Note: Some brands of filter papers have throw-away plastic separators. On occasion, it has happened that people have confused these plastic separators with membrane filters separated by throw-away paper. Be sure you know which is the filter and which is the throw-away!

(f) Place the filter paper in a pre-cooled dark bottle (amber glass, wrapped with aluminum foil and black tape - chlorophyll is very sensitive to degradation by light) that contains a desiccating agent (i.e., silica gel).

Note: Silica gel will take up water until it is saturated, at which point it must be rejuvenated by heating it in an oven for several hours. Ordinary silica gel is white, whether fresh or saturated. However, dye is often added to warn you when the gel has been saturated. Usually fresh silica gel is blue and completely saturated gel is pink. Partially saturated gel is both blue and pink (i.e., purple). Note that some brands of silica gel use other colours so be sure what color change you should expect. This is readily done by wetting a gel crystal to check the colour for saturated silica gel. Never use saturated silica gel.

Two common errors by untrained staff are to use saturated gel, or to attach the gel outside the bottle.

(g) Pack the bottle containing all chlorophyll *a* samples in a cooler with ice packs (or dry ice) so that they remain frozen until they reach the analyzing laboratory.

(h) Filters stored inside a dark bottle with dessicant can be stored in a deep freeze for a week or two but it is far preferable to ship them to the lab immediately.

Appendix 4 Sample Container, Preservation, and Hold Times for Water and Effluent Samples

TYPE OF ANALYSIS[1, 2]	STORAGE TEMP[3]	CONTAINER TYPE	PRESERVATION	HOLD TIME[4] (days)
PHYSICAL & AGGREGATE PROPERTIES				
Acidity	≤6ºC	P, G	none	14
Alkalinity	≤6ºC	P, G	none	14
Colour	≤6ºC	P, G	none	3
Conductivity	≤6ºC	P, G	none	28
pH	≤6ºC	P, G	none	15 min.
Solids (Total, TSS, TDS, Fixed, Volatile, etc.)	6ºC	P, G	none	7
Turbidity	≤6ºC	P, G	store in the dark	3
WATER - INORGANIC ANALYSIS				
Bromide	no req.	P, G	none	28
Chloride	no req.	P, G	none	28
Chlorate, Bromate	≤6ºC	P, G	50 mg/L EDA	28
Chlorine, Total Residual (Free Chlorine)	none	P, G	none	15 min.
Chlorite	≤6ºC	P, A, G	50 mg/L EDA	14
Cyanide, SAD and/or WAD	≤6ºC	P, G	field NaOH, store in dark	14
			none	1
Dissolved Oxygen (Winkler Method)	≤6ºC	G, BOD bottle	Winkler kit, store in dark	8 hours
Fluoride	no req.	P	none	28
Nitrogen, Nitrate + Nitrite	≤6ºC	P, G	H_2SO_4	28
			none (BC MOE)	3
Nitrogen, Ammonia	≤6ºC	P, G	H_2SO_4	28
			none (BC MOE)	3
Nitrogen, Nitrate	≤6ºC, do not freeze	P, G	none	3
Nitrogen, Nitrite	≤6ºC, do not freeze	P, G	none	3

Nitrogen, Total Kjeldahl	≤6ºC	P, G	H_2SO_4 none (BC MOE)	28 3
Nitrogen, Total, Persulfate Method	≤6ºC	P, G	H_2SO_4 none (BC MOE)	28 3
Nitrogen, Total, Combustion Method	≤6ºC	P, G	HCl none (BC MOE)	28 3
Phosphorus, Dissolved (Orthophosphate)	≤6ºC	P, G	filter (field or lab)	3
Phosphorus, Total Reactive (Orthophosphate)	≤6ºC	P, G	none	3
Phosphorus, Total Dissolved	≤6ºC	P, G	filter, H_2SO_4 none	28 3
Phosphorus, Total	≤6ºC	P, G	H_2SO_4 none (BC MOE)	28 3
Silica, Reactive	≤6ºC, do not freeze	P	none	28
Sulfate	≤6ºC	P, G	none	28
Sulfide	≤6ºC	P or G	ZnAc / NaOH to pH >9	7
METALS				
Hexavalent Chominum	≤6ºC	P, G	1ml 50% NaOH per 125ml none	30 1
Metals, Total	≤6ºC	P, G	HNO_3[7]	180
Metals, Dissolved	no req.	P, G	field filter 0.45um + HNO_3[7]	180
Mercury, Total	no req.	G, PTFE	HCL or BrCL[8]	28
Mercury, dissolved	no req.	G, PTFE	field filter 0.45 um + HCL or BrCL[7]	28

AGGREGATE ORGANIC ANALYSIS

AOX (Absorbable Organic Halides)	≤6ºC	A, G	HNO_3, store in dark sodium sulfite if chlorinated, collect with no headspace	14
Biochemical Oxygen Demand (BOD)	≤6ºC, do not freeze	P, G	none	3
Carbonaceous Biochemical Oxygen Demand (CBOD)	≤6ºC, do not freeze	P, G	none	3
Carbon, Dissolved Organic	≤6ºC	P, G	filter, H_2SO_4 or HCl none (BC MOE)	28 3
Carbon, Dissolved Inorganic	≤6ºC	P, G	field filter	14
Carbon, Total Organic	≤6ºC	P, G	H_2SO_4 or HCl	28
Carbon, Total Inorganic	≤6ºC	P, G	none	14
Chemical Oxygen Demand (COD)	≤6ºC	P, G	H_2SO_4 (field or lab) none (BC MOE)	28 3
Chlorophyll *a*	Filters: freeze	Filter	field filter, store in dark	Filters: 28
	≤6ºC	P, A, G	unfiltered, store in dark	2
Phaeophytin	Filters: freeze	Filter	field filter, store in dark	Filters: 28
Surfactants (Methylene Blue Active Substances)	≤6ºC	P, G	none	3
Total Phenols (4AAP)	≤6ºC	P, G	H_2SO_4	28

EXTRACTABLE HYDROCARBONS

Extractable Hydrocarbons (LEPH, HEPH, EPH)	≤6ºC	A, G	HCl, H_2SO_4 or Sodium Bisulfate none	14/40 7/40
Oil & Grease / Mineral Oil and Grease	≤6ºC	A, G	HCL or H_2SO_4	28
Waste Oil Content	≤6ºC	A, G	none	28

INDIVIDUAL ORGANIC COMPOUNDS

Carbamate Pesticides	≤6ºC	A, G	Potassium Dihydrogen Citrate (solid), ~pH 3.8, 9.2-9.5 g/L, + 100 mg/L $Na_2S_2O_3$ if chlorinated	28
			ChlorAC buffer, ~pH 3, 1.8mL/60 mL sample + 100 mg/L $Na_2S_2O_3$ if chlorinated	28
Chlorinated and Non-chlorinated Phenolics	≤6ºC	A, G	0.5g Ascorbic Acid / L + H_2SO_4 or Sodium Bisulfate	14/40
			none	7/40
Dioxins / Furans	≤6ºC	G, A	none	un-limited
Glyphosate / AMPA	≤6ºC	A, G or Poly-propylene	100 mg/L $Na_2S_2O_3$ if chlorinated	14
Glycols	≤6ºC	G	HCL or H_2SO_4 or Sodium Bisulfate	14/40
			none	7/40
Halogenated Hydrocarbons (Semi-Volatile)	≤6ºC	A, G	100 mg/L $Na_2S_2O_3$ if chlorinated	7/40
Herbicides, Acid Extractable	≤6ºC	A, G	HCL (optional), store in dark, 50 mg/L $Na_2S_2O_3$ if chlorinated	14/21
Paraquat / Diquat	≤6ºC	A, G	100 mg/L $Na_2S_2O_3$ if chlorinated	7/21
Pesticides (NP, OP, OC)	≤6ºC	A, G	none	7/40
Polychlorinated Biphenyls (PCBs)	≤6ºC	A, G	none	un-limited
Polycyclic Aromatic Hydrocarbons (PAHs)	≤6ºC	A, G	HCL, H_2SO_4 or Sodium Bisulfate	14/40
			none	7/40

Resin Acids, Fatty Acids	≤6ºC	A, G	(0.5g Ascorbic Acid + 0.4g NaOH) / L none	14/40 7/40
Volatiles Organic Compounds (Trihalomethanes)	≤6ºC	43ml G VOC Vials(2-3)	3 mg Na2S2O3 (see BC Lab Manual method for more details)	14
Volatiles Organic Compounds	≤6ºC	43ml G VOC Vials(2-3)	200 mg NaHSO4, or 3 mg $Na_2S_2O_3$ Id chlorinated (see BC Lab Manual method for other options and details)	14

LEGEND

P = plastic	Ster = sterilized	no req = no requirement
G = glass	Solv = solvent cleaned	P&T = purge and trap vials
A = amber	Fc = foil-lined cap	
W = wide mouth	R = acid rinsed	
T = tissue cup	B = baked	

Note: The preservation acids/bases specify a pH endpoint (pH²2 or pH³12). The appropriate amount of preservative for a set of samples should be determined by titration on water samples collected specifically for that purpose. The amount of preservative needed should never be arrived at by titrating and measuring the pH of the actual sample!!! All preservatives should be high purity, lab approved materials.

The preservatives used should be supplied from the analytical lab in ampules. The lab will verify their purity and provide an expiration date, beyond which they should not be used.

Note: These are the preservation and hold times for the present (2013) BC MOE sample preservation & holding time requirements [1, 2] contract laboratory for the Ministry. Different labs, organizations and protocols may differ, as may future laboratory procedures.

[1] A Director or an Environmental Management Act permit may specify alternate requirements.

[2] Refer to applicable BC Environmental Laboratory Manual methods for additional detail. Where differences exist between Lab Manual methods and this table, this table takes precedence.

[3] Storage temperature applies to storage at the laboratory. For all tests where refrigeration at ≤6°C is required at the laboratory, samples should be packed with ice or cold packs to maintain a temperature of ≤10°C during transport to the laboratory. The storage of ≤8°C for microbiological samples applies during storage at the laboratory and during transport to the laboratory. To prevent breakage, water samples stored in glass should not be frozen. Except where indicated by "do not freeze", test results need not be qualified for frozen samples.

[4] Hold Times: Single values refer to hold time from sampling to analysis. Where 2 values are given, the first is hold time from sampling to extraction, and the second is hold time from extraction to analysis.

[5] Samples received from remote locations more than 48 hours after collection must not be tested.

[6] Methanol extraction or freezing must be initiated within 48 hours of arrival at lab, to a maximum of 7 days from sample collection. Alternatively, samples may be frozen in the field if extracted within 14 days of sampling, or may be methanol extracted in the field.

[7] Samples collected for dissolved metals analysis must be filtered in the field as soon as possible after collection (preferably within 15 minutes). This is particularly important for groundwaters where exposure to atmospheric conditions can trigger redox reactions that cause certain metals to precipitate (particularly iron). If precipitation of iron oxides occurs, many other heavy metals may precipitate or co-precipitate, potentially causing substantially low bias for many metallic elements. In extreme cases, some elements may be 100% removed from solution due to precipitation or co-precipitation caused by delay of filtration. Samples collected for dissolved metals analysis must be field filtered and then preserved with HNO3.

If not field-preserved, water samples collected for total metals analysis must be acidified at the lab in their original containers by addition of HNO_3 (within 14 days of sampling), then equilibrated at least 16 hours prior to sub-sampling or analysis (otherwise, qualify as "received unpreserved"). Not applicable to mercury.

[8] Use only glass or PTFE containers to collect water samples for total or dissolved mercury. For total mercury, field-preserve with HCl or BrCl. Adding BrCl to original sample container at the laboratory within 28 days of sampling is an acceptable alternative for total mercury if samples are oxidized for 24 hours prior to sub-sampling or analysis. Samples collected for dissolved mercury analysis must be field filtered and then preserved with HCl or BrCl although BrCl is not recommended for use in the field for safety reasons.

Appendix 5 Effluent Sampling Checklist Guide

Location _____

Sample point _____

Date _____

NOTE: Ensure sampling point is agreeable to MELP and Permittee for determining compliance and in compliance to WCB regulations and safety requirements. Take samples for what is allowed by permit, or for what is requested. All sampling bottles should be clearly labelled and dated; and shipped to the designated lab immediately.

TEST PARAMETERS OF SAMPLE

Test Parameter	Sample Frequency and Type	Allowable Level

A. SAMPLE POINT **YES** **NO**

Is the sample point:

1. accessible under all weather and tide conditions? ___ ___
2. near the centre of the stream? ___ ___
3. in a turbulent mixing zone (immediately downstream from a flow disturbance such as a pipe constriction, bend or flow control device)? (describe disturbance in Comments) ___ ___
4. at least 6 pipe diameters downstream from where two separate pipe streams combine (point of confluence)? ___ ___

Comments: _____

_____

_____

Appendix 5.1 Effluent Sampling Checklist

B. TYPE OF SAMPLE	YES	NO
1.Grab Sample	___	___
a) Does permit allow grab sample?	___	___
b) Is volume collected ≥ 1 litre?	___	___
c) Is collection time ≤ 15 minutes?	___	___
2.Composite Sample	___	___
a) Does permit allow composite sample?	___	___
b) Compositing period: _____		
c) Is sampling frequency > 4x / hour?	___	___
d) Are individual grabs of equal volume?	___	___
e) Is flow variation less than ± 15% of daily mean more than 10% of the time?	___	___
f) Is flow proportional sampling performed?	___	___
3.Automatic Sampling Device (Grab or Composite)	___	___
a) Type: _____ _____		
b) Is the automatic sampling device equipped with a purge mechanism?	___	___
d) Is the velocity in the sampling line at least 0.75 m/s?	___	___
f) Do the components of the sampling device consist of acceptable materials for the parameter being sampled? (plastic for BOD and TSS analysis)	___	___
4.Continuous Sampling	___	___
a) Parameters sampled: _____ _____		
5.Split Sampling	___	___
a) Is the sample splitting device appropriate?	___	___
b) Has it been approved?	___	___
c) Was the splitter cleaned, as prescribed, prior to use?	___	___
d) Was the entire sample directed through splitter?	___	___

Comments: _____

_____

_____

Effluent Sampling Checklist

C. SAMPLER DESIGN AND OPERATION	YES	NO
1. Are sample bottles lab pre-cleaned?	___	___
2. Are components of storage container compatible with effluent parameter to be tested? (e.g. plastic for BOD, TSS; glass for oil)	___	___
3. Are all parts that come in contact with effluent cleaned regularly?	___	___
4. Are buckets, storage vessels, etc. that are reused		
a) rinsed 3 times with de-ionised water (W) or sample (S)? (if YES, specify whether (W) or (S) was used)	___	___
b) rinsed 3 times with acetone and once with de-ionised water, **if organic parameters are sampled**?	___	___

Comments:_____

_____

_____

_____

D. SAMPLE PRESERVATION AND STORAGE	YES	NO
1. Is sample immediately cooled to 4°C (± 2°C), if required?	___	___
2. Is elapsed time for testing sensitive parameters ≤ 48 hours? (elapsed time for composite sample begins with the last sample collected)	___	___
3. Is sample filtered prior to preservation? (dissolved metals and nutrients)	___	___
4. Is preservation required?	___	___
5. Are blanks submitted with samples?	___	___
6. Parameters to be analysed:_____ _____	___	___

Comments: _____

_____

_____

_____

GROUNDWATER POLLUTION MONITORING

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1. Introduction

The Environmental Protection Department (EPD) of the British Columbia Ministry of Environment, Lands and Parks (MELP) has, as part of its mandate, the regulation of permits related to industrial and domestic effluents, storage and transportation of special wastes, and refuse discharge sites. The ministry must also respond to unregulated discharges, whether accidental or intentional, that could result in contaminant loadings to groundwater.

These guidelines are intended to provide appropriate and effective methods to assess the extent of groundwater contamination and the potential for impact on human health and the environment.

Groundwater monitoring programs must be designed and implemented by qualified personnel to ensure consistent and representative sampling. All monitoring and sampling equipment must be operated and maintained in such a manner as to perform to design specifications for the duration of the monitoring program.

2. Preliminary Assessment

Groundwater monitoring at a site under investigation is intended to detect unacceptable groundwater contamination whether this results from a permitted operation or from an accidental or intentional discharge of contaminants (a spill). Acceptable contaminant levels are specified by the Manager and will generally be in accordance with the *Approved and Working Criteria for Water Quality - 1994*, published by the Water Quality Branch of the BC Ministry of Environment, Lands and Parks. The type of activity at the permitted site or the nature of the material spilled will dictate the parameters sampled for, and the hydrogeology of the area concerned will govern the sampling location(s), methods, and frequency.

2.1 Potential Contaminants

For a site under permit or regulation, the list of regulated parameters and site activities will provide the basis for requested analyses. For non-regulated activities and spill scenarios, investigation may be required to determine what contaminants and parameters need to be determined. This may entail, for example, analysis of the spilled material or tracking of the material through shipping or commercial documentation (e.g., TDG and WHMIS).

2.2 Hydrogeological Studies

The location and number of monitoring wells (piezometers) required to adequately describe hydrogeologic conditions will depend upon the site-specific geology, soil, and groundwater regime as well as the suspected character and quantity of the contaminant. Networks of monitoring wells are often developed in phases, with data reviewed at the end of each phase to determine if the hydraulics of the site are being adequately defined. A groundwater monitoring well network will consist of a sufficient number of wells, installed at appropriate locations and depths, to yield samples that represent the quality of both ambient groundwater and leachate which has passed under or through the affected area of the site.

A groundwater monitoring program for a permitted site is a long term project. For example, a landfill groundwater monitoring program may extend through the entire post-closure period (a minimum period of 25 years) as well as during the operational period of the landfill. Nonpermitted sites may also require extended monitoring depending on the type of contamination (solubility, etc.) and the potential for impact on human health and the environment. As a consequence, planning for the location and installation of monitoring wells in and around the sites should include consideration of both existing and anticipated site development as well as the type of contaminant plume involved and address any predicted changes in groundwater flow.

3. Monitoring System Design

Hydrogeological investigations are required to determine the appropriate location and depth of monitoring wells. Nearly all hydrogeological investigations include a subsurface boring program which is necessary to define the hydrogeology and local geological conditions of the site. For boreholes that will be completed as monitoring wells, generally at least one groundwater sample should be collected from each lithological zone. (If drilling in contaminated materials, care should be taken to prevent contaminants from migrating vertically into clean strata). Boreholes that will not be completed as monitoring wells must be properly decommissioned (e.g., back filled with impervious material if necessary).

The number of boreholes required to delineate hydrogeological conditions will vary from site to site. On average, seven holes are drilled for sites with a relatively uniform lithology. There are exceptions; for example, some sites in British Columbia (former Expo lands and a dichloroethane spill near Fort Langley) have required over two hundred test holes, but these would generally be installed over a multi-phase program.

Considerations for selecting drilling sites should include (Piteau, ‘90):

- Bore holes located both up and down gradient with respect to groundwater flow from the suspected contaminated source

- Bore holes drilled in both permeable zones and zones where low permeable material is expected
- Networks of holes to construct hydrogeologic and contaminant plume profiles.
- Completion of test holes as permanent monitoring wells.

The uppermost aquifer and confining layers should be characterized by installing piezometers to determine:

- The direction and rate of groundwater flow (both horizontal and vertical)
- Seasonal/temporal, natural, and artificially induced short-term and long-term variations in groundwater elevations and flow patterns, contaminant concentrations and free product thicknesses.
- The hydraulic conductivity of the stratigraphic units at the site
- The lateral and vertical extent of contamination.

4. Monitoring Well Specifications

Groundwater monitoring wells are installed in and around a site to allow measurement of water level and sampling of groundwater for contaminants. Monitoring well construction materials are discussed in section 4.2. Although well construction is not, strictly speaking, part of the sampling protocol, improper drilling techniques and screen slot selection may bias subsequent analyses regardless of the care taken to avoid contamination during collection of the sample.

4.1 Well Design and Dimensions

Monitoring wells must include a protective casing that preserves the integrity of the borehole and if required, be monitored to meet design specifications. This casing must be screened and packed with a filter to enable the collection of sediment-free groundwater samples. Well screen slot size should be based on hydrologic characteristics and on the grain-size distribution of the aquifer being monitored. The primary filter pack material should be a chemically inert material, well rounded, and uniform in size. The most common filter packs are made of sand or gravel. At least two inches of filter pack material should be installed in the annular space and sealed above the sampling depth to prevent contamination of samples. The seals and grout are generally constructed of bentonite and/or cement, as appropriate. Refer to Appendix 3 of this chapter for typical monitoring well design.

Monitoring wells can range in diameter from 25mm-150mm, with a 50mm diameter the most common. The diameter of a monitoring well should be the minimum practical size which will allow for proper development of the well screen and operation of the sampling device. Large diameter wells (greater than 50 mm) are not recommended as they hold large volumes of water which require more purging prior to sampling.

Piezometers should have as short a screened interval as possible for measuring total hydraulic head. Screens can range in length from a few centimetres to tens of metres. They are typically found to be between 0.5-1.5 m in length and are sealed in intervals slightly longer. Short screens provide discrete data while long screens have limited application. Longer screens obtain a sample that represents the "average" chemistry of water flowing through the aquifer and is a function of all of the different heads over the entire length of the screened interval.

Well screens longer than 1.5 metres may be justified. Examples are provided below; however, in such cases, wells with smaller screen lengths must be installed in nest formations to facilitate contaminant sampling.

- When natural water level fluctuations dictate a longer screen length (this may be better accommodated by a longer casing);
- When the interval monitored is slightly greater (thicker) than the appropriate screen length;
- When a homogeneous, extremely thick aquifer (i.e., greater than 90m) is being monitored, a longer screen (i.e., 6m), representing a comparatively discrete interval, may be necessary;
- Where soils with extremely low hydraulic conductivity are encountered;
- When monitoring a significant thickness of a light nonaqueous phase liquid (NAPL) on top of groundwater; or
- When monitoring NAPLs in an aquifer with significant seasonal water table fluctuation.

4.2 Materials

Each monitoring program should be considered unique when determining monitoring well construction materials. The choice of construction material will depend on the following factors: cost, availability, strength, and chemical and physical compatibility with groundwater and potential analytes. There are a variety of materials on the market with a wide price range. An assessment of material suitability for monitoring well construction is summarized in Appendix 1.

Due to availability and cost, polyvinylchloride (PVC) tends to be the most common choice. Most often, the piezometer is constructed of 50 mm diameter threaded, sealed PVC pipe with fine slotted manufactured well screens. However, recent studies investigating the absorption and release of organic compounds by rigid PVC have led the EPA to recommend, for EPA protocol sites, the use of well construction materials made of (PTFE) or stainless steel as opposed to PVC. Unfortunately, the costs of stainless steel and PTFE are considerably more expensive than PVC (see Appendix 1). In

certain cases it may be advantageous to design a well using more than one type of material. For example, where stainless steel may be preferred in a specific chemical environment, costs may be saved by using PVC in non-critical portions of the well.

Additional components required for the monitoring well (e.g., primary filter pack, riser, etc.), including joints/couplings, should be comprised of material that will not alter the quality of water samples for the constituents of concern. With the exception of the primary filter pack, the additional components are commonly fabricated from PVC, stainless steel, fibreglass, or fluoropolymer. Materials recommended to prevent joints from leaking include PTFE tape for tapered thread joints and o-rings with a known chemistry for flush joint threads. Glued or solvent joints of any type are not recommended, especially where analysis for organic contaminants is anticipated, since glues and solvents may alter the chemistry of water samples (ASTM D5092-90). For further information regarding size specifications and/or installation procedures, refer to ASTM Designations: D5092-90.

5. Well Construction

5.1 Drilling Techniques

Well drilling methods commonly used in BC include air rotary, sonic drilling, cable tool, hollow stem auger, and Becker hammer. The method selection is usually dictated by the anticipated ground conditions and the availability of equipment.

Whenever feasible, drilling procedures should be utilized that do not require the injection of water or drilling fluids into the borehole, and that optimize cuttings control at ground surface. Where the use of drilling fluids is unavoidable, the selected fluid should have as little impact as possible on the water samples for the constituents of interest (ASTM D5092-90). Preliminary laboratory testing of the fluid may be useful in determining potential for contamination. Furthermore, extreme care must be exercised when drilling at or near a geo technical liner (a punctured liner would severely impact the effectiveness of a leachate collection system). It is the responsibility of both the driller and the permittee to ensure that the monitoring well is installed correctly and the integrity of the liner is maintained.

A matrix of appropriate drilling methods for use in British Columbia is presented in Appendix 2. A further reference of greater scope and detail is *The Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (Aller et al., 1989). It provides a matrix that uses a rating system to establish the desirability of a drilling method based on the general hydrogeologic conditions and well design requirements.

5.2 Monitoring Well Development

Monitoring well development is intended to correct any clogging or compaction that may interfere with water quality analysis, to improve hydraulic characteristics and to restore ground water properties disturbed during the drilling process. Monitoring well development should follow the installation process and continue until the water is representative and free of the drilling fluid cuttings, or other materials introduced during the drilling process. Representative water is assumed to have been obtained when pH, temperature, and specific conductivity readings have stabilized and the water is virtually clear of suspended solids (ASTM D5092-90). Methods of development include mechanical surging, over pumping, air lift pumping, and well jetting.

The combined use of a jetting tool with air-lift pumping is a particularly effective development method. Mechanical surging, as with a surge block or large bailer, can also be used but is less effective (Sabel and Clark, '85). A well recovery test should be carried out immediately after and in conjunction with well development.

5.3 Hydraulic Assessment and Documentation

All constructed piezometers should be tested to determine the hydraulic conductivity of the formation, and to determine if they are sufficiently responsive to the hydraulic flow system to provide reliable monitoring data. The local groundwater flow system can be determined by installing piezometers to measure the hydraulic heads at various points in the system.

At least three piezometers in a triangular array are needed to define the horizontal hydraulic gradient and direction of groundwater flow in simple flow systems. Vertical gradients are determined with nested piezometers. (Nested piezometers are also needed to deliminate vertical contaminant concentration gradients.) In areas of complex geology, additional piezometers are needed since the flow medium will be heterogeneous and will result in a distorted hydraulic head distribution (Piteau, 1990).

Hydraulic head measurements should be collected at different depths, as well as at different locations on the site. Contours of the hydraulic heads will

indicate which areas are located downgradient of the site and are, therefore, at risk of becoming contaminated, and which areas are located upgradient of the site and could thus provide background data. This information is useful for selecting appropriate monitoring sites.

6. Sampling Program

6.1 Sampling Schedule

Sampling frequency is based on the potential human health and environmental impact and on the rate of contaminant movement. Groundwater velocities are usually much less than those of surface waters and, therefore, sampling intervals may be longer. Monitoring parameters and frequency of sampling are site specific.

Water levels should be monitored on at least the same frequency as the regular chemical monitoring. Quarterly monitoring of water levels in all monitoring wells is commonly required to determine seasonal variations in groundwater flow.

A sampling schedule should be developed that takes into consideration the various conditions that influence the extent and direction of groundwater flow and the rate at which potential contaminants migrate into and with the groundwater. Some conditions that influence contaminant transport to the water table are precipitation, temperature, soil permeability, and soil type(s).

6.2 Piezometric Records

It is generally assumed that the flow system of a groundwater system is a steady state situation and that fluctuations in head are minor in comparison to total head drop from recharge to discharge. However, for localized aspects of a system it may be important to quantify and document groundwater level variation. In these cases, piezometric measurements should be recorded on a regular basis to characterize seasonal fluctuations. For wells located near the ocean, tidal effects may be significant and, as well, there is the potential for salt water intrusion to cause variation in chemical composition.

6.3 Field Measurements

Regular monitoring of traditional “field parameters” such as odour, colour, pH, conductance, redox potential, and temperature, may provide an indication that a change in groundwater quality has occurred and that sampling for more extensive analysis is warranted.

7. Quality Assurance and Quality Control

Monitoring programs should include a quality assurance (QA) and quality control (QC) component in their design in order to provide confidence in the data obtained. Refer to the manual *Quality Assurance in Water Quality Monitoring* produced by Environment Canada, the Quality Control and Quality Assurance chapter of this manual (Part A), or the Quality Assurance section of *Ministry Methods Manual - Permittee Edition -1994*, produced by the EPD of BC MELP for the development and implementation of acceptable water monitoring programs. Laboratories generally have their own internal QC program consisting of regular testing of blanks, spikes, and laboratory duplicates.

A field QA protocol is necessary to verify the reliability and accuracy of the combined field sampling/handling and laboratory procedures and should include the following (Piteau, '90):

- Blind replicate samples: identical field samples are submitted under different sample identities to test for reproducibility of the sampling and analytical procedure (precision)
- Blind reference samples: reference samples (may be certified) are prepared to mimic authentic samples and are submitted under fictitious sample identities to test for analytical bias (accuracy)
- Spiked samples: a field sample is split and a known concentration of a contaminant is added to one-half of the sample to check for systematic errors (bias)
- Blank samples: laboratory reagent (distilled or deionized) water is carried through sample collection and handling (including preservation) to check for contamination, purity of preservatives and other systematic errors occurring from time of sampling

The contaminant concentrations in blanks should be recorded, and if concentrations are more than an order of magnitude greater than the detection limit for the parameter and the sample result is less than 5 times detection limit, the groundwater should be resampled to ensure QA and QC standards have been satisfied.

The laboratory should be contacted prior to sampling to ensure that sample handling, preservation, and shipping methods are appropriate. Sample storage time prior to laboratory analysis must not exceed allowable limits. Refer to Appendix 6 for a generalized flow diagram of groundwater sampling steps.

The calibration and maintenance of field equipment is also an integral component of QA/QC. All equipment must be kept clean and in good working condition, using the techniques described by the manufacturer. Calibrations, prior to the sampling event, should be 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. To

ensure a high standard of QA/QC, monitoring personnel must be adequately trained and supervised.

Where a series of samples is to be collected using common equipment, sampling should begin with the (assumed) lesser contaminated sites and progress to sites with higher anticipated levels of contamination.

A log should be kept for each item of equipment to document calibration, exposure, maintenance, and service.

8. Sample Collection

8.1 Sampling and Measuring Methods

A sampling device is chosen based on the parameters that are to be monitored, the compatibility of the rate of well purging with well yield, the diameter of the well, and the depth from which the sample must be collected. The cost, transportability and ease of use of the sampling device are also important considerations.

Appropriate measures are required to prevent cross contamination between wells during the sample collection procedure. For example, drilling equipment must be decontaminated between boreholes; sampling equipment must be decontaminated between each sampling event and, where appropriate, between specific parameter groups such as organic contaminants. Sampling equipment (including automated models) must be made of materials that are compatible with the type of contaminated groundwater being sampled and must not contribute or remove (e.g., by adsorption) any parameter of interest.

The routine parameters monitored in groundwater include pH, redox potential (Eh), dissolved oxygen (DO), specific conductivity, metals, ammonia nitrogen, chloride, and chemical oxygen demand (COD); other parameters may be added to this list on a site specific basis. The standard industry practice is to use a flow through cell to measure the DO, pH, and conductivity. Other parameters are measured with static probes or parameter specific test kits. Routine quarterly sampling and in-situ monitoring will establish the presence of any trends, identify any statistically significant changes, locate contaminant plumes and, most importantly, identify those parameters with values that fail to meet the applicable criteria.

Statistically significant refers to a statistically significant increase or decrease from background values or exceedance of a compliance level for each parameter or constituent being monitored. It is the responsibility of the owner/operator or his agent to choose an appropriate statistical method consistent with the number of samples collected, and distribution pattern of

the parameter. Examples of appropriate statistical methods and performance standards are outlined in the EPA document Criteria For Municipal Solid Waste Landfills, Subpart E section 258.53 paragraphs (g) & (h).

8.2 Immiscible Layers

Immiscible layers may be either light nonaqueous phase liquids (LNAPLs) or dense nonaqueous phase liquids (DNAPLs). LNAPL layers must be sampled before a well is purged. To determine the presence of an immiscible layer, an interface probe should be used to measure the first fluid level in a well. Once this has been recorded, it should be lowered until the immiscible water interface is encountered. The depth interval, or thickness, of a floating immiscible layer can then be established.

8.3 Purging

Water which has resided in a well casing for an extended period of time has the opportunity to exchange gases with the atmosphere and to interact with the well casing. Water standing in the columns inside the well casing must, therefore, be purged prior to sampling so that a representative sample can be obtained. To adequately purge a well, monitor the pH, temperature, and conductance of the water during the purging process, and assume purging is complete when these measurements stabilize. While 3 to 4 purge volumes are common industry practice, it is recommended that the appropriate number be determined on a site specific basis according to the number required to reach equilibrium.

Purging should be accomplished by removing groundwater from the well at low flow rates using a pump. Because they can operate at variable speeds, pumps such as the submersible and bladder variety are considered particularly useful for purging stagnant water from a well. The use of bailers should generally be avoided as the 'plunger' effect of their use can result in the continual development or overdevelopment of the well. A description of six different kinds of pumps is presented in Appendix 4.

Wells should be purged at rates lower than those used to develop the well. A low purge rate will reduce the possibility of stripping VOCs from the water and reduce the likelihood of mobilizing colloids in the subsurface that are immobile under natural flow conditions. For further reference, refer to the designation guide ASTM D4448-85a.

If contaminants are suspected in the groundwater prior to purging, then appropriate disposal measures should be performed. The purged groundwater should be collected and tested and disposed of in accordance with established sanitary/stormwater sewer use criteria and other applicable regulatory requirements.

8.4 Sample Extraction

The rate at which a well is sampled should not exceed the rate at which the well was purged. Low sampling rates, approximately 0.1 L/min, are suggested. Pumps should be operated at rates less than 0.1 L/min when collecting samples for volatile organic compound analysis.

Sample withdrawal methods include the use of pumps, compressed air, syringe sampler, and bailers. The selection of the sampling method must be based on the parameters that are to be monitored, the depth from which the sample is collected, and the diameter of the well (Piteau '90). The primary consideration is to obtain a representative sample of the groundwater body by guarding against mixing the sample with stagnant water in the well casing. This is avoided through adequate purging prior to collecting the sample. Refer to Appendix 4 for a description of a number of different sampling devices that are available to extract water from a variety of monitoring well diameters.

8.4.1 Organic Contaminant Sampling

Groundwater samples collected for analyzing organic constituents should not be field-filtered prior to laboratory analysis. The recommended container for collection is a solvent rinsed, amber coloured glass with an aluminum foil or Teflon liner cap. An emerging technology that promises to provide an alternative to collecting and shipping large samples of water involves a technique called solid phase extraction (SPE). In this technique, a volume of water is passed through a solid phase that adsorbs the organic contaminants. The adsorbent material is sent to the laboratory for extraction and analysis. Consult the manufacturer's literature for further information on this technique. For additional QA details refer to Appendix 5.

8.4.1.1 Volatile Organic Compounds

Volatile organic compounds (VOCs) must be sampled in a manner which does not cause agitation of the sample or exposure of the sample to air. Pumps which induce suction pressure, such as peristaltic pumps, or which have lift devices, may aerate the sample and are not recommended for sampling VOCs. Positive displacement bladder pumps or bailers constructed entirely of fluorocarbon resin or stainless steel are preferred. VOCs should be the first sample that is collected following the purging process (EPA, Sept '88).

During sampling, the pumping rate should be kept to a rate of less than 0.1 L/min. Samples should be placed directly in glass bottles with no air space left and capped with a Teflon septum cap.

8.4.1.2 Extractable Organic Compounds

Samples for extractable organics should be collected after the VOCS samples. Glass or Teflon bottles with Teflon lined caps should be used as sample containers (Piteau, '90); alternatively, solid phase extraction (SPE) may be performed on-site.

8.4.2 Inorganic Contaminant Sampling

8.4.2.1 Specific Conductivity

Specific conductance and temperature should be measured in the field using portable equipment. Since many effluents, and in particular landfill leachate, have substantially higher temperature and specific conductance than natural groundwater, the presence of such a leachate can often be detected using a conductance - temperature probe. Specific conductance can be measured quickly and easily and is useful for estimating the total amount of inorganic dissolved solids.

Specific conductance and pH should ideally be measured both in the field and in the laboratory; differences may indicate that sample degradation has occurred during shipping and storage. For reliable comparisons, it is mandatory that adequate calibration of field instrumentation is maintained. Additional parameters that should be measured in the field include redox potential and dissolved oxygen.

8.4.2.2 Metal Compounds

Groundwater samples collected to monitor total metal contaminants should be collected in an acid-cleaned, plastic container and preserved in an acid solution prior to analysis. Groundwater samples collected for analyzing dissolved metal contaminants should be field-filtered under pressure, collected in an acid-cleaned plastic container, and preserved in an acid solution prior to analysis.

Refer to Appendix 5 for appropriate preservation and collection techniques. Note that samples must not be decanted as an alternative to filtering.

Note: To avoid contamination, the collection containers for groundwater samples to be analyzed for inorganic contaminants should be pre-cleaned and certified by the supplier or by adequate batch testing. Containers should not be rinsed with sample prior to sample collection as surface concentration effects may occur. For appropriate container and rinsing agents refer to Appendix 5.

8.5 Sample Preservation

To assist in maintaining the natural chemistry of the samples, it is necessary to preserve the sample. Methods of sample preservation are relatively limited and are intended to reduce the effects of chemical reactions, the effects of sorption and to arrest biological actions. Preservation methods are generally limited to pH control, refrigeration, and protection from light. Selected parameters or groups of parameters (e.g., metals) may be preserved by addition of a reagent (e.g., acid) that stabilizes their concentration but may preclude the analysis of that sample for other parameters.

Glass, stainless steel, Teflon, or plastic (polyethylene and polypropylene) are the types of containers acceptable for most kinds of sample collection. There are some exceptions to this general rule; for example, plastic is not acceptable for organics and stainless steel is not acceptable for metals. Containers should be kept full until samples are analyzed to maintain anaerobic conditions. The sample container material should be non-reactive with the sample and especially with the particular analytical parameter to be tested. Sample containers used to transport samples to the lab must undergo pre-treatment procedures. Pre-treated containers may be purchased commercially; however, pre-treatment must be repeated if they are re-used. For appropriate sample containers and preservation methods, refer to Appendix 5.

Samples should be placed in bottles immediately upon collection and, where preservation of the sample is required, it should be carried out immediately. Handling of the sample and contact with the atmosphere should be kept to a minimum. The samples should be properly packaged so as to prevent breakage and should generally be kept at 4ºC plus/minus 2ºC until analyzed by the laboratory. It is recommended that the sampler consult with the laboratory to discuss sampling protocols and sample treatment options prior to sample collection.

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10. Revision History

October 10, 2013:	This section republished without change. Notes added to Appendix 5. Sample Container and Preservation Criteria table updated.
February 28, 2001:	This section republished without change. Bottle types adjusted for mercury in Appendix 5.
November 1996:	Initial publication.

Appendix 1 Recommendations for Screen and Casing Materials in Sampling Applications

(in decreasing order of preference)

Material	Applications	Other Considerations	Approximate Cost (Relative to PVC)*
Fluorinated Ethylene Propylene (FEP)	Recommended for most monitoring situations where corrosive environments are anticipated. Also offers good chemical resistance to volatile organics.	Lower strength than steel and iron. Not available in British Columbia.	> 20 x
Polytetra florethylene (PTFE) or Teflon (R)	Recommended for most monitoring situations with detailed organic analytical needs, particularly for aggressive, organic leachate impacted hydrogeologic conditions. Virtually an ideal material for corrosive situations where inorganic contaminants are of interest.	Low strength, not readily available in British Columbia (- 10 days for delivery).	21 x
Kynar	Strong material that is resistant to most chemicals and solvents.	Poor chemical resistance to ketones and acetone. Not commonly available.	
Fibreglass	Historically, fibreglass has not been used for monitoring wells due to potential leaching of epoxy resins. Recent advances in fibreglass technology have created a material that is equivalent to or more inert that Teflon, but is also very strong.	High strength, not readily available in British Columbia. Not available as 50 mm casing.	2 to 5 x
Stainless Steel 316 (flush threaded)	Recommended for most monitoring situations with detailed organic analytical needs, particularly for aggressive, organic leachate impacted hydrogeologic conditions.	High strength, reasonable availability. May be source of Cr, Fe and Ni in low pH environments.	10 x
Stainless steel 304 (flush threaded)	May be prone to slow pitting corrosion in contact with acidic, high TDS aqueous solutions. Corrosion products limited mainly to Fe and possibly Cr and Ni.	High strength, good availability. May be source of Cr, Fe and Ni in low pH environments.	7.5 x

PVC (flush threaded or other noncemented connections)	Recommended for monitoring situations where inorganic contaminants are of interest and it is known that aggressive organic leachate mixtures will not be contacted. Cemented installations have caused documented interferences. The potential for interaction and interferences from PVC well casing in contact with aggressive aqueous organic mixtures is difficult to predict. PVC is not recommended where ppb or corrosive concentrations of organic contaminants are expected.	PVC can be used as casing with stainless steel screens for composite well. Moderate strength, good availability. Deteriorates when in contact with ketones, esters and aromatic hydrocarbons.	1 x

Materials below this line are not recommended as they cost more than PVC while rated as inferior.			
Acrylonitrile Butadiene Styrene (ABS)	Not commonly used for groundwater monitoring.	Lower strength than steel and iron. Not readily available other than in domestic plumbing format which is not generally suitable for piezometer applications.	2 x
Polypropylene	Resistance to mineral acids and moderate resistance to alkalis, alcohols, ketones and esters make polypropylene a suitable material for many applications. It deteriorates when in contact with oxidizing acids, aliphatic and aromatic hydrocarbons.	Low strength, not readily available in British Columbia.	
Polyethylene: High Density	Polyethylene is less reactive then PVC but more reactive than PTFE.	Low strength. Not commonly available in format other than flexible water line. Not threadable.	1 x
Low Carbon Steel	May be superior to PVC for exposures to aggressive aqueous organic mixtures. These materials must be very carefully cleaned to remove oily manufacturing residues.	Prone to rusting.	

Galvanized Steel	Corrosion is likely in acidic, high TDS environments, particularly when sulfides are present. Products of corrosion are mainly Fe and Mn, except for galvanized steel which may release Zn and Cd.	High strength, good availability. Prone to rusting.	1.25 to 3 x
Carbon Steel	Weathered steel surfaces present very active absorption sites for trace organic and inorganic chemical species.	Prone to rusting.	

(Piteau March 1990. Table 5.2)

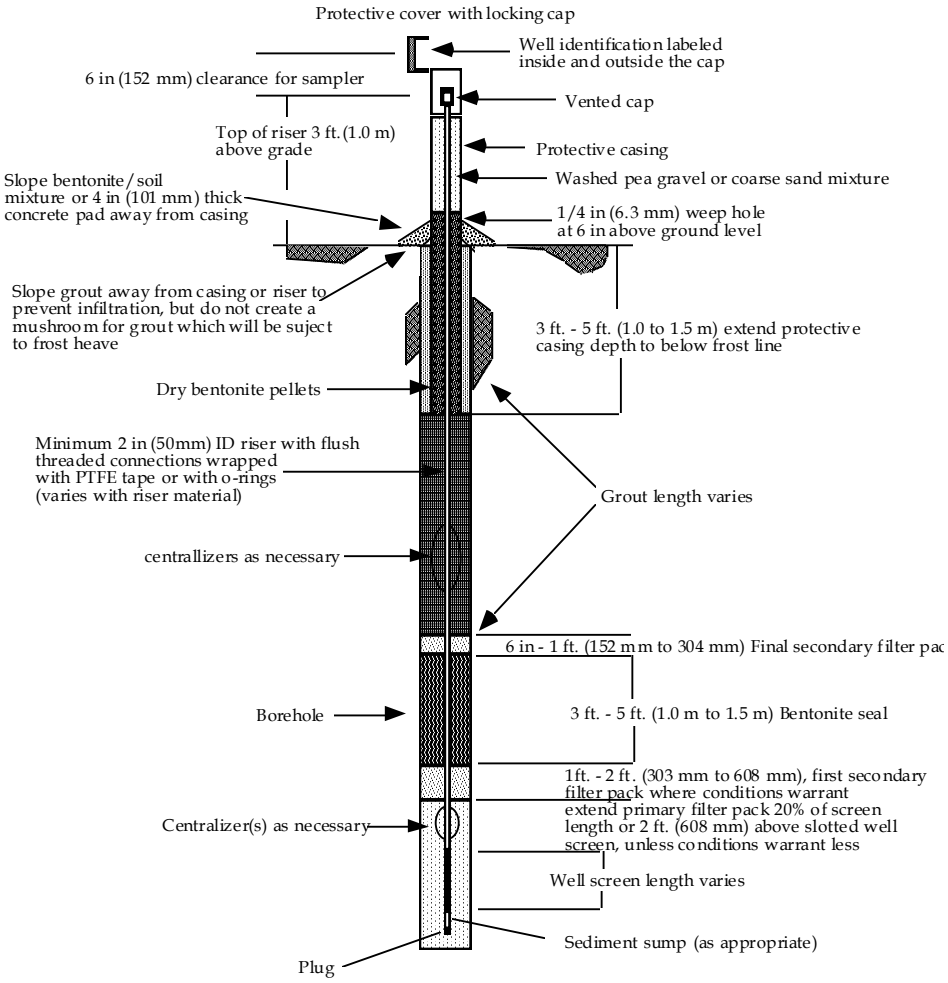
* Source of availability and relative cost: CPI Equipment, the largest supplier of drilling equipment in B.C.

Appendix 2 Drilling Methods Matrix

	DRILLING METHODS							
	Air Rotary	**Cable Tool**	**Hollow Stem Auger**	**Sonic Drilling**	**Becket Hammer**	**Mud Rotary**	**Bucket Auger**	**Backhoe Excavation**
Applicable Geology								
Unconsolidated Overburden	X	X	X	X	X	X	X	X
Fine Grained Sediments	X	X	X	X	X	X	X	X
Soft Rock	X	X				X		
Cohesive Sediments	X	X		X		X		
Unconsolidated Sediments	X	X	X	X	X	X	X	X
Bedrock	X	X				X		
Surficial Sediments	X	X	X	X	X	X	X	X
Soft to Mod. Dense Sediments	X	X	X	X	X	X		
Maximum Depth (m)	>300	>200	50		50	>300	10	8
Avg. Hole Diameter (mm)	150	150	125		150	150	800	1,000

(After Piteau, 1990)

Appendix 3 Typical Monitoring Well Design



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Appendix 4 Sampling Equipment

Sampling Devices	How the Sampling Device Operates	Pumping Rates	Characteristics	Disadvantages
Air Lift Pump	An air lift pump collects a water sample by bubbling a gas at depth in the well or tube.	Pumping rates depend on the size of the pump being used and how many pumps are used for each well.	Air lift sampling can be useful in monitoring wells that need to be pumped only at periodic intervals.	Air lift methods result in considerable sample agitation and mixing in the well.
Submersible Pump	Water is transported to the surface by centrifugal action through an access tube.	Vary from 26.5-53.0 Lpm depending upon the depth of the pump.	A submersible pump provides higher extraction rates than most other methods.	Considerable sample agitation and the potential introduction of trace metals into the sample from pump materials results.
Suction Lift Pump	Suction lift can be categorized as direct line, centrifugal and peristaltic.	Vary from 19-151 Lpm for direct line method. Approximately 3.7 Lpm for peristaltic pump method.	Suction lift approaches offer a simple retrieval method for shallow monitoring.	Degassing and agitation occur as a result of suction lift.
Bladder Pump	Water enters the flexible membrane through the lower check valve; compressed gas is injected into the cavity between the stainless steel housing and the bladder.	The 4.4 cm pump is capable of providing samples (Approx. 2.6 - 5.6 Lpm) from depths in excess of 76m.	Bladder pumps prevent contact between the gas and water sample and can be fabricated entirely of Teflon and stainless steel.	The large gas volumes required, especially at depth, potential bladder rupture, and the difficulty in disassembling the unit for thorough cleaning. Piezometers must be developed with no fines inside casing.
Gas Displacement Pump	A column of water under linear flow conditions is forced to the surface without extensive mixing of the pressurized gas and water.	Flow rates of about 2.8 Lpm at 36.5m are possible with a standard 3.7 cm inner diameter by 4.57 cm long pump.	Gas displacement pumps provide a reliable means for obtaining a highly representative ground water sample.	Possibility of gas water interface, a degree of mixing, and sample degassing can occur during transport.
Gas Piston Pump	A double piston pump utilizes compressed air to force a piston to raise the sample to the surface.	Pumping rates of 0.5 Lpm have been reported from 30.5 m; sampling depth of 152 m are possible.	The gas piston pump provides continuos sample withdrawal at depths greater than is possible with most other approaches.	Contribution of trace elements from the stainless steel and brass is a potential problem.
Packer Pump	The hydraulic activated packers are wedged against the casing wall or screen, the sampling unit collects water samples only from the isolated portion of the well.	Vertical movement of water outside the well casing during sampling is possible with packer pumps but depends upon the pumping rate and subsequent disturbance.	A packer assembly allows the isolation of sampling points within a well.	Deterioration of the expandable material will occur with time thereby increasing the possibility of undesirable organic contaminants entering the water sample.
Inertial Lift Pump	The operating principle of the pump is based on the inertia of a column of water contained within a riser tubing.	Pumping rates of between 0.05 to 10.0 Lpm have been recorded.	The inertial pump is inexpensive and offers multiple uses for ground water monitoring wells.	The tubing coils, though reasonably lightweight, are stiff and may be awkward to transfer from well to well.

* Text extracted from Appendix D, Piteau (1990), from R.D. Morrison (1983).

Appendix 5 Sample Container and Preservation Criteria

TYPE OF ANALYSIS[1, 2]	STORAGE MAXIMUM TEMP[3]	CONTAINER TYPE	PRESERVATION	HOLD TIME[4] (days)
WATER - BACTERIOLOGY PARAMETERS				
Coliforms, Total, Fecal and E. coli	<8ºC, do not freeze	Ster P or G	$Na_2S_2O_3$	30 hours[5]
Cryptosporidium, Giardia	<8ºC, do not freeze	Ster P or G	$Na_2S_2O_3$	96 hours
Enterococcus	<8ºC, do not freeze	Ster P or G	$Na_2S_2O_3$	30 hours[5]
Heteroprophic Plate Count	<8ºC, do not freeze	Ster P or G	$Na_2S_2O_3$	24 hours
TOXICITY				
Daphnia, Chronic 21 day/ Chronic EC25	4±2ºC	P, G (non-toxic)	collect with no headspace	5
Daphnia, LC50 / LT50	4±2ºC	P, G (non-toxic)	collect with no headspace	5
Microtox	4±2ºC	P, G (non-toxic)	collect with no headspace	3
Trout, LC50	4±2ºC	P, G (non-toxic)	collect with no headspace	5
Trout, LT50	4±2ºC	P, G (non-toxic)	collect with no headspace	5
PHYSICAL & AGGREGATE PROPERTIES				
Acidity	≤6ºC	P, G	none	14
Alkalinity	≤6ºC	P, G	none	14
Colour	≤6ºC	P, G	none	3
Conductivity	≤6ºC	P, G	none	28
pH	≤6ºC	P, G	none	15 minutes
Solids (Total, TSS, TDS, Fixed, Volatile, etc.)	6ºC	P, G	none	7
Turbidity	≤6ºC	P, G	store in the dark	3

WATER - INORGANIC ANALYSIS

Bromide	no req.	P, G	none	28
Chloride	no req.	P, G	none	28
Chlorate, Bromate	≤6ºC	P, G	50 mg/L EDA	28
Chlorine, Total Residual (Free Chlorine)	none	P, G	none	15 minutes
Chlorite	≤6ºC	P, A, G	50 mg/L EDA	14
Cyanide, SAD and/or WAD	≤6ºC	P, G	field NaOH, store in dark	14
			none	1
Dissolved Oxygen (Winkler Method)	≤6ºC	G, BOD bottle	Winkler kit, store in dark	8 hours
Fluoride	no req.	P	none	28
Nitrogen, Nitrate + Nitrite	≤6ºC	P, G	H_2SO_4	28
			none (BC MOE)	3
Nitrogen, Ammonia	≤6ºC	P, G	H_2SO_4	28
			none (BC MOE)	3
Nitrogen, Nitrate	≤6ºC, do not freeze	P, G	none	3
Nitrogen, Nitrite	≤6ºC, do not freeze	P, G	none	3
Nitrogen, Total Kjeldahl	≤6ºC	P, G	H_2SO_4	28
			none (BC MOE)	3
Nitrogen, Total, Persulfate Method	≤6ºC	P, G	H_2SO_4	28
			none (BC MOE)	3
Nitrogen, Total, Combustion Method	≤6ºC	P, G	HCl	28
			none(BCMOE)	3
Phosphorus, Dissolved (Orthophosphate)	≤6ºC	P, G	filter (field or lab)	3
Phosphorus, Total Reactive (Orthophosphate)	≤6ºC	P, G	none	3
Phosphorus, Total Dissolved	≤6ºC	P, G	filter, H_2SO_4	28
			none	3

Phosphorus, Total	≤6ºC	P, G	H_2SO_4 none (BC MOE)	28 3
Silica, Reactive	≤6ºC, do not freeze	P	none	28
Sulfate	≤6ºC	P, G	none	28
Sulfide	≤6ºC	P or G	ZnAc/NaOH to pH >9	7
METALS				
Hexavalent Chominum	≤6ºC	P, G	1 ml 50% NaOH per 125 ml none	30 1
Metals, Total	≤6ºC	P, G	HNO_3[7]	180
Metals, Dissolved	no req.	P, G	field filter 0.45 um + HNO_3[7]	180
Mercury, Total	no req.	G, PTFE	HCL or BrCL[8]	28
Mercury, dissolved	no req.	G, PTFE	field filter 0.45 um + HCL or BrCL[7]	28
AGGREGATE ORGANIC ANALYSIS				
AOX (Absorbable Organic Halides)	≤6ºC	A, G	HNO_3, store in dark sodium sulfite if chlorinated, collect with no headspace	14
Biochemical Oxygen Demand (BOD)	≤6ºC, do not freeze	P, G	none	3
Carbonaceous Biochemical Oxygen Demand (CBOD)	≤6ºC, do not freeze	P, G	none	3
Carbon, Dissolved Organic	≤6ºC	P, G	filter, H_2SO_4 or HCl none (BC MOE)	28 3
Carbon, Dissolved Inorganic	≤6ºC	P, G	field filter	14
Carbon, Total Organic	≤6ºC	P, G	H_2SO_4 or HCl	28
Carbon, Total Inorganic	≤6ºC	P, G	none	14
Chemical Oxygen Demand (COD)	≤6ºC	P, G	H_2SO_4 (field or lab) none (BC MOE)	28 3

Chlorophyll *a*	Filters: freeze ≤6ºC	Filter P, A, G	field filter, store in dark unfiltered, store in dark	Filters: 28 2
Phaeophytin	Filters: freeze	Filter	field filter, store in dark	Filters: 28
Surfactants (Methylene Blue Active Substances)	≤6ºC	P, G	none	3
Total Phenols (4AAP)	≤6ºC	P, G	H_2SO_4	28
EXTRACTABLE HYDROCARBONS				
Extractable Hydrocarbons	≤6ºC	A, G	HCl, H_2SO_4 or Sodium Bisulfate none	14/40 7/40
Oil & Grease / Mineral Oil and Grease	≤6ºC	A, G	HCL OR H_2SO_4	28
Waste Oil Content	≤6ºC	A, G	none	28
INDIVIDUAL ORGANIC COMPOUNDS				
Carbamate Pesticides	≤6ºC	A, G	Potassium Dihydrogen Citrate(solid), ~pH 3.8, 9.2-9.5 g/L, + 100 mg/L $Na_2S_2O_3$ if chlorinated ChlorAC buffer, ~pH 3, 1.8mL/60 mL sample+ 100 mg/L $Na_2S_2O_3$ if chlorinated	28 28
Chlorinated and Non-chlorinated Phenolics	≤6ºC	A, G	0.5g Ascorbic Acid / L + H_2SO_4 or Sodium Bisulfate none	14/40 7/40
Dioxins / Furans	≤6ºC	G, A	none	unlimited
Glyphosate / AMPA	≤6ºC	A, G or Poly-Propylene	100 mg/L $Na_2S_2O_3$ if chlorinated	14

Glycols	≤6ºC	G	HCL, H_2SO_4 or Sodium Bisulfate none	14/40 7/40
Halogenated Hydrocarbons (Semi-Volatile)	≤6ºC	A, G	100 mg/L $Na_2S_2O_3$ if chlorinated	7/40
Herbicides, Acid Extractable	≤6ºC	A, G	HCL (optional), store in dark, 50 mg/L $Na_2S_2O_3$ if chlorinated	14/21
Paraquat / Diquat	≤6ºC	A, G	100 mg/L $Na_2S_2O_3$ if chlorinated	7/21
Pesticides (NP, OP, OC)	≤6ºC	A, G	none	7/40
Polychlorinated Biphenyls (PCBs)	≤6ºC	A, G	none	unlimited
Polycyclic Aromatic Hydrocarbons (PAHs)	≤6ºC	A, G	HCL, H_2SO_4 or Sodium Bisulfate none	14/40 7/40
Resin Acids, Fatty Acids	≤6º C	A, G	(0.5g Ascorbic Acid + 0.4g NaOH) / L none	14/40 7/40
Volatiles Organic Compounds (Trihalomethanes)	≤6ºC	43ml G VOC Vials (2-3)	3 mg $Na_2S_2O_3$ (see BC Lab Manual method for more details)	14
Volatiles Organic Compounds (VOC, BTEX, VH)	≤6ºC	43ml G VOC Vials (2-3)	200 mg $NaHSO_4$, or 3 mg $Na_2S_2O_3$ Id chlorinated (see BC lab Manual method for other options and details	14
SOIL & SEDIMENT				
INORGANIC				
Bromide / Chloride and Fluoride	no req.	P, G	none	unlimited
Cyanide (WAD / SAD)	≤6ºC	P, G	store in dark, field moist	14
Hexavalent Chromium	≤6ºC	P, G	store field moist	30/7
Metals, Total	no req.	P, G	none	180

Mercury, Total	no req.	P, G	none	none 28
Moisture	≤6ºC	P, G	none	14
pH	no req.	P, G	none	365
Sulfide	≤6ºC	P, G	store field moist	7
TCLP - Mercury	no req.	P, G	none	28/28
TCLP - Metals	no req.	P, G	none	180/180
ORGANICS				
Carbon (TC, TOC)	≤6ºC	P, G	none	28
	no req.	P, G	dried stage	unlimited
Chlorinated and Non-chlorinated phenolics	≤6ºC	G	none	14/40
Dioxins / Furans	≤6ºC	G	none	unlimited
Extractable Hydrocarbons (LEPH, HEPH, EPH)	≤6ºC	G	none	14/40
Glycols	≤6ºC	G	none	14/40
Herbicides, Acid Extractable	≤6ºC	G	none	14/40
Oil and Grease/Mineral Oil and Grease/Waste Oil Content	≤6ºC	G	none	28
Pesticides (NP, OP, OC)	≤6ºC	G	none	14/40
Polychlorinated Biphenyls (PCBs)	≤6ºC	G	none	unlimited
Polycyclic Aromatic Hydrocarbons (PAHs)	≤6ºC	G	none	14/40
Resin Acids, Fatty Acids	≤6ºC	G	none	14/40
TCLP - Volatile Organic Compounds	≤6ºC	G	none	14/14
TCLP - Semi-Volatile Organic Compounds	≤6ºC	G	none	14/40
Volatile Organic Compounds (VOC, BTEX, VH, THM)	≤6ºC	G	none	7 (6)/40

LEGEND

P = plastic	Ster = sterilized	T = tissue cup
G = glass	Solv = solvent cleaned	B = baked
A = amber	Fc = foil-lined cap	P&T = purge and trap vials
W = wide mouth	R = acid rinsed	no req = no requirement

[1] A Director or an Environmental Management Act permit may specify alternate requirements.

[2] Refer to applicable BC Environmental Laboratory Manual methods for additional detail. Where differences exist between Lab Manual methods and this table, this table takes precedence.

[3] Storage temperature applies to storage at the laboratory. For all tests where refrigeration at ≤6°C is required at the laboratory, samples should be packed with ice or cold packs to maintain a temperature of ≤10°C during transport to the laboratory. The storage of ≤8°C for microbiological samples applies during storage at the laboratory and during transport to the laboratory. To prevent breakage, water samples stored in glass should not be frozen. Except where indicated by "do not freeze", test results need not be qualified for frozen samples.

[4] Hold Times: Single values refer to hold time from sampling to analysis. Where 2 values are given, the first is hold time from sampling to extraction, and the second is hold time from extraction to analysis.

[5] Samples received from remote locations more than 48 hours after collection must not be tested.

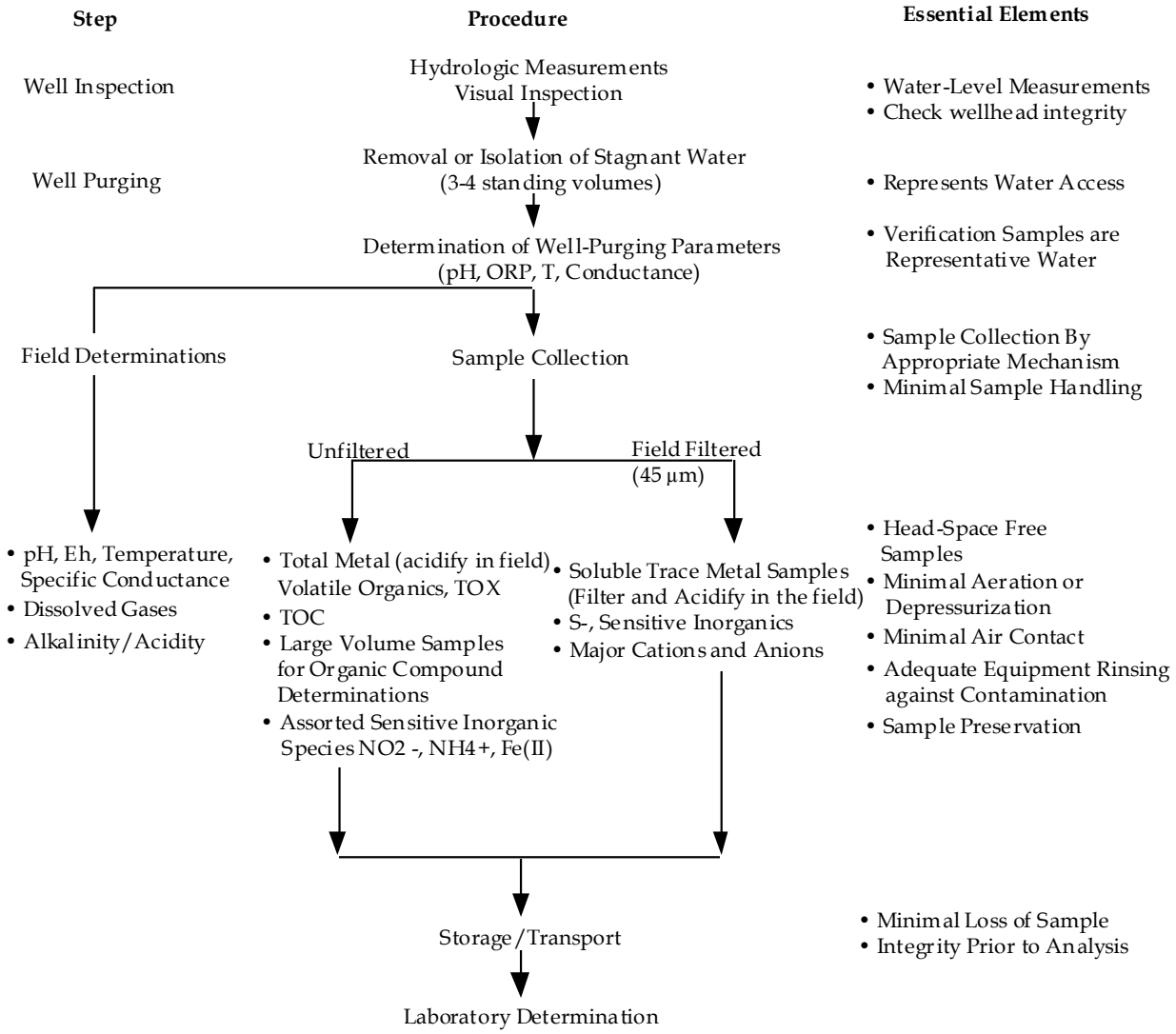
[6] Methanol extraction or freezing must be initiated within 48 hours of arrival at lab, to a maximum of 7 days from sample collection. Alternatively, samples may be frozen in the field if extracted within 14 days of sampling, or may be methanol extracted in the field.

[7] Samples collected for dissolved metals analysis must be filtered in the field as soon as possible after collection (preferably within 15 minutes). This is particularly important for groundwaters where exposure to atmospheric conditions can trigger redox reactions that cause certain metals to precipitate (particularly iron). If precipitation of iron oxides occurs, many other heavy metals may precipitate or co-precipitate, potentially causing substantially low bias for many metallic elements. In extreme cases, some elements may be 100% removed from solution due to precipitation or co-precipitation caused by delay of filtration. Samples collected for dissolved metals analysis must be field filtered and then preserved with HNO3.

If not field-preserved, water samples collected for total metals analysis must be acidified at the lab in their original containers by addition of HNO_3 (within 14 days of sampling), then equilibrated at least 16 hours prior to sub-sampling or analysis (otherwise, qualify as "received unpreserved"). Not applicable to mercury.

[8] Use only glass or PTFE containers to collect water samples for total or dissolved mercury. For total mercury, field-preserve with HCl or BrCl. Adding BrCl to original sample container at the laboratory within 28 days of sampling is an acceptable alternative for total mercury if samples are oxidized for 24 hours prior to sub-sampling or analysis. Samples collected for dissolved mercury analysis must be field filtered and then preserved with HCl or BrCl although BrCl is not recommended for use in the field for safety reasons.

Appendix 6 Generalized Flow Diagram of Groundwater Sampling Steps



Filtration should be accomplished preferably with in-line filters and pump pressure or by N2 pressure methods. Samples for dissolved gases or volatile organics should not be filtered. In instances where well development procedures do not allow for turbitity-free samples and may bias analytical results, split samples should be spiked with standards before filtration.
Both spiked samples and regular samples should be analyzed to determine recoveries from both types of handling.
Assorted Field Blanks and Standards: as needed for good QA/QC.

(Modified Piteau 1990, Fig. 5.7)

EFFLUENT FLOW MEASUREMENT

NOTE: The section on Effluent Flow Measurement was prepared for the Ministry by NovaTec Consultants Ltd.

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1. Introduction

The accurate measurement of wastewater flows is critical to the successful performance of a wastewater treatment plant. Flow measurement is of interest from an operations perspective at various stages of the treatment process including process flow streams within the plant, and effluent leaving the plant. The primary factor in the selection of the measurement device is whether the wastewater or effluent is being transported under open channel (e.g. open trough or partially filled pipes) or under full pipe conditions.

2. Open Channel Flow

Open channel flow is defined as the flow in a conduit, in which the upper surface of the liquid is in contact with the atmosphere (free surface), such as in the case of an open trough, or a partially filled pipe (see Figure 1). Open channel flow measurement devices are traditionally the most common method of flow measurement in wastewater treatment plants but as the use of metering increases, this is changing. The flow in an open channel is measured using a combination of a primary device (a structure restricting flow and causing the liquid level to vary proportionately with flow), and a secondary device (which measures the variation in liquid level caused by the primary device) (Kirkpatrick and Shelley [1]).

2.1 Primary Devices (Weirs and Flumes)

Primary devices are calibrated restrictions (structures) which are inserted into the channel, and which cause the upstream liquid level to vary proportionately with channel flow. A secondary device is used to measure variations in the liquid level.

Wastewater systems typically use two broad categories of primary devices: 1) weirs, and 2) flumes (see Figure 2). The relationship between liquid depth and flow rate depends upon the shape and dimensions of the restriction (primary device), and is calculated using a known equation called the head/flow or stage/discharge relationship.

The selection of whether to use a weir or a flume as a primary measuring device is based on a number of factors, including:

- Installation cost;
- Upkeep and maintenance cost;
- Expected head loss;
- Site configuration;
- Location configuration (i.e. space availability, slop, channel size);
- Rate of expected flow;
- Wastewater characteristics (i.e. suspended solids).

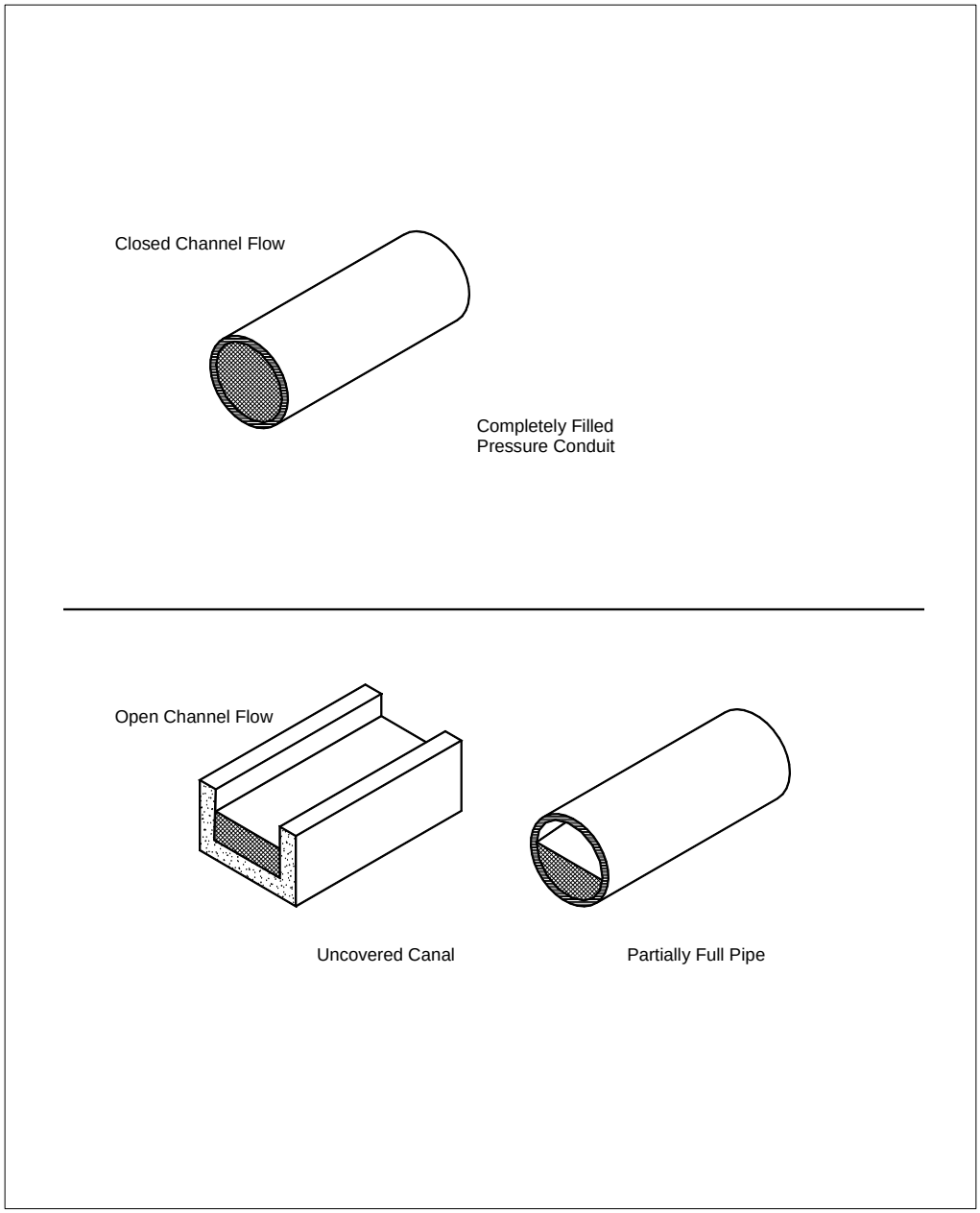


Figure 1. Closed Channel and Open Channel Flow

Measurement accuracy is generally not a factor in choosing between weirs and flumes as most types of weirs and flumes have a relative accuracy range of +/- 10% (Kirkpatrick and Shelley [1]).

The selection of the size of a primary device depends on the minimum and maximum flow rate expected for the location. The primary device must have a useful measurement range, which encompasses the minimum and maximum expected flow rates. It should be sized such that an appreciable change in liquid level occurs for the transition from the minimum to maximum flow.

A detailed discussion on the relative advantages and disadvantages of weirs and flumes can be found in the Channel Flow Measurement Handbook (Grant and Dawson [2]).

2.1.1 Weirs

Definitions and Description

A weir is a calibrated obstruction or dam built across an open channel over which the liquid flows, often through a specially shaped opening or notch

(see Figure 2). Weirs are the simplest, least expensive, and most common form of primary measuring device. They are typically made of aluminum or fiberglass. Definitions for two related terms are:

1. Crest: the edge or surface over which the liquid passes;
2. Nappe: the stream of water leaving the crest.

2.1.1.2 Flow Conditions

There are two possible flow conditions through a weir.

1. **Free (critical) Flow Condition**: This condition occurs when the water surface downstream from the weir is far enough below the weir crest so that air flows freely below the nappe (the nappe is aerated), and only the head upstream of the weir is needed to determine the flow rate. The head of the weir is the vertical distance from the crest to the liquid surface in the upstream channel, and the measuring point should be upstream of the weir at a distance of at least three or four times the maximum head expected over the weir (see Figure 2).

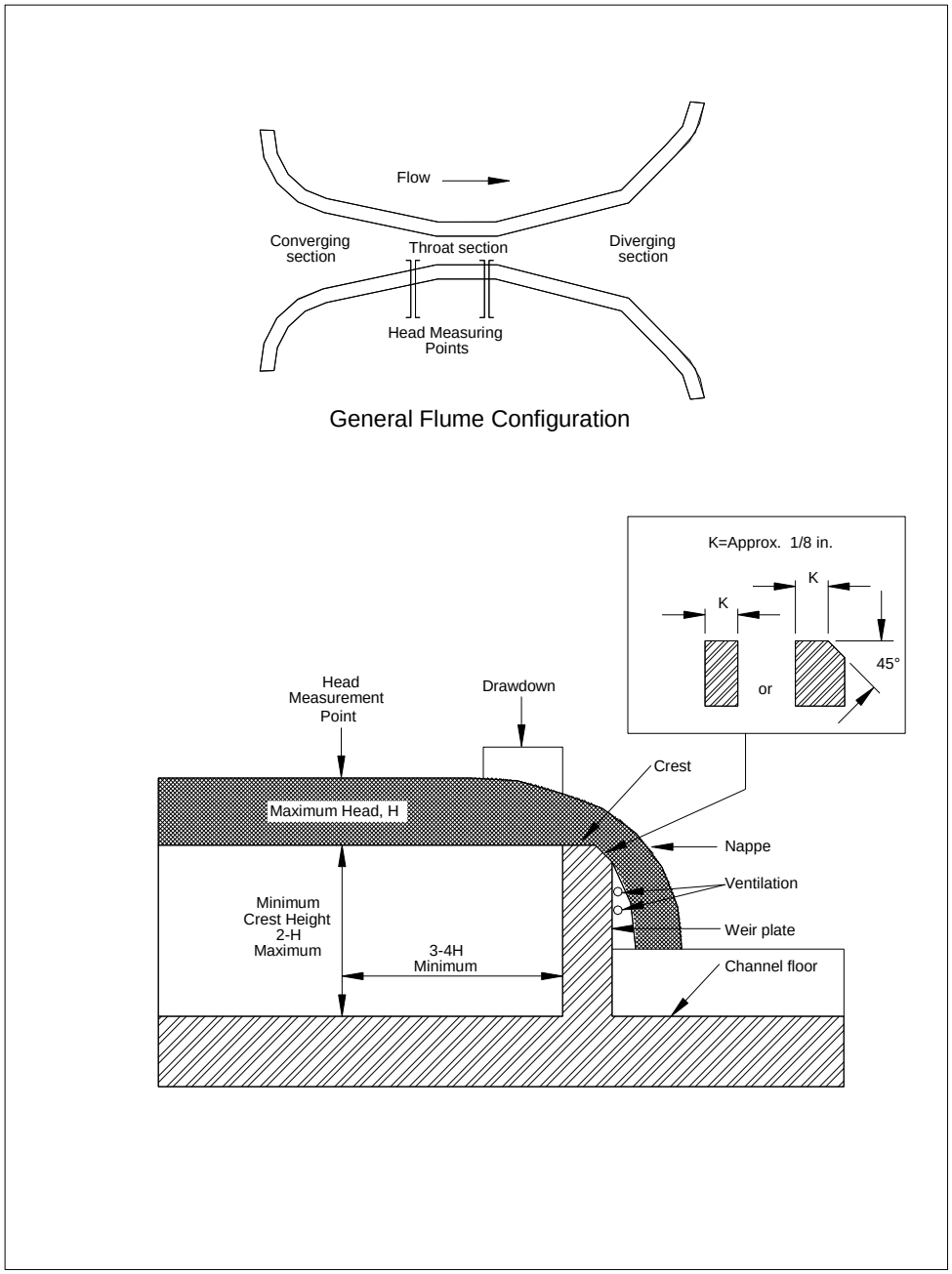


Figure 2. General Sharp-crested Weir Configuration

2. **Submerged (Subcritical) Flow Condition:** This condition occurs when the downstream water rises above the crest. Under submerged flow conditions the water depths upstream and downstream of the weir are needed to determine the flow rate. For wastewater applications weirs should be sized and installed to ensure that a free-flow condition is always maintained. Under free-flow conditions only one secondary device is required to measure liquid levels, located upstream of the weir.

2.1.1.3 Application

Weirs are well suited for measuring low flows, particularly where there is little head available. In addition to being used to measure flows, weirs are commonly used in wastewater treatment systems in secondary clarifiers to ensure uniform flow distribution along the effluent channel. Weirs are not generally considered suitable for raw wastewater (influent) flow measurement as solid materials can accumulate on the upstream side of the weir, which can disturb the conditions for accurate discharge measurement or even block the weir.

2.1.1.4 Common Weir Types

Weirs are classified according to the shape of the notch, and they can be sharp-crested or broad-crested (Pratt [3]). Sharp-crested triangular (V-notch), rectangular, and trapezoidal (Cipolletti) weirs are the most common type of primary measurement devices used in wastewater treatment plants (see Figure 3). Each notch shape has its own characteristic equation for determining the flow rate. The minimum and the maximum flow rates of each weir are given in standard tables (Grant and Dawson [2]).

V-notch (triangular) Weir

The V-notch weir consists of triangular notch cut in the channel which has its apex at the bottom, and the sides are set equally on either side of a vertical line from the apex (see Figure 4). The most commonly used angle sizes of the notch are 90, 60 and 45 degrees, although 120, 30, and 221/2 degree weirs are sometimes used under special circumstances.

A V-notch weir has to fulfil all of the installation requirements shown in Figure 4 in order to accurately estimate the flow. V-notch weirs are particularly suited for low flows, and can be used for discharges with an order of magnitude difference in flow (i.e. a

range from 1 L/s to 10 L/s). The equation used to determine the discharge (head/flow) for a free-flowing V-notch weir is as follows (Grant and Dawson [2]):

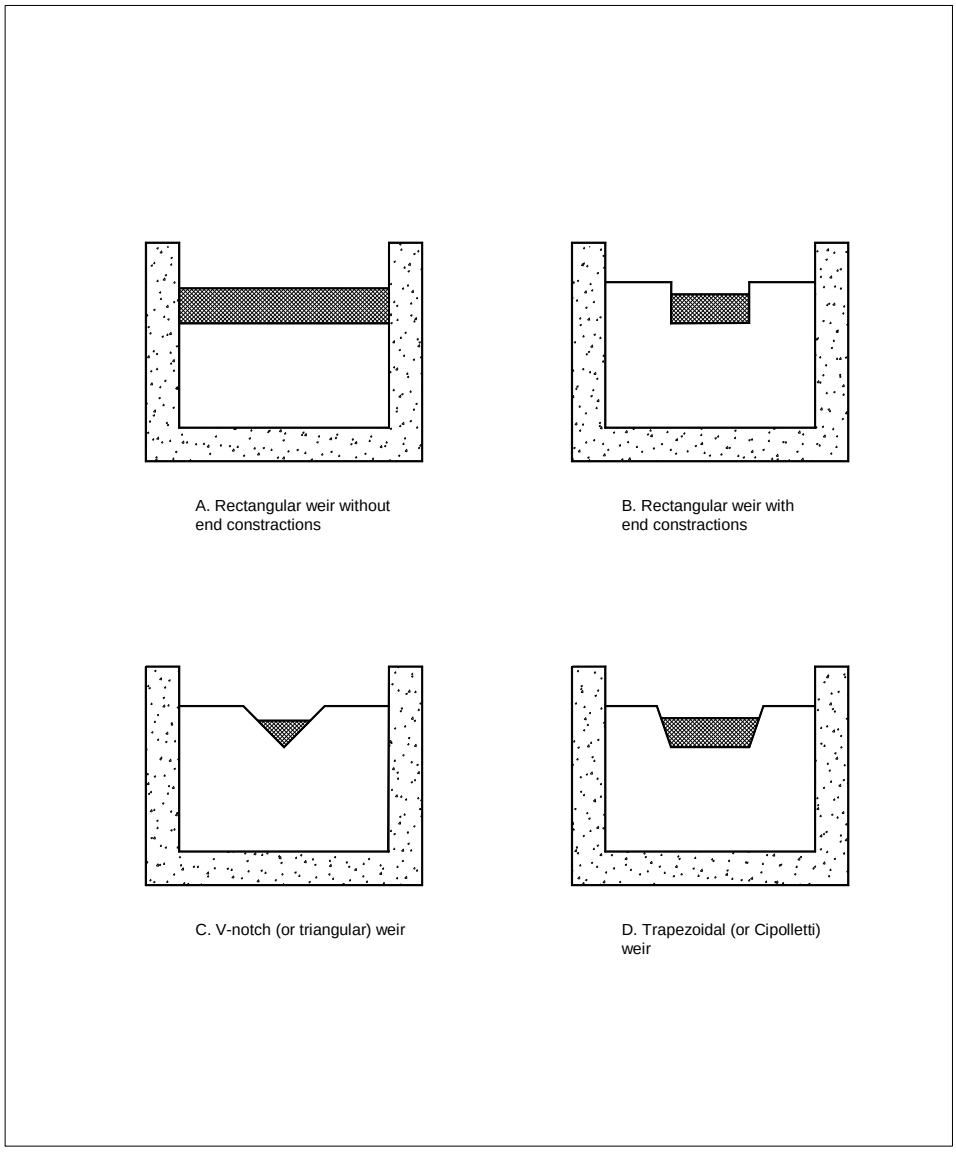


Figure 3. Various Sharp-crested Weir Profiles

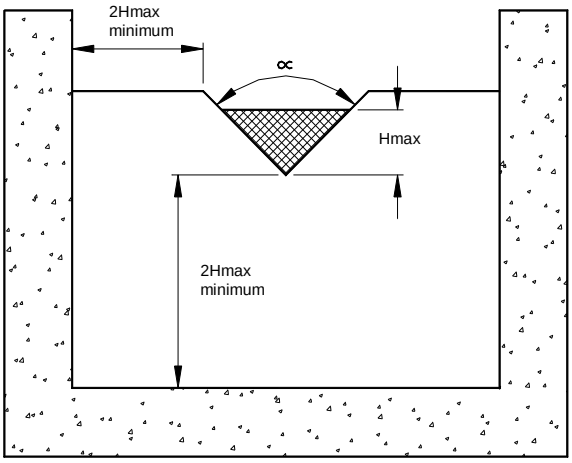


Figure 4. V-notch (triangular) Sharp-crested Weir

$$Q = K H^{2.5}$$

Where:

Q = flow rate
H = head on the weir
K = a constant which is a function of the angle of the weir and the unit of measurement

Rectangular (Contracted and Suppressed) Weir

The rectangular sharp-crested weir can be used in two different configurations:

1. *Rectangular Contracted Weir*: Consists of a rectangular notch cut in the channel to produce a box-like opening, where the horizontal distance from the end of the weir to the side walls of the channel are called the end contractions (see Figure 5a), and are used to:

- Reduce the channel width;
- Speed up the channel flow;
- Provide the needed ventilation as the flow passes over the weir.

2. *Suppressed Rectangular Weir*: When the end contractions are totally suppressed, and the channel's sides become weir's sides the weir is called a suppressed rectangular weir (see Figure 5b). Experience has shown that when constructing a rectangular weir a crest length of 30 cm (12 inches) is the minimum that should be considered, and 15 cm (six inches) increments are used to increase the crest length up to 90 cm (36 inches). Beyond the 90 cm a 30 cm (12 inches) increment is used to suit a particular installation. Installation requirements should be as shown in Figure 5b, and 5a. Special care often needs to be taken to ensure proper ventilation of the nappe - usually through the placement of vent pipes in the side walls to allow air to reach under the nappe.

The minimum head should be at least 5 cm (2 inches) to prevent the nappe from clinging to the crest, and generally the maximum head is recommended not to be more than one half the crest length.

The equation below is used to determine the discharges (head versus flow rate) of a free flowing rectangular weir with two end contractions:

$$Q = K (L-0.2H) H^{1.5}$$

$$Q = 1838 (L-0.2H) H^{1.5} \text{ (l/s), L (m)}$$

$$Q = 6618\ (L-0.2H)\ H^{1.5}\ \ (m^3/h),\ L\ (m)$$

Where:

Q= flow rate
H= head on the weir
L = crest length of the weir
K = constant dependent on measurement units

Trapezoidal (Cipolletti) Weir

A trapezoidal weir is a rectangular weir with an end contraction, which has its sides inclined outwardly, producing a trapezoidal opening as shown in Figure 6. When the sides are inclined in the ratio of four vertical to one horizontal the weir is known as Cipolletti weir. To be able to measure the flow rates accurately, trapezoidal weirs have to fulfill the installation requirements shown in Figure 6. The minimum head should be at least 5 cm (2 inches) to prevent the nappe from clinging, and the maximum head is recommended not to be more than one half the crest length. The discharge (head versus flow rate) equation of a free flowing Cipolletti weir is as follows:

$$Q = K\ L\ H^{1.5}$$
$$Q = 1859\ L\ H^{1.5}\ \ (l/s),\ L\ (m)$$
$$Q = 6692\ L\ H^{1.5}\ \ (m^3/h),\ L\ (m)$$

Where:

Q= flow rate
H = head on the weir
L = crest length of the weir
K = a constant dependent on the measurement units

Other Weirs

The most commonly used weir types in the wastewater flow measurements are the one discussed above. But there are other special profiles, and less-common types of primary devices classified as weirs, such as broad-crested weirs, and compound weirs, which are used in particular site configurations or to achieve a certain head/discharge relationship (see Figure 7).

The most common of these special designed devices is the proportional weir or Sutro weir. Please refer to Pratt [3] for more details on alternative weirs.

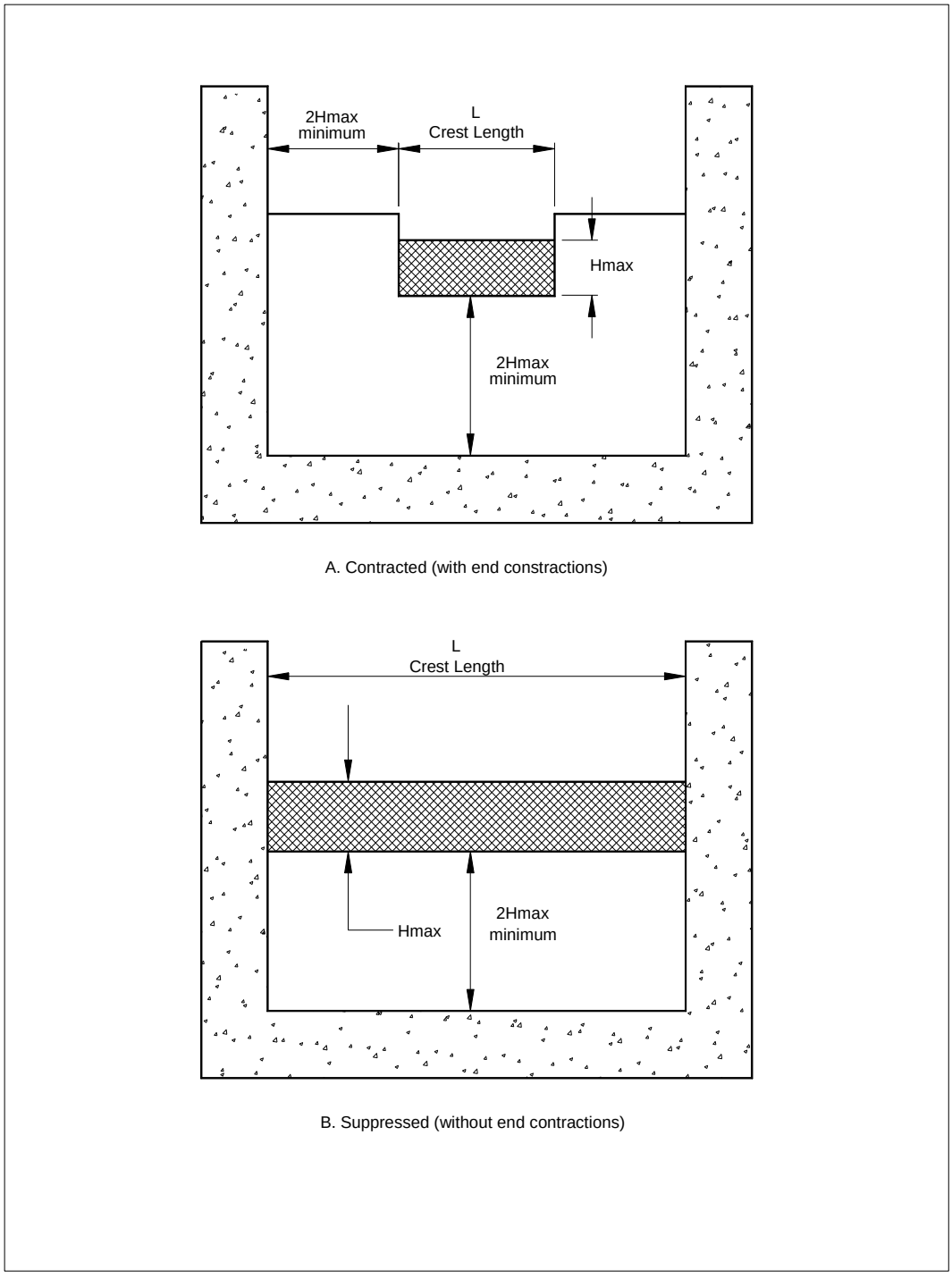


Figure 5. Rectangular Sharp-crested Weirs

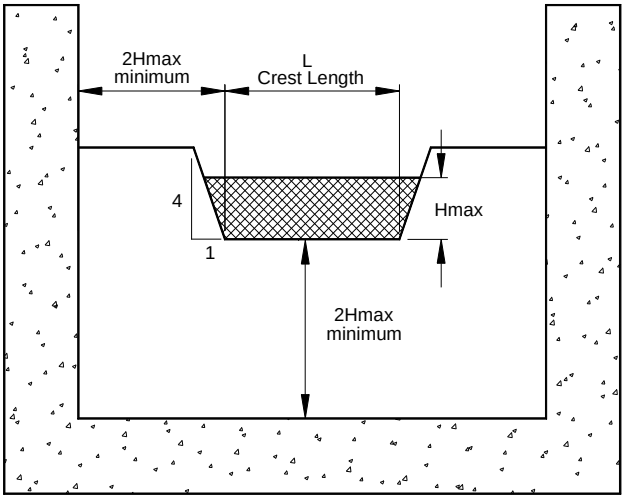


Figure 6. Trapezoidal (Cipolletti) Sharp-crest Weir

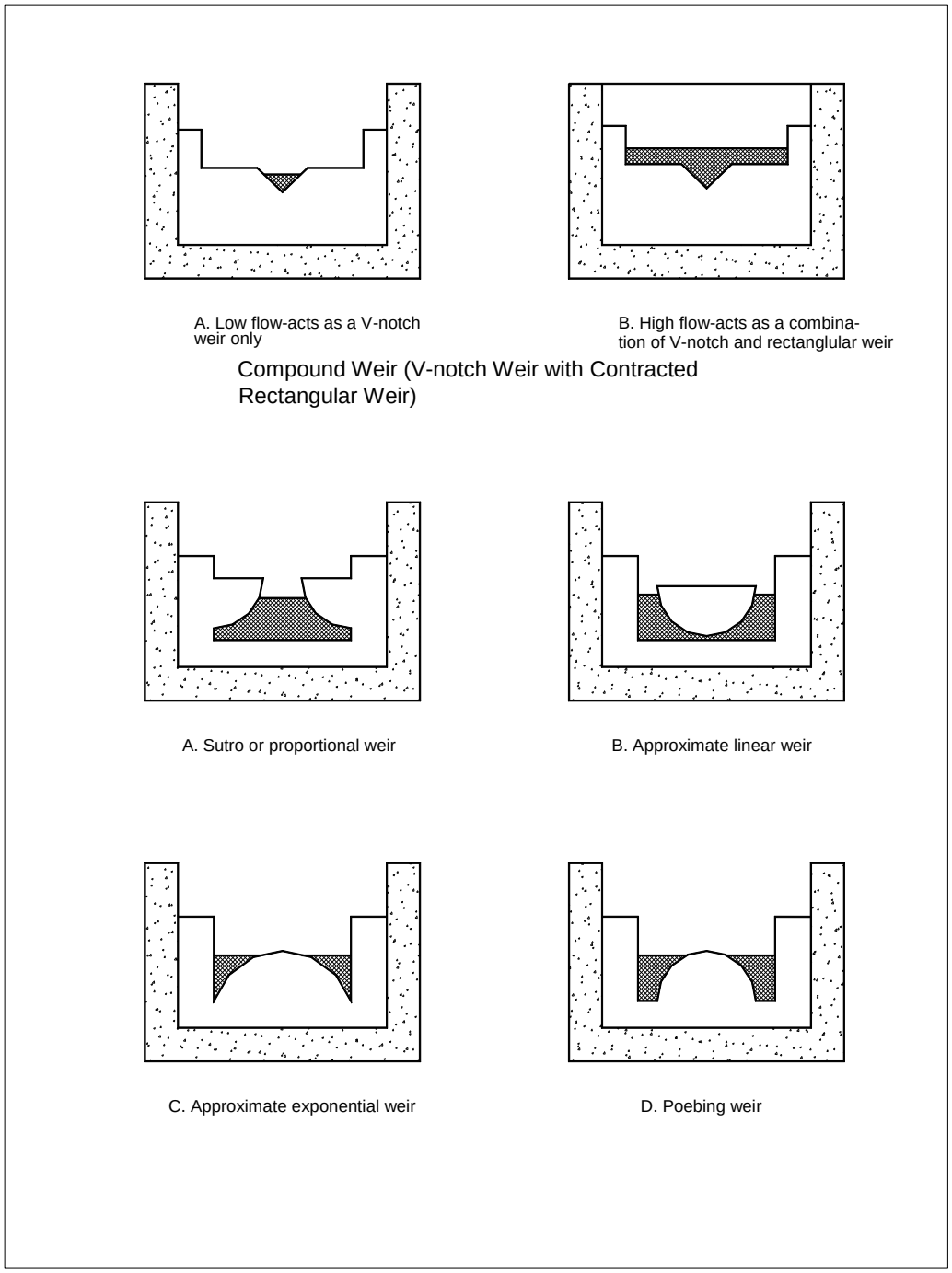


Figure 7. Special Sharp-crest Weir Profiles

2.1.2 Flumes

2.1.2.1 Definition and Description

Flumes are the second class of commonly used primary measuring devices. They are specially shaped channel restrictions, which change the channel area, and slope. This change increases the velocity, and the level of the liquid, flowing through the flume (see Figure 2). They can be made from various construction materials such as fiberglass, and concrete, and their structure is composed of three main components:

1. Converging section used to restrict the flow;
2. Throat section;
3. Diverging section used to ensure a free flow condition.

The flume should be installed to ensure it operates under a free-flow condition. The flow rate in the channel is determined by measuring the liquid level at a specified point in the flume. For more detail on various flume design approaches refer to Kirkpatrick and Shelley [1].

2.1.2.2 Flow Conditions

Flumes can be categorized into three main groups based on the flow-state through the flume:

1. Subcritical;
2. Critical;
3. Supercritical.

Similar to a weir, there are two flume discharge conditions, which can occur:

1. Free-flow condition, when there is insufficient backwater to reduce the flow rates. Under this condition only the upstream head is needed to determine the flow rate.
2. Submerged-flow condition, when backwater is high enough to reduce the discharge. Under this condition both the head upstream of the flume and in the throat are needed to determine the flow rate. The point at which the flow changes from free flow to submerged flow is called the submergency point.

   It is expressed as a percentage, which is the ratio of downstream liquid depth/ upstream liquid depth and it varies from size to size being as low as 55% and as high as 80% through the range of throat sizes from 2.54 - 240 cm.

Flumes should be sized and installed to ensure that a free-flow condition is always maintained. Under free-flow conditions only one secondary device is required to measure liquid levels, located upstream of the flume.

2.1.2.3 Application

Flumes are usually used to measure flow in open channels where higher flows are expected, and are better suited for use with flows containing sediment or solids than weirs. Flumes are self-cleaning, and require less maintenance in comparison to weirs, but they still need to be cleaned specially when used with sewage flows where more sediments are expected.

2.1.2.4 Common Flume Types

Some of the commonly used flume types are:

Parshall Flume

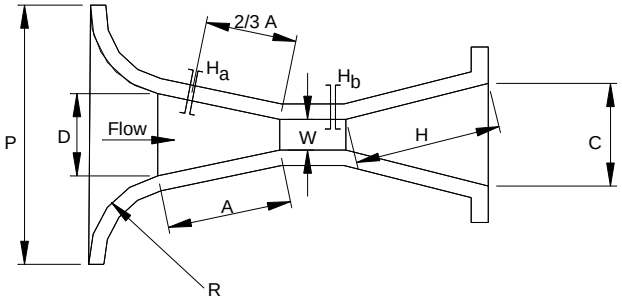
Parshall flumes (see Figure 8) are primarily used for permanent installations. Their design and sizes are dictated by the throat width, which for wastewater applications is usually a minimum of 25 mm (one inch). The throat width and all other dimensions must be strictly followed so that standard discharge tables can be used (Grant and Dawson [2]). Parshall flumes in turbulent flows are typically equipped with an integral floatwell to house the secondary-measuring device, and to ensure a correct liquid level reading. They are designed in a way to be able to withstand a high degree of submergence without affecting the rate of flow, and to have a self-cleaning capability as shown in Figure 8.

The flow rate in the Parshall flume is determined by measuring the liquid level one third of the way into the converging section, and the discharge rates are determined using the following head versus flow relationship:

$$Q = K H^{n}$$

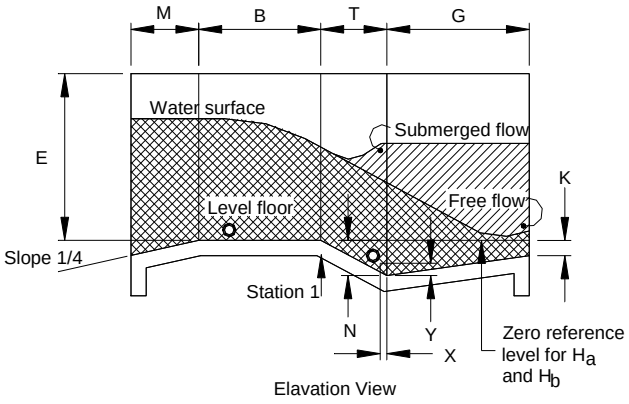
Where:

Q = flow rate
H = head measured at point Ha (Figure 8)
K = constant, function of throat width and measurement units
n = constant (function of throat width)



Plan View

The parshall flume dimensions A,B,C,D,E,T,G,H,K,M,W,P,R,X,Y are given in special tables.



Elavation View

Figure 8. Parshall Flume

Palmer - Bowlus Flume

The Palmer-Bowlus flume also produce a high velocity critical-flow in the throat by constricting the flow through the flume. The Palmer-Bowlus flume was designed to be installed in an existing channel, and its measurement accuracy is less sensitive to upstream flow disturbances (e.g. turbulent flow conditions) than the Parshall flume. It is often used in manholes or open round or rectangular bottom channels, or in channels with excessive slope and/or turbulence (see Figure 9a). The flume sizes are designated by the size of the pipe or conduit into which they fit, and the volume of expected flow, not by the throat width as is the case with the Parshall flumes. Palmer-Bowlus flumes are available from various manufacturers to fit pipe sizes ranging from 10 to 100 cm (4 - 42 inches), and larger sizes can be specially ordered.

The flow rate through a Palmer-Bowlus flume is determined by measuring the liquid depth at a point one-half pipe diameter upstream from the flume throat, and the most popular and preferred design for circular pipes and conduits is the Palmer-Bowlus flume which has a trapezoidal throat (see Figure 9b).

The Palmer-Bowlus flume main advantages comparing to Parshall flume are:

- less energy loss;
- minimal restriction to flow;
- Easy installation in existing conduits.

Because of possible wide variation in Palmer-Bowlus design, and different manufacturers, it is very important to assure that the rating curve (head versus flow) being applied is the correct one for that particular flume. The rating curve should be the one provided by the manufacturer.

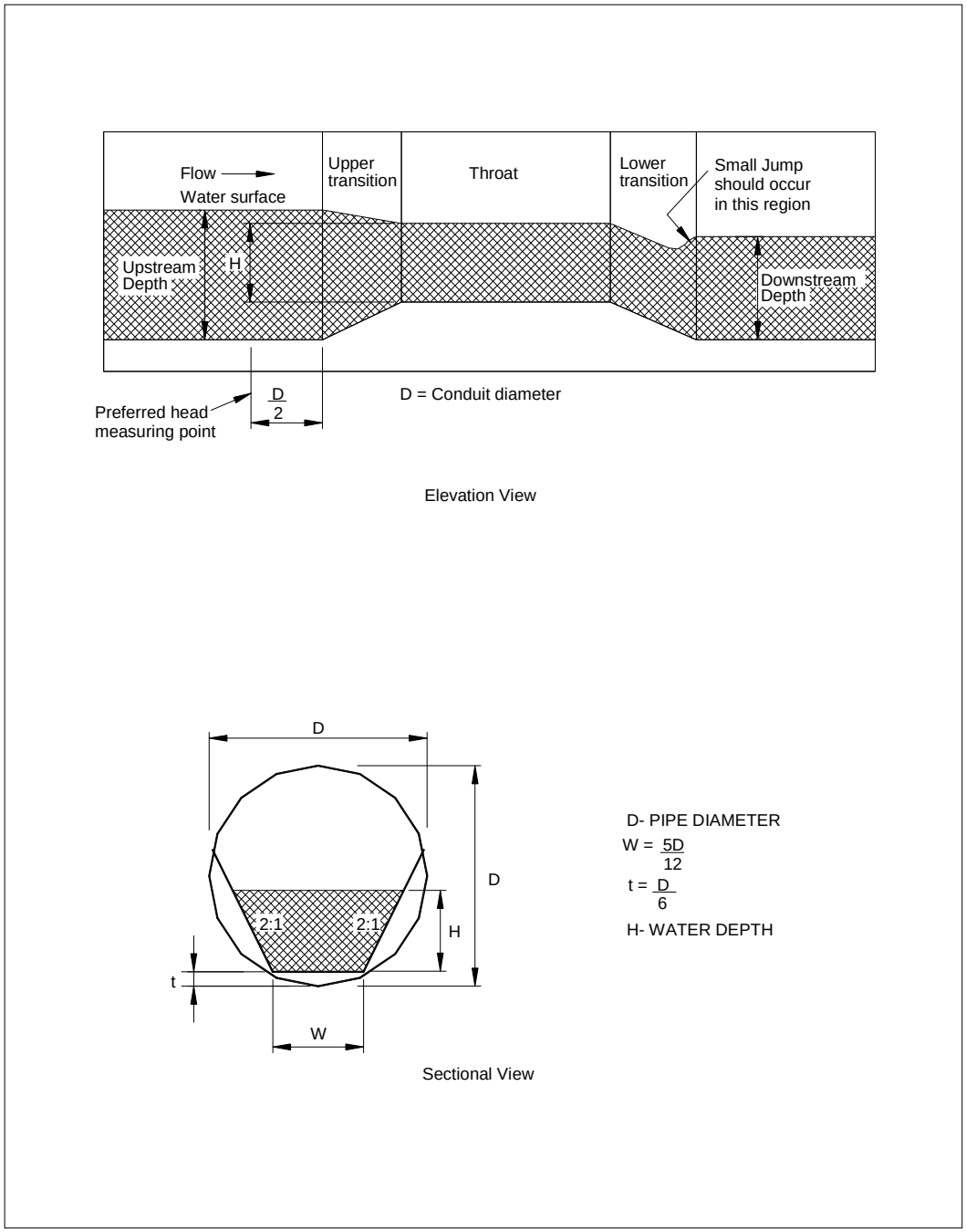


Figure 9A. Palmer-Bowlus Flow Measuring Flume

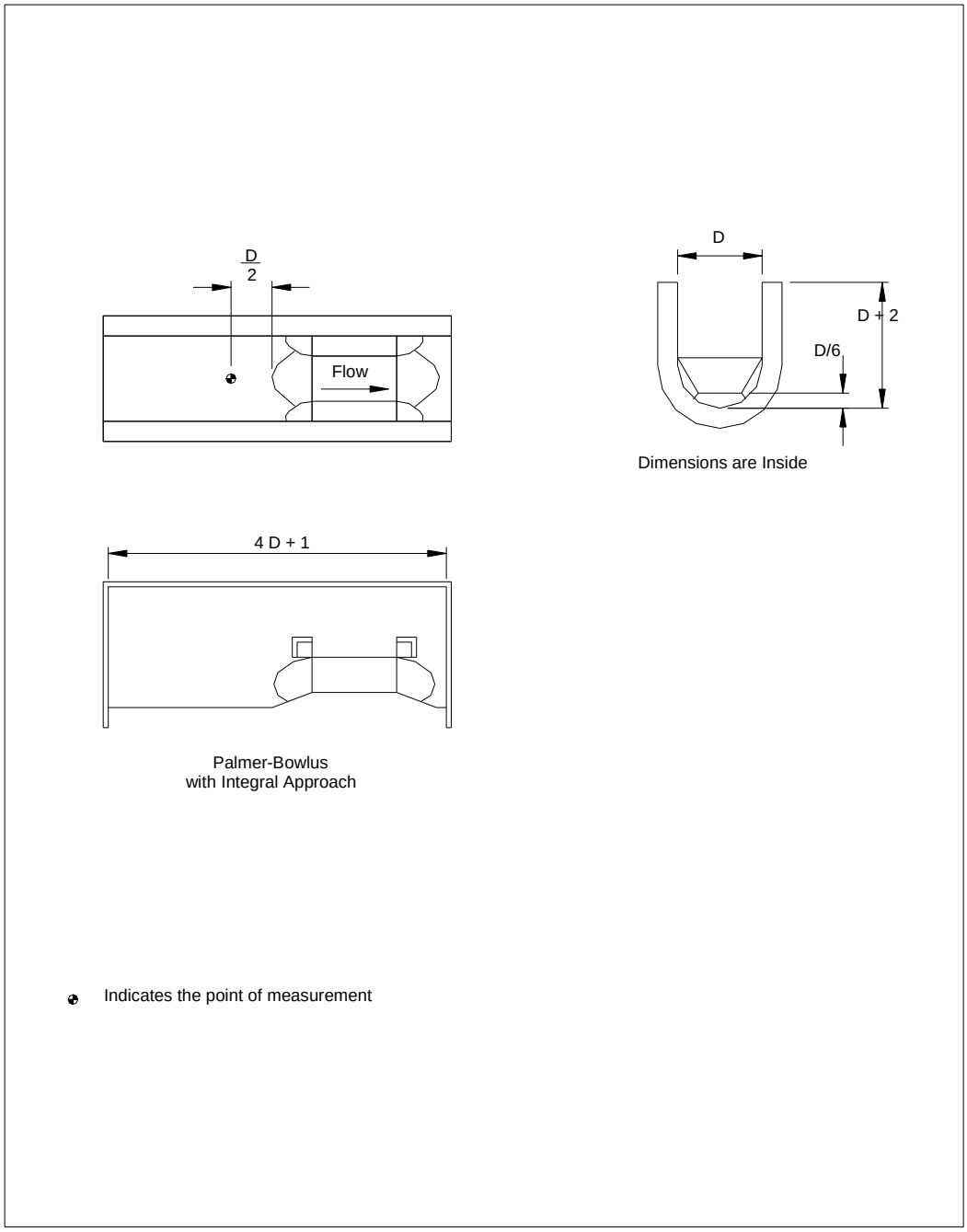


Figure 9B. Palmer-Bowlus Flow Measuring Flume

Other Flumes

There are a number of other types of flumes, which can find application in effluent flow measurement. These are usually purchased prefabricated from one of the many flume manufacturers to meet special design criteria or to solve a specific problem. Some common types are:

- Leopold-Lagco Flume: a proprietary flume manufactured by the F.B. Leopold Company (see Figure 10). They are mainly used in the measurement of sewer flows, and their sizes are designated by the size of the conduit in which they are to be installed and the expected range of flows. They are available to fit pipe sizes ranging from 10 - 183 m (4 to 72 inches). They provide an accurate flow measurement when used on a minimum grade or grades up to 2%. The best location for the level measuring point is at a distance of 1/12 D or 25 mm (one inch) minimum upstream of the flume. The discharge equation is as follows:

  $$Q = K\, D^{0.953}\, H^{1.547}$$

  Where:
  Q = flow rate
  H = head
  D = pipe diameter
  K = constant function of units

HS, H, and HL flumes were developed by the U.S. Department of Agriculture (USDA). They are capable of monitoring flows that vary over wide ranges (100:1) with a high degree of accuracy. As per Grant and Dawson [2] the maximum flow rates range from:

2.4 - 23.2 L/s
8.6 - 83.6 m^3/hr for HS flume

9.5 - 2380 L/s
34 - 8580 m^3/hr for H flumes

586 - 3290 L/s
2110 - 11,800 m^3/hr for HL flumes

When installing an H-type flume it is recommended that the approach channel is rectangular, having the same depth and width as the flume, and a length three to five times the depth of the flume.

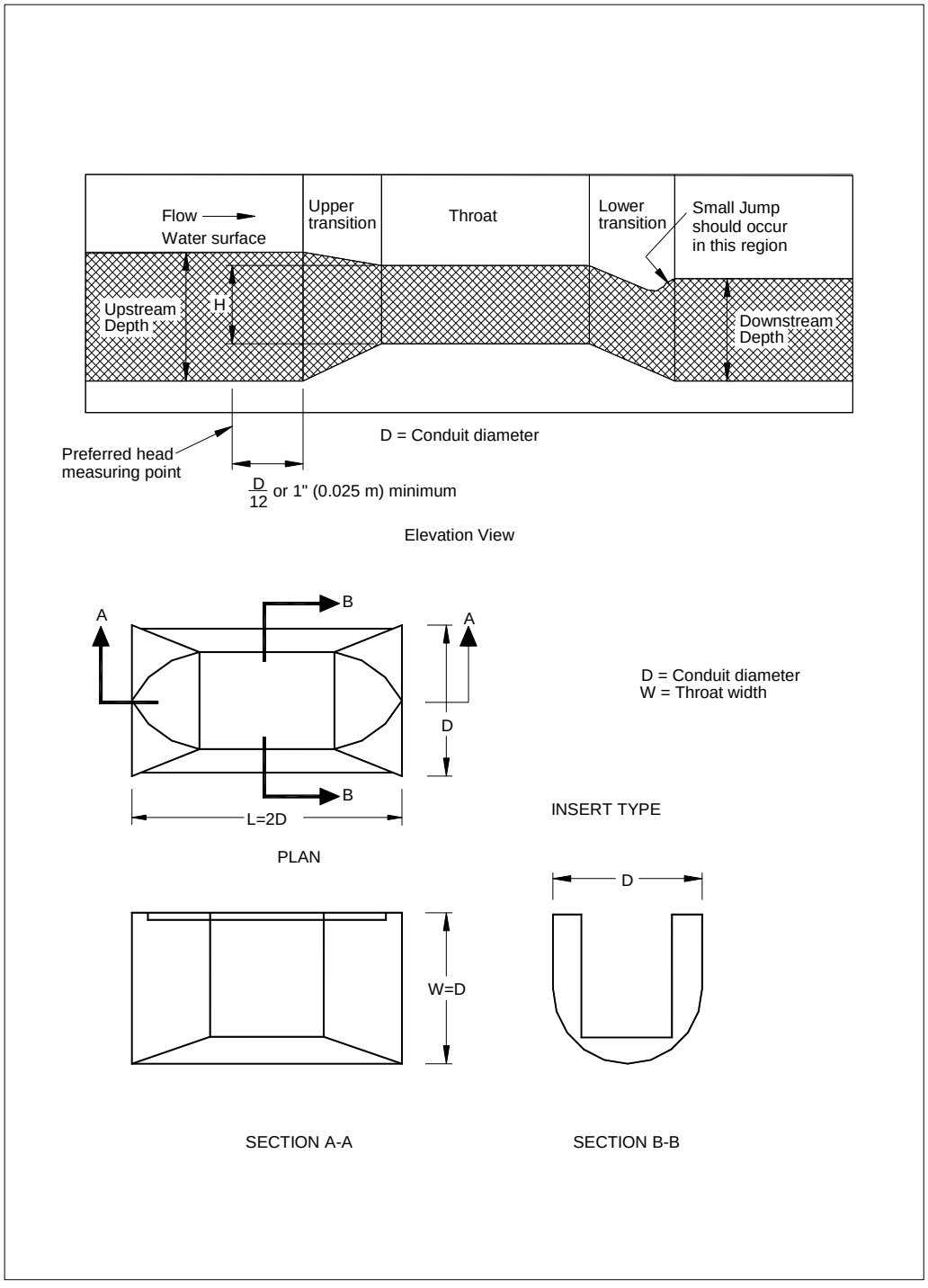


Figure 10. Leopold-Lagco Flume

Trapezoidal flumes have been used by the U.S. Department of Agriculture (USDA) to measure small flows. Its sloping sides permit a very wide range of measurable flow and cause a minimum backwater. Various trapezoidal flumes have been constructed to measure maximum flow rates ranging from 1-2,650,000 m3/hr (0.010 to 26,000 cfs).

- Cutthroat flumes were developed by Utah State University Water Resources Laboratory and as the name indicates the flume does not have a throat section (see Figure11). The flume is a flat-bottomed device and its main advantage is extreme simplicity of form and construction. It is recommended that cutthroat flumes be used in channels where free and submerged flow conditions may be desired. For more detail on these types refer to Grant and Dawson [2].

2.1.3 Installation and Design of Primary Flow Measurement Devices

The various flow-monitoring methods have distinct advantages or disadvantages under different conditions and, therefore, specific installation requirements. Prior to the device installation a field inspection is recommended to investigate hydraulic conditions in the conduit such as, flow direction, obstructions, expected flow rates, presence of debris, and flow regime. The manufacturer's recommendations for installation always need to be followed.

2.1.3.1 Weir Installation

To ensure accurate discharges measurement, there are certain general design requirements that apply to all weir types:

- The upstream face of the weir should be smooth and perpendicular to the axis of the channel;
- The connection to the channel should be waterproof;
- The length of the weir or the notch angle must be accurately determined;
- The weir should be ventilated if necessary to prevent a vacuum from forming below the nappe;
- The height from the bottom of the channel should be at least 2 times the maximum expected head of the liquid above the crest;
- The approach section upstream of the weir should be straight for at least 20 times the maximum expected head of liquid. For more design requirements refer to Grant and Dawson [2];
- The weir should be made of a thin plate 3 - 6mm;

- (1/8 - 1/4 inch) thick with a straight edge or thicker with a downstream chamfered edge;
- The device for measuring the head should be placed upstream at a distance of at least three times the maximum expected head on the weir.

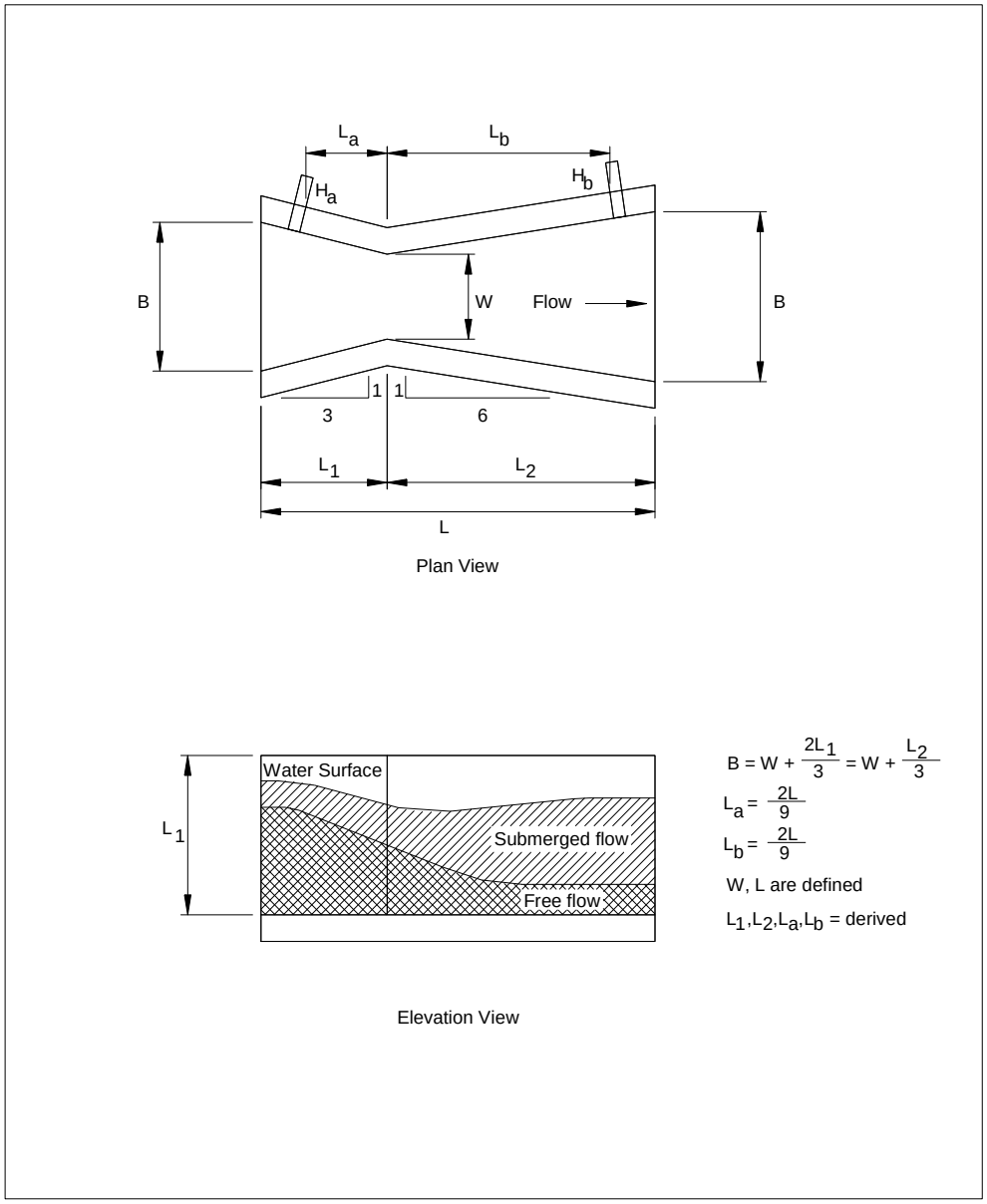


Figure 11. Dimensional Configuration of Rectangular Cutthroat Flume

2.1.3.2 Flume Installation

The following points need to be taken in consideration when selecting, and installing a particular type of flume:

- A flume should be located in a straight section of the open channel;
- The flume should be set on a solid foundation;
- The approaching flow velocity should be free of turbulence, and waves, and well distributed in the channel;
- The upstream banks should be high enough to sustain the increased liquid depth caused by the flume installation;
- If possible always install the flume to obtain a free flowing condition.

2.1.4 Calibration of Primary Flow Measurement Devices

Some form of calibration method must be provided for in every field installation. To calibrate the complete measuring system there are three main methods commonly used:

1. Volumetric flow measurement;
2. Dilution (dye);
3. Point velocity and depth measurement.

2.1.4.1 Volumetric Method

The volumetric method is considered to be one of the most accurate methods for obtaining liquid-flow relationships. This method is typically used for only small volumes of liquid, but can be applied to larger flows if suitably large enough basins are available. The volumetric method involves determining the amount of time to fill a tank or container of a known volume. The rate of flow is calculated by dividing the volume by the fill time.

The volumetric method requires only a sensor to monitor liquid level, or to determine when the tank volume is full. It can be applied to sewage pumping stations as a routine method of estimate sewage flows by recording the off-on times of the pumps through telemetry or SCADA systems. There is also a commercially available product, which uses this principal to estimate flow (Volumeter-Model 300 made by Marsh-McBirney, Inc.).

2.1.4.2 Dilution (dye) Method

This method measures the flow rate by determining the dilution of a tracer solution. The dye is continuously injected at a constant rate, from a distance far enough upstream to ensure the dye is uniformly concentrated through the cross section at the point of measurement. The dye concentration change is proportional to the change in flow rate.

2.1.4.3 Point Method

This method requires the collection of depth and velocity measurements at specific points across the channel cross section to determine the flow, which is equal to mean velocity x cross sectional flow area (VxA). The Two-point method can be used to determine the mean velocity.

2.1.5 Maintenance of Primary Flow Measurement Devices

Proper function and accurate flow measurement are directly related to the level of maintenance of primary measuring devices.

A frequent inspection and maintenance of the devices is recommended on a bi-weekly basis to:

- Clean sediment and debris from the upstream channel;
- Check the primary and secondary devices zero-setting.

2.2. Secondary Measuring Devices (Flow Meters)

Secondary measuring devices are devices used to measure liquid level variations in conjunction with primary measuring devices (weir or flume). The liquid level is used to estimate the flow rate based on the known liquid-level flow-rate relationship of the primary measuring device.

2.2.1 Floats

Historically, floats have been the most commonly used secondary devices used for monitoring liquid level variations, because of their relatively low cost, and availability. However, this has changed in recent years due to the decreased cost, increased availability, and improved reliability of electronic measuring devices such as ultrasonic sensors.

Floats are suspended in a stilling well area, located to the side of the flume. The stilling well is connected to the channel by a slot or port, such that the liquid level in the stilling well is the same as the critical hydraulic level in the flume. The stilling well is required for a float system, as a float could not be placed in the flume channel without creating a hydraulic

disturbance, which would interfere with the flume hydraulics and measurement accuracy. The stilling well also prevents the float from being affected by any hydraulic surges.

The float is usually connected by a cable to chart recorder pulley, and as the float rises and falls, the pen on the chart recorder moves correspondingly. A movable weight can be attached to the cable, which keeps it taut (see Figure 12). The cable will cause the rotating member to be angularly positioned proportional to the level of the liquid in the primary device. When the float is used in a combination with an electronic relay the level is read electronically. A system of gears enables the chart recorder to be calibrated and record information in specific units (i.e. inches of liquid, flow in gallons, etc.).

Floats include moving parts, which are subject to wear, and are subject to build-up of grease and solids. Thus they require periodic maintenance and repair. The accuracy of floats used as level measuring devices ranges from 1.5 mm – 6 mm (0.005 ft - 0.020 ft) (Irwin [4]).

2.2.2 Electrical (Capacitance Probe)

The capacitance probe utilizes the electrical conductivity of the liquid to monitor variations in liquid level. Electrodes or probes are suspended vertically into the liquid being controlled, thus completing a circuit which actuates the control relay. The changing liquid level causes an electrical capacitance change, where the difference in capacitance indicates the depth of the liquid. Electrodes and holders should be selected according to the specific characteristics of the liquid involved, and the lengths required to monitor the potential range in liquid level. Electrode holders and electrodes are available for measuring liquid level in temperature up to 232 C0, and pressure of 13790 kpa pressure (MagneTek Controls [5]).

The changing liquid characteristics, or coatings of grease, hair, or solids can adversely affect the accuracy of the electrical system, and the plates are subject to damage by floating debris. Thus this method of measurement can be used to measure flow in raw sewage or in-process flows only if applied as a short-term installation. Capacitance probes are better suited to measuring effluent flows, which are less likely to contain materials which will interfere with measurement. Electrical type level measurement devices are available to measure the liquid level with 0.5 % to 1 % accuracy of full-scale level (Irwin [4]).

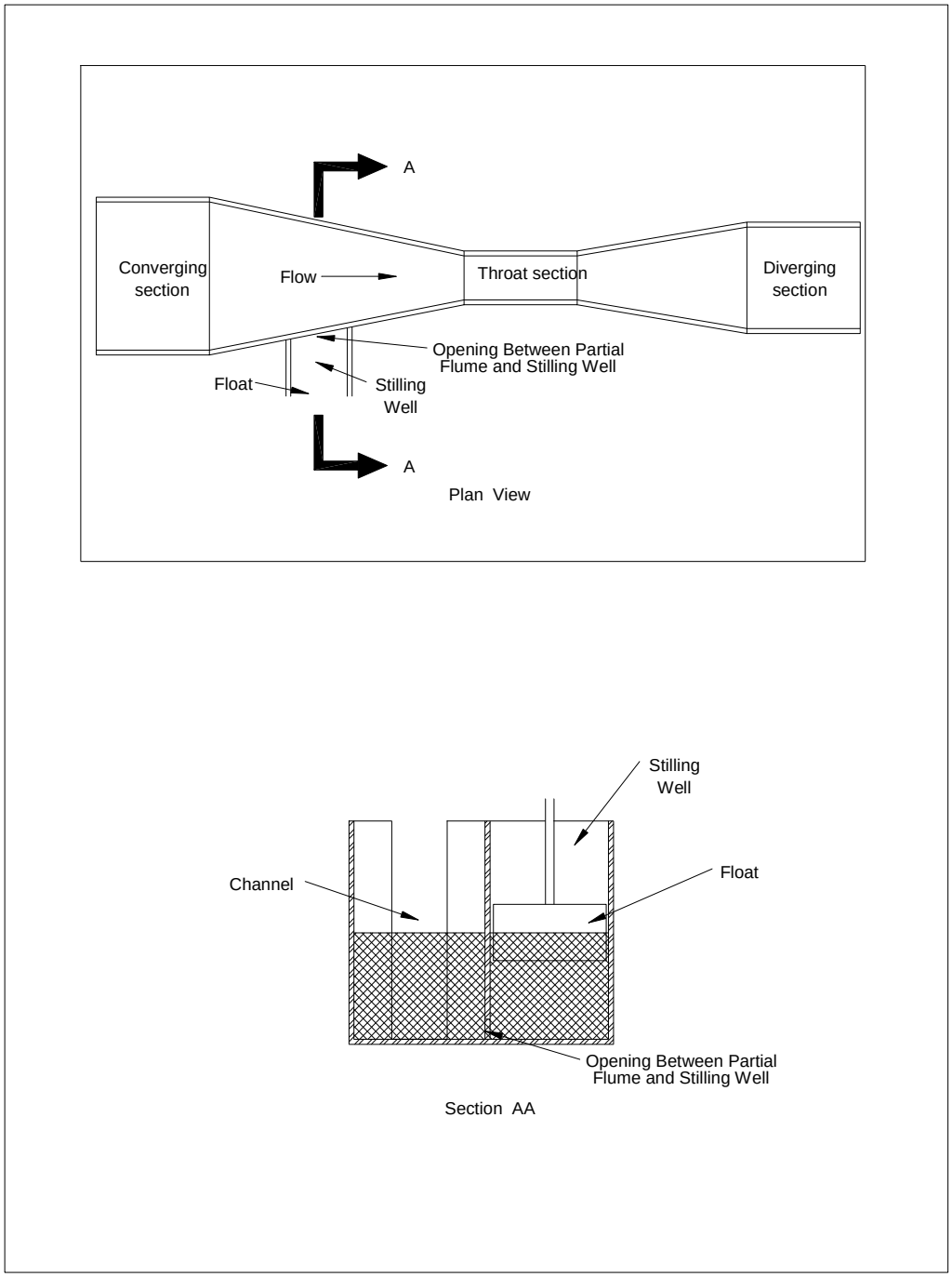


Figure 12. Float level measuring device

2.2.3 Ultrasonic Level Sensors

An ultrasonic sensor mounted above the flow stream transmits a sound pulse that is reflected by the surface of the liquid. The time required for a pulse to travel from the transmitter to the liquid surface and back to the receiver is used to determine the liquid level. Ultrasonic systems are available to monitor levels from a few centimeters and up to 61 meters (Milltronics Process Measurements [6]). There are various types of transducers used, and their selection depends on the material and application range to be monitored. The distance between the transducer and the transceiver depends on the type of the transducer used (available for distances up to 366 m [6]). They can operate under pressure up to 200 kPa, and temperature range –40C° to 150 C° [6] with range of accuracy 0.25%-0.5%. The selection of the proper transducer is based on:

- Maximum level to be measured;
- Characteristics of the transducer (pressure, temperature, corrosivity, etc);
- Mounting configuration.

Since the ultrasonic level sensors are fixed above the flow stream, grease, suspended solids, silt, corrosive chemicals in the flow stream, and liquid temperature fluctuation do not affect the sensors. However, ultrasonic systems may be affected by wind, high humidity, air temperature, radio and electromagnetic waves, rain, shock waves, and floating foam and debris, and they are not suitable for use in very narrow channels.

2.2.4 Bubblers

Bubblers consist of an air tube, which is anchored in the flow stream at a fixed depth along the side-wall of a primary device (flumes or weirs). Bubbler flow meters use an air compressor to force a metered amount of air through a line submerged in the flow channel. The pressure needed to force the air bubbles out of the line corresponds to the hydraulic head of the liquid above the tube. Thus the pressure in the tube is proportional to the liquid level in the primary device, and can be measured with a mechanical pressure sensor or an electronic pressure transducer.

Some bubblers have a built in plotter, flow conversion equations, telemetry capabilities, and data storage (ISCO 3230). This allow them to provide and transmit a time based level or flow rates and total flow.

Bubblers are highly velocity sensitive, and readings may be greatly influenced by the non-vertical installation of the tube, disturbance of the tube by floating debris, suspended solids, and rapidly rising and falling head levels. Thus periodic maintenance (cleaning) is required. To prevent the building-up of potentially clogging solids some bubblers have an exclusive automatic bubble line purge.

The purge can be set to occur at selected time interval or can be activated manually. Usually special software is used to sense the rising heads and automatically increase the bubble rate to maintain the maximum accuracy.

2.3 Selection Criteria for Secondary Measuring Devices

The most important criteria to be considered in the selection of a secondary measuring device includes:

- Type of application; is the metering device appropriate for open or closed conduit flow?
- Proper sizing for range of depths to be measured; is the device appropriately sized for the range of flows that needs to be monitored?
- Fluid composition, does the device have the recommended minimum clear opening for the fluid being monitored, and is it compatible with the fluid?
- Accuracy and repeatability: is the stated accuracy of the component consistent with overall system accuracy?
- Installation requirements; is there enough length in front and behind of the device, and are measuring devices accessible for service?
- Ease of maintenance; how often the device needs to be cleaned, and are cleaning systems available?
- Operating environment; where necessary is the equipment resistant to moisture and corrosive gases?
- Head loss.

2.4 Installation of Secondary Flow Measurement Devices

Proper installation of secondary flow measurement devices is directly related to the amount of information collected regarding the location, characteristics of the liquid to be monitored, operating environment (temperature, gases, moisture...), and flow conditions.

The manufacturer's installation instructions should always be followed. The following recommendations should be taken in consideration when installing these devices:

- The upstream section should be cleared of debris and sediments (at least 15 diameters upstream from the sensor);

- The level sensor in an open channel should be housed in a stilling well;
- When applicable, it should be ensured that the sensors are installed centered and flat on the conduit bottom;
- If the flow velocity is greater than 1.5 m/s, better results may be obtained by mounting the sensor facing the downstream direction, if possible.

2.5 Calibration of Secondary Flow Measurement Devices

Level sensors are pre-calibrated at the factory or are calibrated by the distributor upon installation using the equipment available from the meter manufacturer. The calibration of the level sensors is simply checked by comparing the sensor reading to the tape measurement of the depth. In open channel systems a known depth of flow is simulated, then verified if the sensor read and totalized correctly for that depth. If any discrepancies are discovered, the manufacturer's instructions for re-calibration should be followed.

2.6 Maintenance of Secondary Flow Measurement Devices

Regular site inspection and maintenance is recommended on a weekly or bi-weekly basis. Frequency is dependent on type of instrument – ultrasonic level sensors tend to be relatively maintenance free. The inspection should include:

- Clean the sensor and the instrument enclosure;
- Remove sediment and debris from around the cable and sensor cables;
- Check the accuracy of the time display;
- Check the power availability;
- Compare the depth reading to a manual measurement of the depth, before and after clean-up, and if the difference in depth is greater than 5 cm (two inches) or 10% the effective range, the meter should be removed for re-calibration;
- Note any irregularities;
- When devices are used to measure raw wastewater a flushing system should be provided where appropriate. Self-cleaning electrodes are available for use with used with magnetic flow meters using either high frequency ultrasonic waves or heat;
- For long-term installations, complete maintenance is required every six months, and a record of all flow monitoring, cleaning, and maintenance activities must be kept. The maintenance record should describe the system condition before and after any work was undertaken.

The maintenance should include:

- Removal of sensors and cables for cleaning;
- Cleaning of the pipes upstream for at least 15 pipe diameters upstream of the sensor location.

3. Closed Channel Flow Measurement

Closed channel flow is flow in completely filled pressure conduit (pipes) (see Figure 1). There are three main methods used to measure the flow rates in closed conduits.

1. Insertion of an obstruction to create a predictable head loss or pressure difference.
2. Measurement of the effect of the moving fluid (momentum change, magnetic field shift, etc.).
3. Measurement of increment unit of fluid volume.

The most common devices used for flow measurement in closed channels are: Venturi meters, flow nozzles, Orifice meters, magnetic meters, Doppler meters, and Pitot tube flow meters. Not all these devices are suitable for specific waste-waters. These commercially available measuring devices use the Principe of Continuity, and one of several equations that define flow motion such as the energy equation or the momentum equation. Others use physical principals such as Faraday's law of electromagnetic induction, used in magnetic flow meter, and Ohm's law utilized in hot wire anemometers measuring the rate of cooling by flow of fluid past an electrically heated resistance wire.

The simplest way to measure pressure and pressure differential in a closed pipe is to use a vertical standpipe called a Piezometer tube connected to a tap on the pipe in which the pressure is to be measured. If the piezometer tube has a U-shape the instrument than is called a manometer. To produce uniform conditions in the closed pipe it is recommended that at least a length of 6 times the pipe diameter be straight in front of the measuring device (Simon and Korom [8]). A straight run of about 5 times the pipe diameter is desirable after the measuring device (Simon and Korom [8]). The most commonly used methods are described in the following sections.

3.1 Orifice Flow Meter

It should be noted that the orifice flow meter is not considered suitable for wastewater flow measurement, due to the solids content of the flow. An orifice is a cylindrical or prismatic opening through which fluid flows.

The size of the opening is accurately calculated and bored to produce the required differential pressure for the specified flow condition (see Figure 15). Usually pressures and differential pressures are determined using one of the above, discussed instruments. Most of commercially available orifice meters are supplied with a calibration chart.

Because of its simplicity, low cost, ease of installation, and high accuracy, orifice plates are commonly used to determine the flow rates based on the deferential pressure readings, and in order to measure flow rates accurately it is necessary that the interior of the pipe be smooth and round. Two main types of orifices are available:

1. Thin plate orifice,
2. Sharp-edged orifice.

Orifices can be made of various materials with different corrosion-resistant characteristics and can be assembled in two ways:

1. The orifice is completely welded in place and cannot be removed. Commercially available orifices can support up to 4137 kpa pressure and 371 C° operating condition (Badger Meter [7]).
2. The orifice plate is retained in place with flanges.

Flow estimation is based on the following equation:

$$Q = KA\sqrt{(2gh)}$$

Where:

k = flow coefficient
h = h1-h2 pressure head (m)
g = 9.81(m/s^2)

3.2 Venturi Flow Meter

Venturi meters are used to measure the flow in closed conduits, and they consist of:

1. The inlet cone, where the diameter of the conduit is gradually reduced.
2. The throat or constricted section; in standard meters the throat has a size range of 1/5 D - ¾ D the diameter of the pipe, and its length is equal to its diameter.
3. The outlet cone, in which the diameter increases gradually to that of the pipe in which the meter is inserted.

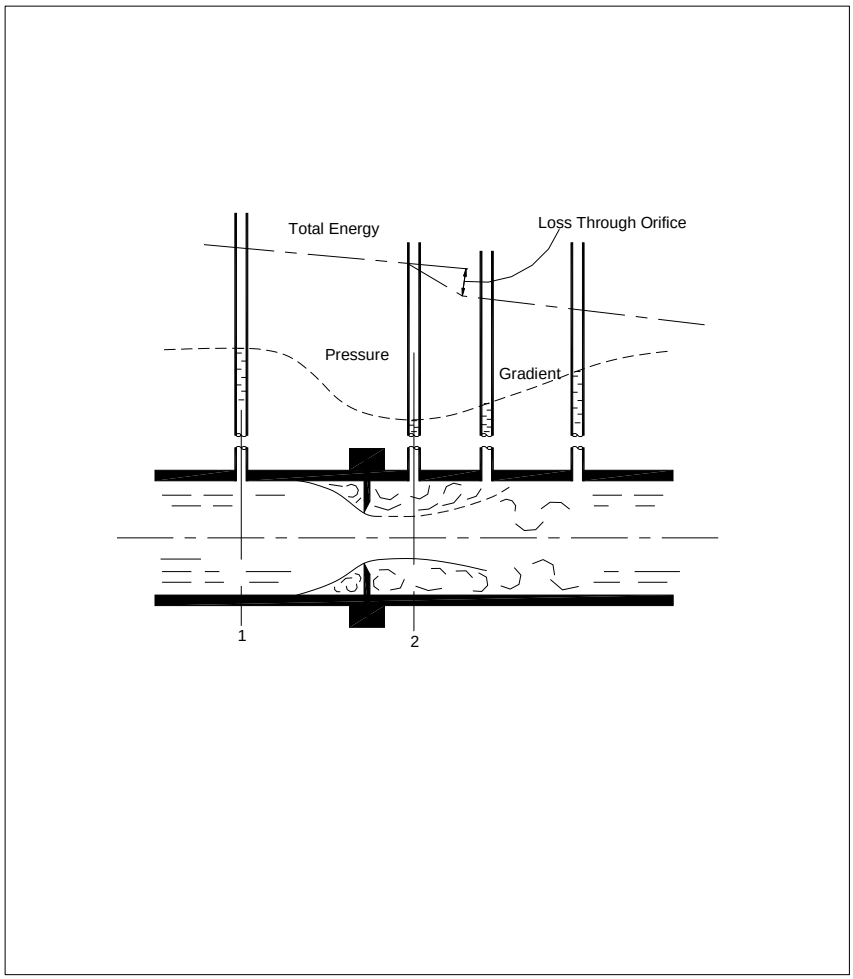


Figure 13. Continuity Equation

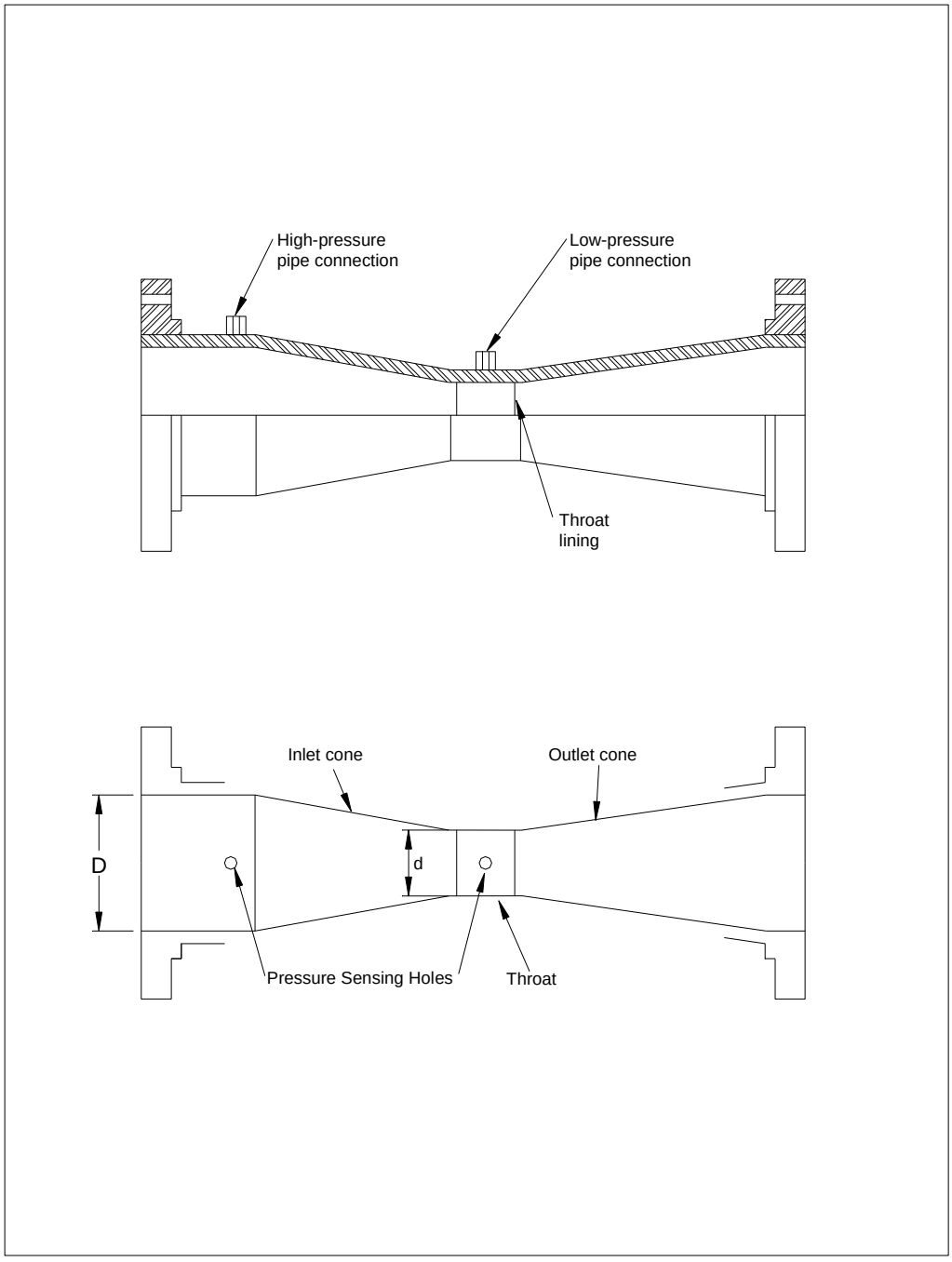


Figure 14. Typical Venturi meter

A Venturi meter operates on the same principle as the orifice but with a much smaller head loss (see Figure14). The flow rates through the meter are determined based on the difference between pressures indicated at the inlet and at the throat of the meter, and the equation used to determine the discharge is:

$$Q = CA\sqrt{(2gh)}$$

Where:

A = Area at throat of meter (m^2)
H = h1 - h2, pressure heads (m)
g = 9.81 m/s^2
C = Coefficient of energy losses

Venturi meters need to be cleaned periodically to remove solids, which may clog them, and affect the accuracy of the measurement. A flushing system is necessary for good performance, to keep the pressure sensors from clogging.

3.3 Electromagnetic Flow Meter

The electromagnetic flow meter operation is based on Faraday's law, which simply states that a voltage is generated in any conductive liquid as the liquid moves through a magnetic field. This voltage is sensed by electrodes embedded in the sensor, and is transmitted to the meter. The voltage is proportional to the velocity of the conductive liquid (conductor).

Electrodes are made of various materials (e.g. stainless steel) depending on the fluid characteristics in which they are applied, and can be easily fouled by floating materials, oil, and grease, thus requiring frequent cleaning. The key disadvantages of electromagnetic flow meters are the high cost when used in large pipe diameters, high operational costs and maintenance, and their complex installation.

Electromagnetic flow meters for wastewater applications range in size from 15 - 2200 mm with a claimed accuracy in the range of +/- 0.15% under ideal conditions.

The following points should be taken into consideration when choosing and installing electromagnetic flow meters:

The meter and transmitter should be located a minimum of 6m (20ft) from EMI (Electro-Magnetic-Interference) generating machinery;

The installation should be downstream of a pump, and upstream of control valves (100 hp or larger);

The meter and the transmitter should not be installed after a double change in plane (i.e. elbows, or a tee and an elbow).

3.4 Doppler Flow Meter

A Doppler flow meter (a type of area-velocity meter) operates by emitting into the flow ultrasonic waves of known frequency and duration from a transmitter located either on the channel invert or on the outside of the conduit in the 3 or 9 o'clock position. Suspended particles and air bubbles in the flow reflect the emitted waves.

The sensor receives and detects the deflected frequencies, and processes them to determine the average velocity.

The frequencies are proportional to the velocity of the points in the liquid flow at which the reflection occurred. The measurement accuracy is a function of the percent sound reflectors (solids and bubbles), their sizes, distribution, and the flow meter design features. For the appropriate selection and installation of this type of flow meter the following points should be considered:

Sonic reflectors (i.e. suspended solids, etc.) representative of fluid velocity must be present in the liquid;

The pipe should have a uniform cross section without abrupt changes in direction for a minimum of 10 pipe diameters upstream and 5 diameters downstream;

Manufacturers' minimum distance requirements should be met;

If transducers are to be mounted on the outside, the pipe material should allow the penetration of the ultrasonic signal.

3.5 Pressure Transducers

Transducers are devices that produce an electrical signal proportional to some physical phenomenon (pressure, temperature, humidity, flow, etc.). The main element of the pressure transducer is the sensing element, consisting of a membrane (diaphragm) which is able to respond to the applied process pressure and static pressure. The diaphragm is deformed by the pressure differential applied on it, and the deflection is transmitted to a gauge or meter, either electrically or magnetically. The change in measured voltage flowing through the electric strain gauge is proportional to the pressure of the fluid on the diaphragm.

The diaphragm is usually made of stainless steel, copper or silicon. Stainless steel diaphragms are well suited for high pressures and have superior corrosion resistance. Silicone diaphragms have greater accuracy, but are limited to use with lower pressure transducers.

Pressure transducers can be classified as:

- Absolute pressure transducers; measure pressure in relation to zero pressure (a vacuum on one side of the diaphragm) (PSIA).
- Differential transducers; measure pressure difference between two points (PSID).
- Gage pressure transducers; a form of differential pressure measurement, which takes atmospheric pressure as a reference (PSIG).

3.5.1. Selection of Pressure Transducers

The following are the main considerations in selecting pressure transducers:

- The pressure requirements of the system, which means the normal working pressures should be below the maximum used range of the transducer. (As a guideline, select a transducer with a range of 125% of the normal working pressure and refer to the pressure strain and force (OMEGA Technologies Company [9]);
- Compatibility of the transducer with the fluid;
- The maximum system temperature should not exceed the stated maximum operating temperature of the transducer;
- Durability within the pressure environment.

Commercially available pressure transducers are able to measure pressures in a range of 0-2000 PSIG in operating temperatures (-55 - +125C°) with an accuracy range of * 0.1 - 1.5% (OMEGA Technologies Company [9]).

3.6 Area Velocity

The Area-Velocity method consists of measuring both cross-sectional area of a flow stream at a certain point, and the average velocity of the flow in that cross section. The Area-velocity method can be used either with open channel or closed channel flows. In addition to measuring flow under free conditions it can also be used to measure flow under submerged, full pipe, and surcharged flow conditions. This method does not require the installation of a weir or flume and it is used usually for temporary flow monitoring applications such as inflow and infiltration studies.

The flow rate is calculated by multiplying the area of the flow by its average velocity Q=AxV (Figure15). The Area-Velocity method requires two separate measurements, one to determine the flow depth and the other the average velocity of the section. This method can be implemented in two ways: 1) The depth and velocity are measured manually and used to determine the area and flow rates in a particular time. 2) An Area-Velocity flow meter used to measure the liquid level and velocity and automatically calculate the flow rate.

4. Flow Recorders

Flow recorders (applicable to both open channel and full pipe flow meters) can be distinguished based on the method by which flow data is managed and stored.

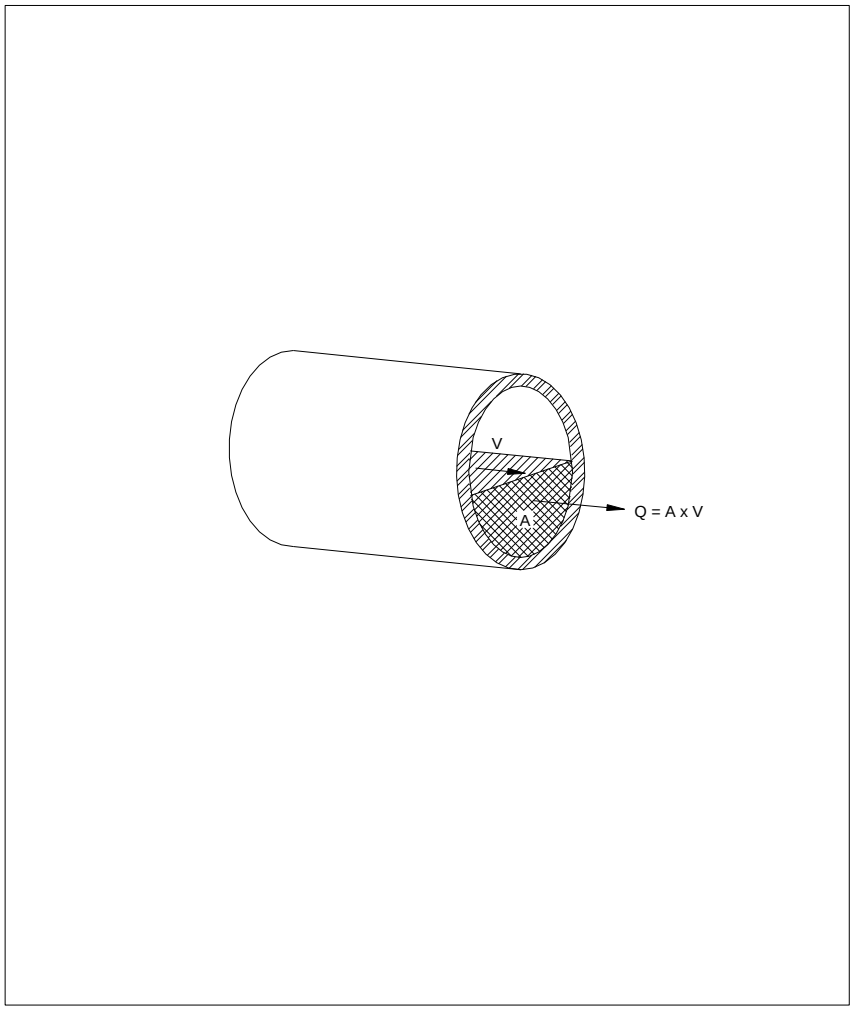


Figure 15. Area - Velocity Method (Continuity Equation)

4.1 Flow Transmitters

Flow transmitters are used to calculate the flow based on secondary device level information and the primary device flow equation, and then transfer the flow data to other recording instruments, and computers. These devices also usually include a digital display, which can be set to display both flow and liquid level information. Flow transmitters usually output an analog signal (e.g. 4 to 20 mA), but may also produce a digital output (e.g. RS-232 serial output). Most data recorders and display devices will accept an analog signal, but this should be confirmed with the manufacturer. Many transmitters also incorporate limited data logging features.

4.2 Chart Recorders and Data Loggers

Chart recorders offer immediate visual information, whereas data loggers usually allow the data to be stored in memory, and downloaded to a central computer for later data analysis.

Recorders and data loggers are used to record and store both analog and digital data by writing either an analog or digital trace, or actual numeric values, onto paper for a specific period of time. These devices can be programmed to take input directly from the secondary measuring device and convert the information to flow.

The resulting recording is a permanent analog and/or digital printout. Most of today's recorders are able to record multiple variables such as pH, temperature, flow, velocity, etc. There are many types of recorders
such as:

- Flatbed recorder; used where portability is a major factor (e.g. laboratory, field, etc.).
- Vertical recorder; used where permanent installation is required
- (e.g. industrial applications).
- X-Y recorder; used where two input signals need to be compared.
- (e.g. recording temperature vs pressure instead of recording temperature vs time).
- Circular chart recorders; most often used in remote locations, computer rooms for a permanent record over a long time of period, generally use wider chart paper (up to 250mm). Their key advantage lies in the ability to readily view the flow records to assist in operating tasks without having to analyze the recorded data. Charts are available to record for periods of 24 hours, 7 days, 30 days and 4 months.

Most of today's recorders and data loggers use a 4-20 mA input circuit (industry standard) and can interface with other devices to record other parameters. Stored data can be downloaded to a computer through either a RS-232 serial port or via a standard or wireless modem. Depending on the type of input signal, recorders can have plug-in modules where the type of input signal can be changed by simply unplugging the old module and plugging in the new input module, or integrally selectable inputs where a selection of the desired input type for each channel in possible.

4.2.1 Charts vs Data Loggers

The major difference between a data logger and a recorder is the way the data is recorded, stored and analyzed. In addition to a chart's capability to offer immediate visual information, charts provide a continuous trend recording. Most recorders accept an input and compare it to the chart's full scale value, which makes it easy to visually analyse the data (e.g. if the recorder has 1 volt full scale, then an input of 0.5 volts will move the recording pen to 0.5/1 or 50% of the distance across the recording width). Given that most small wastewater treatment plants do not have a central computer station; the use of a chart recorder is still considered one of the best approaches in assisting the operator in daily operations.

Most data loggers usually store the data in their own built in memory, to be retrieved at a later time for further data analysis.

To retrieve and analyse the stored data, other external and peripheral equipment are required such as a standard or wireless modem, central computer and a printer if a hard copy is needed.

4.2.2 Selection Criteria of Recorders and Data Loggers

When choosing a recorder or a data logger the following should be taken into consideration:

- Determine the type or types of the input signals that need to be measured;
- Determine how many inputs need to be fed to the device at one time, this will determine the number of channels needed;
- Determine the type of chart needed based on the period and accuracy of the recording;
- Determine the type of recorder and data logger based on factors such as portability, permanent installation, application, data transfer, recording intervals, etc.

5. Sources of Further Information

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6. Revision History

February 28, 2001:	Re-publication. Figures enhanced by Bert Brazier. Appendix 1 added.
March 2000:	NovaTec replaced figures since CAD format was not compatible with Ministry software.
1999:	Draft manual prepared by NovaTec Consultants Inc. under contract to the Ministry (NovaTec Project 1231.14). Method vetted and approved by BCLQAAC.

APPENDIX 1 Effluent Flow Measurement Checklist

A. General Information

Type of flow measurement device: _____

- Make/model: _____
- Date of installation: _____
  - Installation according to manufacturer's specification — **Yes** ___ **No** ___
  - Comments: (Attach manufacturer's instructions) _____

_____

_____

B. Measuring Devices

1. **Weirs** — **Yes** **No**
   - Is the weir horizontal? (Use a level to check) ___ ___
   - Is the weir knife-edged? (For plates thicker than 3.2 mm) ___ ___
   - Is head measurement device located at a point located greater than 2.5 H upstream of the crest of the weir? ___ ___
   - Is the device free from hydraulic disturbance? ___ ___
   - Are there any leaks? ___ ___

2. **Parshall Flumes**
   - Is the upstream flow head measured at a point located at 2/3 of the length along the converging section upstream of the throat (narrowed section) of the flume? ___ ___
   - Are there any leaks? ___ ___

3. **Orifice, Venturi and Magnetic Flow Meters** — **Yes** **No**
   - Is the meter installed in a section of pipe that ensures full-pipe flow? ___ ___
   - How was this verified? _____

_____

_____

C. Maintenance

	Yes	No
– Is the meter installed in a section of pipe that ensures full-pipe flow?	___	___

– How was this verified? _____

_____

_____

D. Calibration

Frequency of calibration of measuring system: _____
(Should be at least annually)

– Method of calibration: _____
(Attach latest calibration calculations)

– Accuracy ± _____ %

	Yes	No
– Is recorder service required regularly?	___	___
– Is gauge zeroed?	___	___

– Comments: _____

_____

_____

Inspector: _____

Date: _____

APPENDIX D – HISTORICAL WATER QUALITY

Hay River Harbour

Historic Water Quality Results

Location ID	Location Name	Latitude	Longitude	Sample Date	Sample Time	Parameter	Result	Unit	Detection Condition	Detection Limit (mg/L)	Detection Limit Type	Result Comment
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2012-09-25	00:00:00	Total suspended solids	6	mg/L				CBM-2012-00017-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2012-09-25	00:00:00	Total suspended solids	6	mg/l				CBM-2012-00017-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-06-23	00:00:00	Total suspended solids	48	mg/l				CBM-2013-00006-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-06-23	00:00:00	Total suspended solids	48	mg/L				CBM-2013-00006-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-06-23	00:00:00	Total suspended solids	74	mg/L				CBM-2013-00006-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-06-23	00:00:00	Total suspended solids	74	mg/l				CBM-2013-00006-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-07-22	00:00:00	Total suspended solids	20	mg/L				CBM-2013-00016-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-07-22	00:00:00	Total suspended solids	16	mg/L				CBM-2013-00016-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-07-22	00:00:00	Total suspended solids	16	mg/l				CBM-2013-00016-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-07-22	00:00:00	Total suspended solids	20	mg/l				CBM-2013-00016-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-08-27	00:00:00	Total suspended solids	20	mg/l				CBM-2013-00031-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-08-27	00:00:00	Total suspended solids	16	mg/L				CBM-2013-00031-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-08-27	00:00:00	Total suspended solids	16	mg/l				CBM-2013-00031-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2013-08-27	00:00:00	Total suspended solids	20	mg/L				CBM-2013-00031-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-06-02	00:00:00	Total suspended solids	127	mg/L				CBM-2014-00001-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-06-02	00:00:00	Total suspended solids	127	mg/l				CBM-2014-00001-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-06-24	00:00:00	Total suspended solids	158	mg/l				CBM-2014-00006-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-06-24	00:00:00	Total suspended solids	158	mg/L				CBM-2014-00006-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-07-28	00:00:00	Total suspended solids	24	mg/l				CBM-2014-00021-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-07-28	00:00:00	Total suspended solids	24	mg/L				CBM-2014-00021-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-09-08	00:00:00	Total suspended solids	8	mg/L				CBM-2014-00039-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2014-09-08	00:00:00	Total suspended solids	8	mg/l				CBM-2014-00039-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-06-16	15:33:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2015-00002-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-06-16	15:33:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2015-00002-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-07-14	13:15:00	Total suspended solids	3	mg/l				CBM-2015-00007-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-07-14	13:15:00	Total suspended solids	3	mg/L				CBM-2015-00007-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-08-17	13:00:00	Total suspended solids	86	mg/l				CBM-2015-00018-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-08-17	13:00:00	Total suspended solids	86	mg/L				CBM-2015-00018-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-09-17	15:00:00	Total suspended solids	7	mg/l				CBM-2015-00028-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2015-09-17	15:00:00	Total suspended solids	7	mg/L				CBM-2015-00028-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-06-16	15:19:00	Total suspended solids	98	mg/l				CBM-2016-00003-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-06-16	15:19:00	Total suspended solids	98	mg/L				CBM-2016-00003-002
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-07-14	14:20:00	Total suspended solids	115	mg/L				CBM-2016-00014-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-07-14	14:20:00	Total suspended solids	115	mg/l				CBM-2016-00014-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-08-09	14:45:00	Total suspended solids	9	mg/l				CBM-2016-00023-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-08-09	14:45:00	Total suspended solids	9	mg/L				CBM-2016-00023-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-09-08	00:00:00	Total suspended solids	7	mg/L				CBM-2016-00034-003
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-09-08	00:00:00	Total suspended solids	7	mg/l				CBM-2016-00034-003
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-09-09	15:10:00	Total suspended solids	11	mg/L				CBM-2016-00034-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2016-09-09	15:10:00	Total suspended solids	11	mg/l				CBM-2016-00034-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2017-08-14	16:04:00	Total suspended solids	11	mg/L				CBM-2017-00021-003
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2017-08-14	16:04:00	Total suspended solids	11	mg/l				CBM-2017-00021-003

Hay River Harbour

Historic Water Quality Results

Location ID	Location Name	Latitude	Longitude	Sample Date	Sample Time	Parameter	Result	Unit	Detection Condition	Detection Limit (mg/L)	Detection Limit Type	Result Comment
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2017-08-15	16:04:00	Total suspended solids	20	mg/L				CBM-2017-00021-004
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2017-08-15	16:04:00	Total suspended solids	20	mg/l				CBM-2017-00021-004
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2017-09-05	14:20:00	Total suspended solids	302	mg/L				CBM-2017-00031-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2017-09-05	14:20:00	Total suspended solids	302	mg/l				CBM-2017-00031-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2018-07-10	12:00:00	Total suspended solids	96	mg/l				CBM-2018-00008-003
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2018-07-10	12:00:00	Total suspended solids	96	mg/L				CBM-2018-00008-003
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2018-08-16	00:00:00	Total suspended solids	88	mg/L				CBM-2018-00026-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2018-08-16	00:00:00	Total suspended solids	88	mg/l				CBM-2018-00026-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2018-09-24	00:00:00	Total suspended solids	46	mg/l				CBM-2018-00040-001
HAY-U/S	Hay River at Hay River / Upstream of West Channel	60.86488333	-115.7327833	2018-09-24	00:00:00	Total suspended solids	46	mg/L				CBM-2018-00040-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2014-06-23	00:00:00	Total suspended solids	104	mg/l				CBM-2014-00005-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2014-06-23	00:00:00	Total suspended solids	104	mg/L				CBM-2014-00005-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2014-07-29	00:00:00	Total suspended solids	22	mg/l				CBM-2014-00021-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2014-07-29	00:00:00	Total suspended solids	22	mg/L				CBM-2014-00021-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2014-09-02	00:00:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2014-00038-005
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2014-09-02	00:00:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2014-00038-005
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-06-16	10:50:00	Total suspended solids	11	mg/L				CBM-2015-00002-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-06-16	10:50:00	Total suspended solids	11	mg/l				CBM-2015-00002-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-07-14	13:15:00	Total suspended solids	14	mg/L				CBM-2015-00007-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-07-14	13:15:00	Total suspended solids	14	mg/l				CBM-2015-00007-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-08-17	13:00:00	Total suspended solids	51	mg/L				CBM-2015-00018-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-08-17	13:00:00	Total suspended solids	51	mg/l				CBM-2015-00018-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-09-17	00:00:00	Total suspended solids	7	mg/L				CBM-2015-00028-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2015-09-17	00:00:00	Total suspended solids	7	mg/l				CBM-2015-00028-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-06-16	00:00:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2016-00014-003
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-06-16	00:00:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2016-00014-003
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-06-16	16:07:00	Total suspended solids	73	mg/l				CBM-2016-00003-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-06-16	16:07:00	Total suspended solids	73	mg/L				CBM-2016-00003-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-07-14	15:30:00	Total suspended solids	70	mg/L				CBM-2016-00014-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-07-14	15:30:00	Total suspended solids	70	mg/l				CBM-2016-00014-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-08-09	16:00:00	Total suspended solids	8	mg/l				CBM-2016-00023-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-08-09	16:00:00	Total suspended solids	8	mg/L				CBM-2016-00023-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-08-11	00:00:00	Total suspended solids	7	mg/l				CBM-2016-00023-003
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-08-11	00:00:00	Total suspended solids	7	mg/L				CBM-2016-00023-003
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-09-09	15:50:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2016-00034-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2016-09-09	15:50:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2016-00034-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2017-08-08	14:50:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2017-00021-002

Hay River Harbour

Historic Water Quality Results

Location ID	Location Name	Latitude	Longitude	Sample Date	Sample Time	Parameter	Result	Unit	Detection Condition	Detection Limit (mg/L)	Detection Limit Type	Result Comment
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2017-08-08	14:50:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2017-00021-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2017-08-08	14:50:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2017-00021-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2017-08-08	14:50:00	Total suspended solids			Below Detection/ Quantification Limit	3	Method Detection Level	CBM-2017-00021-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2017-09-06	14:15:00	Total suspended solids	13	mg/l				CBM-2017-00031-004
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2017-09-06	14:15:00	Total suspended solids	13	mg/L				CBM-2017-00031-004
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-07-10	12:00:00	Total suspended solids	82	mg/l				CBM-2018-00008-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-07-10	12:00:00	Total suspended solids	76	mg/l				CBM-2018-00008-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-07-10	12:00:00	Total suspended solids	76	mg/L				CBM-2018-00008-001
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-07-10	12:00:00	Total suspended solids	82	mg/L				CBM-2018-00008-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-08-15	00:00:00	Total suspended solids	22	mg/l				CBM-2018-00026-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-08-15	00:00:00	Total suspended solids	22	mg/L				CBM-2018-00026-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-09-18	00:00:00	Total suspended solids	28	mg/L				CBM-2018-00040-002
HAY-GSL	Hay River at Mouth of Hay River / Great Slave Lake	60.81978333	-115.7692333	2018-09-18	00:00:00	Total suspended solids	28	mg/l				CBM-2018-00040-002

April 4, 2024

Kathy Racher
Executive Director
Mackenzie Valley Land and Water Board
PO Box 2130
Yellowknife, NT X1A 2P6

Dear Ms. Racher:

RE: Submission of Updated Management Plans for the Hay River Harbour Restoration Type B Water Licence MV2023L8-0005

The Government of Northwest Territories (GNWT) – Department of Infrastructure (INF) is submitting the management plan revisions in accordance with the Type B Water Licence MV2023L8-0005.

The following management plans required revisions as per recommendations provided in letters from the MVLWB (dated March 19, 2024)

- Engagement Plan (Version 2.1);
- Sediment and Erosion Control Plan (Version 2.1); and
- Monitoring Plan (Version 2.1).

The appended conformance table demonstrates how the contents of the report meet the conditions and requirements of the licence, and includes a summary of the revisions made to the management plans.

Should you have any questions or concerns please contact Aileen Stevens, Senior Technical Officer, at (867) 767-9048 ext. 32066 or by email at Aileen_Stevens@gov.nt.ca at your earliest convenience.

Sincerely,

Mark Cronk
Director, Design and Technical Services
Department of Infrastructure

Attached:

- Conformance table
- Version 2.1 of the Hay River Harbour Restoration Monitoring Plan
- Version 2.1 of the Sediment and Erosion Control Plan
- Version 2.1 of the Engagement Plan

Conformance Table – MV2023L8-0005_Water Licence March 2024 Submission

Plan Title	Summary of Changes/Plans
Engagement Plan Version 2.1	• Updated Table 9-2 to include that affected parties will be notified by email a month prior to the start of dredging activities, and send an email notification to affected parties that the Monitoring Report (which is a component of the WL Annual Report) has been posted and is available for review.
Monitoring Plan Version 2.1	• Clarified the use of 'NTU' and 'TSS' terminology. In instances that 'TSS' was stated, additional information regarding this being extrapolated from turbidity data will be provided. • Justification for the reference sites associated with dredging area A has been provided in Section 3.1.1. • Updated Fig 1-1 and 1-2 to include all 10 stockpile properties (and property #s) • Updated Fig 3-3 and 3-4 to include all 10 stockpile properties, and SNP sump locations. Removed reference to historic MW locations as they are not related to the project. • Updated Section 4.1 Water Quality Monitoring in Receiving Waters - revisions to include additional guidance on TSS exceedance reporting and high action level response. Text modified to explain that low and medium actions are focused on investigation; whereas the high action is a stop work. • Updated Section 4.2 to clarify that Sump water quality will be included in the Surveillance Network Program (SNP) report, provided within 30 days of the month being reported (as per the Water Licence), and that any guideline exceedances (and mitigations) will be included in the specific pump-off plan. • The triggers for enacting adaptive management of sump water are captured in Section 4.2, specifically that if any excessive water is collecting on any of the temporary storage sites from precipitation events or slow infiltration, resulting in sumps reaching capacity or the risk of release to locations off site. Any guideline exceedances (and mitigations)

Plan Title	Summary of Changes/Plans
	will be included in the specific pump-off plan for disposal, however water quality is not a trigger for pump-off.
Sediment and Erosion Control Plan Version 2.1	• Updated Fig 1-1 and 1-2 to include all 10 stockpile properties (and property #s) • Clarified the use of 'NTU' and 'TSS' terminology. In instances that 'TSS' was stated, additional information regarding this being extrapolated from turbidity data will be provided.