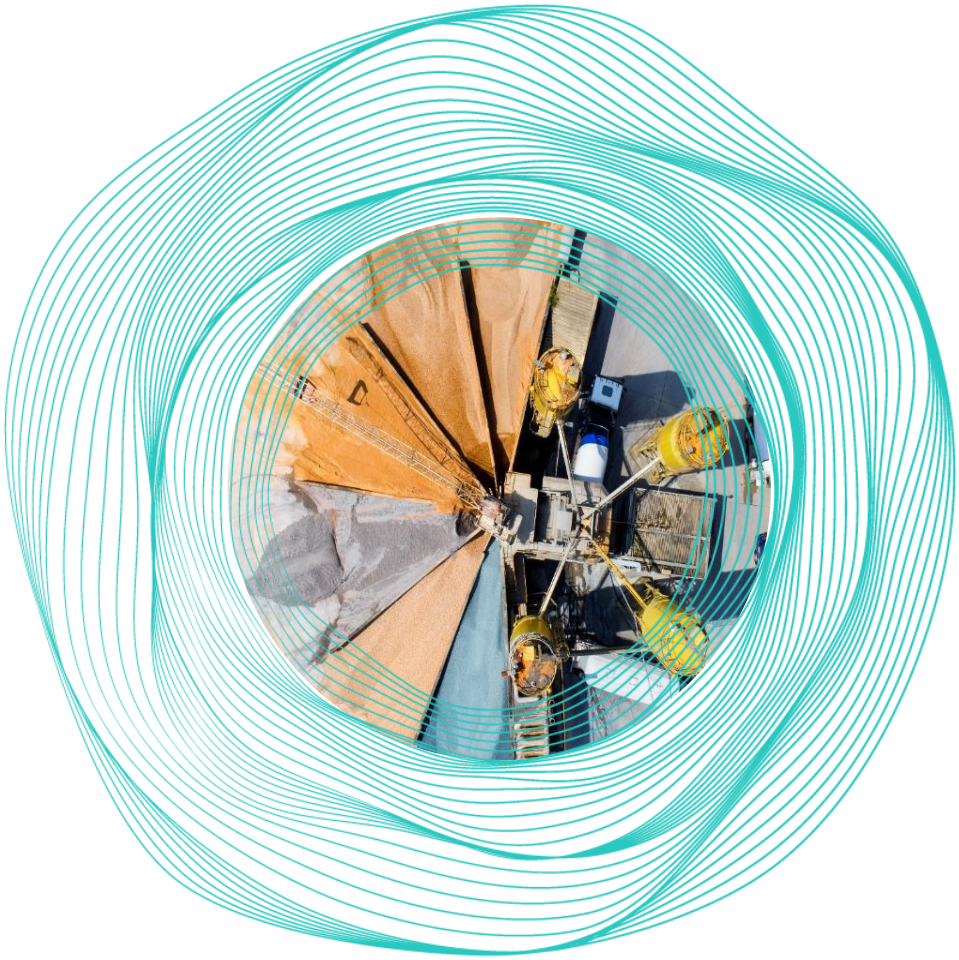
IMPERIAL OIL RESOURCES LTD.

Norman Wells Operations Interim Care & Maintenance (ICM)

Groundwater Management Plan

Document No. Rev. 2: 417085-49223-CA-REP-00002



20 July 2026

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PROJECT 417085-49223-CA-REP-00002 : Norman Wells Operations - Interim Care & Maintenance (ICM) - Groundwater Management Plan					
Rev	**Description**	**Originator**	**Reviewer**	**TRSA Approver**	**Revision Date**
0	Issued as Final	S. Gibb/L. Glatiotis/ A. Haigh	M. Brown	S. Gibb	28 March 2024
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2	Re-Issued as Final	S. Gibb/L. Glatiotis/ A. Haigh	M. Brown	S. Gibb	20 July 2026

Plain Language Summary

Summary

Imperial has been a member of the Norman Wells community since the early 1900s. During active operations, they took oil and gas from below the ground, treated it at the plant, and then sent it south in Enbridge's pipeline. Cessation of production is planned for August 2026, at which point the site will transition into an Interim Care and Maintenance (ICM) period pending the approval of the final closure and reclamation plan.

What is a Groundwater Management Plan?

Imperial has been given permission to use water from the Mackenzie River by the Sahtu Land and Water Board (SLWB). The licence includes rules about how much water can be taken, the quality of water returned to the environment, and how they monitor to check for potential impacts on surface water and groundwater.

This plan talks about how Imperial will monitor groundwater in and around the former operation to check that their ICM activities are not impacting the surrounding environment. The plan helps community members, Imperial's employees and Imperial's consultants understand how the groundwater monitoring program should work by:

- Describing how Imperial will use existing groundwater wells to test water in the ground.
- It talks about when, where, and how they will collect groundwater samples.
- Describing how the sampling results will be studied so we can figure out if the groundwater is changing because of something unusual, or just because it normally changes with the seasons.
- Talking about how they would do extra work if the groundwater quality is changing more than normal, so they can figure out why and fix it.

This groundwater program takes samples from groundwater wells to check them for changes that might indicate a problem with the way the site currently operates.

Imperial will also continue to work on their Closure and Reclamation (C&R) Program that separately monitors a larger network of groundwater wells and does cleanup work in areas where they already know there have been historical impacts that have come in contact with the groundwater. They will continue to work with the SLWB on these sites and continue to send them a report on this work each year. The C&R report is also available on the SLWB's public registry [https://mvlwb.com/registry/S13L1-007] so community members can look at it any time.

What, where, and when will groundwater be measured?

There are 47 monitoring wells in this program, including 19 older wells and 28 new locations. This represents an increase in the number and location of many monitoring wells in the program, from what is listed on their water licence from the SLWB as being part of the formal Surveillance Network Program (SNP). The program includes wells that are close to the previously active oil and gas facilities, the Mackenzie River, Bosworth Creek and on the natural islands. Areas where there are known natural seeps were avoided because this would make it more difficult to be sure if what is measured in the water samples was natural or from the oil and gas operations. Imperial will collect samples between July and September each year when the shallow groundwater is not frozen in most wells.

Maps of the sampling well locations and nearby facilities are in the back end of this document.

How does the warning system work?

Samples of the groundwater will be collected and sent to a lab for testing. Once the groundwater has been measured in the lab, the results will be sent to Imperial. They will check parameters in the groundwater that would be expected to change if fluids from the oil and gas operations touch them, called "indicator parameters". Many of these parameters also occur naturally in groundwater, so Imperial will have to look at changes over time to see if they are increasing, decreasing, or staying the same and whether those changes are normal or unusual. For some of the wells, Imperial already knows what normal changes for a specific well look like, because they have been measuring them for quite some time already. For others wells that are newer installations, it will take a few years before it is known how much change is normal. Understanding what is normal at each well is called the "baseline".

The indicator parameter results will be assessed using a statistical analysis, called Mann-Kendall analysis. The indicator parameter results will also be put on graphs to help visualize what is changing. If an increase or upward trend is identified, Imperial will take a deeper look to see why there is an increase. These changes (usually increases) are sometimes useful as a warning to help identify a potential issue, such as a leaking pipe or tank. In other cases, the increasing or decreasing trends may be natural occurrences.

What will Imperial do if a warning sign shows up?

The first thing Imperial will do if the lab reports an unusual result is check it. Sometimes samples can be contaminated on their way to the lab, or lab instruments are not working properly, or something gets entered into the computer incorrectly. The first step is therefore to confirm that these issues are not the cause of the unusual result. If the data quality review indicates that there are no errors with data entry or management, Imperial, and their consultants, would also check the result in comparison to the next sampling event to verify whether the warning sign is repeated. They would look at the sampled well to make sure it is not broken or otherwise compromised. Imperial might also check to see if a natural seep in the area may have caused the result. This process is called "verification".

Depending on the indicator parameter and the size of the change noted, it might be required to evaluate changes over several sampling seasons to determine if there is a significant trend.

If it turns out an unusual sample result is correct, then Imperial will start an investigation to determine what has happened and what is causing it. The key steps in an investigation may include:

- Quantification & Evaluation: to fully understand how big the change is and what is causing it.
- Delineation: to determine the size and shape of the change in water quality.

If Imperial's oil and gas activities are found to be causing the impact and are of concern, a remediation plan to fix it will be developed. Investigation and remediation work might include increased sampling, installing more wells, cleanup activities or changes to how the facility operates.

Does Imperial do all this alone?

Imperial hires third-party environmental consultants to install and maintain the groundwater wells, collect the groundwater samples, assess the data and prepare the annual reports to summarize and interpret all the information. Imperial also engages a third-party environmental analytical laboratory to complete the sample analysis and provide results to the consultants. The consultants and laboratories are independent, professional organizations who must adhere to professional standards of practice and follow established, industry and government recognized procedures.

How are the data shared?

Imperial will share all of the data, the trends and graphs, whether there are any warning signs, and how the warning signs are being dealt with. This information will be shared in the Annual Water Use Report that Imperial sends to the SLWB each year in March. It will be posted on the SLWB's public registry [https://mvlwb.com/registry/S13L1-007]. Imperial is also committed to sharing these data in meaningful and accessible ways, determined in consultation with the SLWB and the communities.

What has changed from previous versions of this program?

Imperial has been working with the SLWB to improve the overall understanding of groundwater conditions since the issuance of the Water Licence in 2015. Several studies have been completed to determine which parameters are most relevant to the operation and, therefore, which ones require the most focus. This plan incorporates the findings of those studies.

In addition, this plan broadly expands the monitoring network to 47 wells located between the main former operating areas and the main potential receptors (i.e., Mackenzie River and Bosworth Creek). The plan was reviewed once the intent to cease operations was announced, in order to ensure that it would remain suitable for continued monitoring as the site enters into ICM.

This plan also further defines the process of how data will be analyzed to look for potential changes related to the former operation.

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Revision History and Conformity Table

The Norman Wells Operations (NWO) Groundwater Management Plan (GMP) was created to meet the requirements of the Licence in accordance with Imperial standards, and the Land and Water Boards of Mackenzie Valley guiding document titled Standard Outline for Management Plans (LWBMV 2021).

This document was updated in March 2024 to reflect ongoing improvements in the understanding of groundwater quality at NWO and incorporate requests and direction from the SLWB since submission of the previous GMP. The GMP revision history is given in Table 0-1.

Table 0-1: Revision History

Date	Version	Revision	Details of Revision
September 2014	1	1	Created Groundwater Management Plan for submission to the SLWB.
September 2015	2	2	Updated plan as per Water Licence S13L1-007.
June 2021	4	4	Annual review of plan as per Water Licence S13L1-007 completed. Updated plan to reflect new replacement groundwater well (BIBG-20-01-4 to replace BIBG-12-1-7)
December 2022	5	5	Annual review of plan as per Water Licence S13L1-007 completed. Updated list of primary indicator parameters to be evaluated in future groundwater surveillance network programs based on findings from the completed Special Effects Study (2022). SNP Monitoring locations updated to reflect adjustment of GIP11 09-1-4 from contingency well to list of SNP monitoring well.
March 2024	6	0	Expansion of the groundwater network with focus on more near-facility locations, and larger network on natural islands. Refined list of indicator parameters. Defined analytical and reporting requirements.
August 2025	6	1	Revision based on review comments.
June 2026	6	2	Final submission, including revision to support Imperial's Type A Water Licence Application for ICM.

Concordance with document requirements listed in the Land and Water Boards of Mackenzie Valley (LWBMV 2021) Standard Outline for Management Plans is provided in Table 0-2.

Table 0-2: Submission Conformity Table

Document Requirement[1]	Section
Document Title, Submission Date, Version Number, Applicant Name, Authorization Number	Cover Page
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Table of Contents, Glossary	Page vi
Revision History and Conformity Table	Page 1

[1] As per Land and Water Boards of the Mackenzie Valley, Standard Outline for Management Plans (2021).

Document Requirement[1]	Section
Introduction and Background: • Objectives, Updates, Responsible Parties	Section 1
Description of Management Subject, Facilities and Processes	Sections 1, 2, 3, and 4
Description of How Climate Change is Considered	Sections 1.5.2, 1.6, and 5
Description of How Cumulative Effects are Considered	Section 1
Maps of the Site and Monitoring Locations	Figures
Details of Plan Execution	Sections 3, 4, 5, and 6, Appendix E and Appendix F
Monitoring and Response Plan	Sections 3, 4, and 5
Contingencies	Sections 4, 5, and 6
References	Section 8
Standard Operating Procedures	Appendix E

Glossary and Acronyms

Term	Description
Active Layer	The upper layers of soil (from surface to permafrost) that are seasonally thawed during summer allowing groundwater flow and collection of water samples.
Adaptive Monitoring	An approach that responds to a potential effect by triggering confirmation steps which may include changing the extent and magnitude of monitoring. The process and steps that serve as a response framework in this document.
Background Chemistry	The chemical characterization of substances or locations that are not influenced by releases from a site (USEPA 2002). This may represent the natural state of the environment or a state that has been influenced by other factors, but not by operations at the site in question.
Baseline Chemistry	Data that serves as a basis for comparison with the subsequently acquired data.
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CCME	Canadian Council of Ministers of the Environment
CER	Canada Energy Regulator
CPF	Central Processing Facility – the main facility that processes oil at Norman Wells prior to shipment.
Groundwater	Water located beneath the surface that exists in the pore spaces of soil and rock formations. At this site, an active layer of non-frozen groundwater exists seasonally above permafrost.
GMP	Groundwater Management Plan: Imperial monitors select groundwater wells across the operating site. The groundwater wells included in this program are located in proximity to operating facilities and nearby potential receptors.
GW-SNP	Groundwater Surveillance Network Program: The groundwater-specific component of the larger SNP program
ICM	Interim Care & Maintenance
KIPs	Key Indicator Parameters. Chemical and water quality parameters that have been identified as the most applicable to understanding potential water quality impacts from operating facilities at the Site.
LCL	Lower Control Limit - a statistical lower boundary for expected values of a parameter at a given sampling location.
LWBMV	Land and Water Boards of the Mackenzie Valley
masl	meters above sea level
mbgs	meters below ground surface
Norman Wells Operations (NWO)	The department within Imperial which is responsible for the operation and decision making associated with all well sites, flowlines, the central processing facility and maintenance activities.
Pathway	How a stressor (such as a KIP) can reach the environment.
Permafrost	This is any ground that remains completely frozen (0°C or colder) for more than two straight years. This permanently frozen layer consists of soil, silt, sand and is typically bound together by ice.
Receptor	A living organism, ecosystem or natural resource that is responding to environmental changes.
SES	Special Effect Study

Term	Description
SIPs	Secondary Indicator Parameters – parameters identified to be potentially related to site operations, but which are not the primary or key indicators (KIPs) of most interest
SLWB	Sahtu Land and Water Board
SNP	Surveillance Network Program – a groundwater and surface water monitoring program associated with the Water Licence. Surface water monitored within the SNP program includes runoff/storm collection ponds, sumps and potentially process-affected waters.
TDS	Total Dissolved Solids
UCL	Upper Control Limit – a statistical upper boundary for expected values of a parameter at a given sampling location.

1. Introduction

Norman Wells Operations is owned by Imperial Oil and the Government of Canada and is operated by Imperial. It is an upstream oil and gas facility located approximately 700 km northwest of Yellowknife, Northwest Territories (NT) near the Town of Norman Wells (Figure 1). Operations included a central processing facility (CPF), which received production from the mainland, along the north-eastern shore of the Mackenzie River, natural islands (Goose Island, Bear Island, and Frenchy's Island), and six artificial islands (Figure 2). Oil was shipped via the Enbridge pipeline to Zama, Alberta.

The planned cessation of production was announced for August 2026, after which point the site will transition into an ICM and review period, followed by final closure and reclamation.

Imperial currently holds a Type A Water Licence, S13L1-007 (the Licence; renewal of Licence S03L1-001), which was approved by the Sahtu Land and Water Board (SLWB) on 5 March 2015 and is set to expire on 3 May 2028. The Licence is used to regulate the use of water resources and the deposits of waste as they pertain to Imperial's site. Imperial will be applying for a new Type A Water Licence with the SLWB in December 2026 to support upcoming ICM activities on site.

The ***Norman Wells Operations Groundwater Management Plan*** **(GMP)** was created to meet the requirements of the Licence in accordance with Imperial standards and the Land and Water Boards of Mackenzie Valley (LWBMV 2021) guiding document titled *Standard Outline for Management Plans*. This document was updated in March 2024 to reflect ongoing improvements in the understanding of groundwater quality at NWO and incorporate requests and direction from the SLWB since submission of the previous GMP (Table 0-1). The document was updated once again in June 2026 to reflect the revised production status and transition into ICM.

Imperial files an annual Water Use Report with the SLWB per Part B(13) of Water Licence S13L1-007. Included in this annual report is a discussion of the outcomes of the groundwater Surveillance Network Program (SNP), as described in this document. The 47 groundwater monitoring wells chosen to form the groundwater portion of the SNP. For simplicity when referring to the operations groundwater surveillance network program in this plan it will be identified as GW-SNP. The GW-SNP is one component of a wider SNP program that includes monitoring of intake water, discharge water and various surface water runoff facilities such as impound basins, drainage ditches and bunkers. This document is focused on the GW-SNP component only.

These monitoring wells were selected based on proximity to formerly operating facilities. Well locations on the mainland were selected to cover the central processing facility (CPF) and tank farm. Four sites were selected on Bear Island to cover production well and tank pads and two were selected on Goose Island to cover production well and tank pads (Figure 2). In the selection of the GW-SNP wells, areas of known natural seeps were avoided.

Groundwater wells deeper than 15 m depth were not considered to be part of the GW-SNP. Shallow wells are better able to detect early changes in groundwater quality that could result from on-going operations, which is aligned with the intent of this monitoring program.

The objective of this plan is to describe the execution of the GW-SNP and includes:

1. Meet the requirements of the Water Licence S13L1-007.
2. Monitor select existing groundwater wells, most of which are inferred to have had no current impact source, in and around former operations across NWO. Some of the selected wells may exhibit historical impacts from non-operational sources.
3. Install new groundwater monitoring wells for addition to GW-SNP to fill possible data gaps and to monitor near operational areas.
4. Use the monitoring results to serve as early detection of change in groundwater quality.
5. Provide a description of the groundwater information that will be provided in the Annual Water Use Report.
6. Assist stakeholders in understanding the scope of the groundwater monitoring, the evaluation process, and the response plan.

It is important to note that this plan is not intended to monitor and track the progress of reclamation and remediation sites. A separate report is submitted annually to address reclamation and remediation sites per Part J (F) of Water Licence S13L1-007.

This plan has been developed by Tłegǫ̀hłı Reclamation Services Advisian (TRSA), at Imperial Oil's request. The Limitation of Liability, Third-Party Reliance and Scope of Report are included in Appendix A.

1.1 Company Information

1.1.1 Norman Wells Operations

Imperial's Norman Wells site is located at Latitude 650 17' N., Longitude 126 0 51' W., in Norman Wells, NT. The facility is owned and managed by:

Imperial Oil Resources N.W.T. Limited
Bag 5000, 1001 Canol Drive
Norman Wells, Northwest Territories
X0E 0V0, Canada

The Government of Canada retains partial ownership of NWO; however, Imperial is responsible for regulatory compliance.

1.2 Purpose

The purpose of this GMP is to support operations in a manner that ensures effective groundwater management while minimizing safety hazards, and potential adverse environmental effects.

The plan outlines the framework for the groundwater monitoring program, including the selection of the groundwater wells in Section 3.1, data evaluation in Section 4, Groundwater Response Plan in Section 5 and reporting framework in Section 6. This monitoring is intended to act as an early detection system of changes to groundwater quality in and around former operations.

The outcome of GW-SNP as described within this document will be reported in the SLWB Annual Water Use Report submitted every March as required by the Licence. This report will assist stakeholders and community members in understanding site conditions as they relate to operating areas.

This plan is one of many management plans annually reviewed and updated, if required, as per the SLWB and Canada Energy Regulatory (CER) licenses. For a list of all plans, please refer to the Water Licence S13L1-007 posted on the SLWB's public registry. The GMP and associated GW-SNP are intended to serve as a near-site monitoring system that may capture site-related effects in groundwater that could potentially migrate to surface water receptors. Surface water is managed under the Aquatic Effects Monitoring Program. As data from each program are developed and issues are identified, if any, data may be reviewed between programs to understand water interactions and cumulative effects in the aquatic environment. Assessment of overall environmental cumulative effects from NWO is beyond the scope of this plan and program; however, data collected within the GW-SNP will be used for such assessments.

1.3 Scope

The purpose of the GW-SNP is to monitor shallow groundwater quality at key surveillance locations, sample these locations twice per year, report findings to the SLWB and share them with the public via the SLWB's public registry, and to trigger the groundwater response plan when changes in chemistry are measured, as per Section 5 in this document. The GW-SNP includes the following:

- Two sampling events between the months of July and September. Previous experience has shown that shallow groundwater is frozen from early October to early July.
- Check monitoring well physical condition and determine need for maintenance or replacement.
- Measure the depth to groundwater.
- Sampling of operational groundwater monitoring wells as per the GW-SNP analytical schedule and frequency, according to established procedures and protocols.
- Compile and review field and laboratory analytical results.
- Report findings annually to the SLWB for public distribution, in March of the following year.
- Trigger the groundwater response plan, if required.

The GW-SNP does not include the following:

- Information required by other terms and conditions of Water Licence S13L1 007.
- Information related to Imperial's long-term management and remediation of legacy areas through its progression reclamation programs, and as communicated via the annual Closure and Reclamation report.
- Thermistor ground temperature data and assessment.
- Surface water locations that may be sampled as part of the broader operations water monitoring program.
- Groundwater wells deeper than 15 m depth as the historic database has shown that natural occurrences of hydrocarbons and/or saline groundwater tend to dominate in the deeper monitoring locations.

1.4 Imperial's Groundwater Management Explained

Imperial's existing groundwater monitoring well network has two main categories:

- Category 1: Former Operations
- Category 2: Monitoring and Remediation

Monitoring wells installed for the purposes of monitoring former operations (Category 1) are intended for the early identification of changes in and near active work sites. Of the Category 1 wells, historically a set of 13 sentinel wells were used; after reviewing the intent and purpose of this program, there are now 47 wells included (consisting of 19 existing wells and 28 new wells installed in 2025-2026) that will form this GMP.

Monitoring wells installed for the purposes of monitoring and remediation of legacy contamination (Category 2) are intended to identify and delineate areas of historic impact and track the progress of remediation programs.

For each category listed above, there is a separate report which is filed annually and located on the SLWB public registry.

- Category 1:
  - Report on 47 GW-SNP wells submitted annually in March.
  - Referred to as the "Annual Water Use Report".
- Category 2:
  - Report submitted annually in May.
  - Referred to as the "Closure and Reclamation Program Annual Report".

A more detailed discussion of the parameters measured and frequency of sampling is described in Section 3 of this plan. This plan will be reviewed and updated, as needed, or as directed by the SLWB per Part E (4) of Water Licence S13L1-007.

Imperial is responsible for maintaining, executing and updating this plan with support from the SLWB and Imperial's third-party consultants.

1.5 Site Overview

1.5.1 Site Location and Description of Operations

Imperial produced oil from wells drilled in the vicinity of the Town of Norman Wells (Figure 2). The oil-bearing reservoir lies largely under the Mackenzie River at depths ranging from 320 to 625 meters below ground surface (mbgs). Within the operation, there were active production and injection wells connected through a flowline network to a Central Processing Facility (CPF).

Former production wells are located on the Mainland, the Natural Islands (Goose, Bear, and Frenchy's), and the Artificial Islands (1-Rayuka, 2-Rampart, 3-Dehcho, 4-Ekwe, 5-Iteh K'ee and 6-Little Bear). Crude oil production was received at the CPF, where it was processed for shipment via the Enbridge pipeline to Alberta. No refining has been conducted on-site since 1996, when the former refinery facility was shut down (Komex 2009).

1.5.2 Climate

NWO is located within the Canadian sub-arctic climate zone. The Canadian sub-arctic climate zone and in turn, the Norman Wells area, are characterized by long cold winters, short cool summers, and extreme annual temperature variations (Indian and Northern Affairs Canada [INAC] 2001). Rainfall in the region typically occurs as prolonged, low-intensity events. Normal annual total precipitation in the area around Norman Wells averages 290 mm (SLUPB 2010), with about half of that falling seasonally as snow. However, much warmer winters are being observed across the NWT (GNWT 2022). The hours of sunshine in the Norman Wells area vary between approximately 18.5 hours per day during the month of June, to 5.3 hours per day during the month of December (Environment Canada 2015). NWT air quality is typically good, with some notable exceptions in 2014 due to wildfire smoke (GNWT 2022a).

Based on data collected from the Environment Canada Norman Wells A Station between 1981 and 2010, the minimum and maximum temperatures recorded were -54.4°Celsius (C) (recorded in February 1990) and 35.0°C (recorded in July 1989), respectively. A summary of the daily average, minimum, and maximum temperatures recorded between 1981 and 2010 is shown in Table 1-1 (Government of Canada 2022).

Table 1-1: Daily Average, Minimum, Maximum, and Extreme Minimum and Maximum Temperatures (1981-2010) - Norman Wells Station A (Government of Canada 2022)

Mean Temperature	Lowest (°C)	Highest (°C)	Yearly Average (°C)
Daily Average (°C)	-26.1	17.1	-5.1
Daily Minimum (°C)	-29.9	11.5	-9.9
Daily Maximum (°C)	-22.2	22.5	-0.4
Extreme Minimum (°C)	-54.4	N/A	N/A
Extreme Maximum (°C)	N/A	35.0	N/A

A review of the precipitation data collected from the Environment Canada Norman Wells A Station indicates relatively low precipitation in the Norman Wells area, consistent with regional observations. Between 1981 and 2010, the mean annual rainfall, snowfall and precipitation were estimated to be 171.1 mm, 161.5 mm, and 294.4 mm, respectively (Government of Canada 2022). The highest precipitation was observed between June and August. Snow cover was typically observed between September and May. A summary of available precipitation data for this local weather station is presented in Table 1-2.

A warming climate is expected to have impacts on shallow permafrost, which may result in changes to groundwater flow mechanics, connectivity, active layer depth and the seasonally active layer period. Climate change will be considered as a potential contributing factor if changes in groundwater physical or chemical characteristics are observed.

Table 1-2: Average Monthly and Yearly Rainfall, Snowfall, and Precipitation between 1981 and 2010 - Norman Wells Station A (Government of Canada 2022)

Month	Rainfall (mm)	Snowfall (cm)	Precipitation (mm)
January	0.2	21.1	15.6
February	0.0	19.9	14.9
March	0.1	14.4	10.7
April	1.2	12.8	11.1
May	13.3	6.4	19.0
June	42.4	0.4	42.7
July	41.8	0.0	41.8
August	41.1	0.7	41.8
September	26.7	6.9	33.1
October	4.6	27.3	26.7
November	0.0	26.0	18.7
December	0.2	25.9	18.2
Yearly	**171.7**	**161.5**	**294.4**

1.5.3 Topography

The Norman Wells site is located predominantly on the north shore of the Mackenzie River. Elevations range from approximately 50 to 70 meters above sea level (masl). The river flows in a west-northwesterly direction past the Town of Norman Wells. The valley within which this major river flows is bounded on the south by the Mackenzie Mountains and on the north by the Franklin Mountains.

The water levels in the Mackenzie River are quite variable throughout the year. Typical levels are approximately 41 masl during the winter, with short-term peaks of up to 51 masl in spring (Komex 1980). The topography along the northern riverbank rises steeply from the lower flood plain to a relatively flat terrace about 65 masl. The site is bisected by Bosworth Creek, a steep-banked drainage feature that is confined to a relatively narrow valley.

The mainland facilities of the site itself are situated on an upper terrace of the Mackenzie River, approximately 15 m above average water level. The slopes of the Bosworth Creek valley are quite steep, having an angle of up to roughly 35° in some areas.

The natural islands have low-lying areas that are prone to flooding. Bear Island rises naturally to approximately 52 masl and well pads near the river edge have been built up above the flood level. Goose Island is predominantly within the flood level and much of the island is inundated each spring; well pads are built approximately 10 m higher than surrounding terrain to be above the flood elevation.

1.5.4 Bedrock

Underlying the recent glacial and post-glacial sediments in the Mackenzie Valley are the Cretaceous and Devonian-aged Imperial and Canol Formations (Figure 1-1). The Imperial Formation comprises interbedded sandstones, siltstones, and shales and is underlain by the Canol Formation. The fractured shale of the Canol Formation is highly bituminous and is the interval within which the original oil discovery was made. Below the highly bituminous interval, is up to 100 m of oil saturated reef limestone, known as the Kee Scarp Formation. The contact between the formations forms a stratigraphic trap reservoir which accumulates oil, the source of the oil production extracted by Imperial.

Local folding and fracturing of the shales, siltstones and sandstones overlying the oil saturated Kee Scarp has resulted in natural seepages at ground surface.

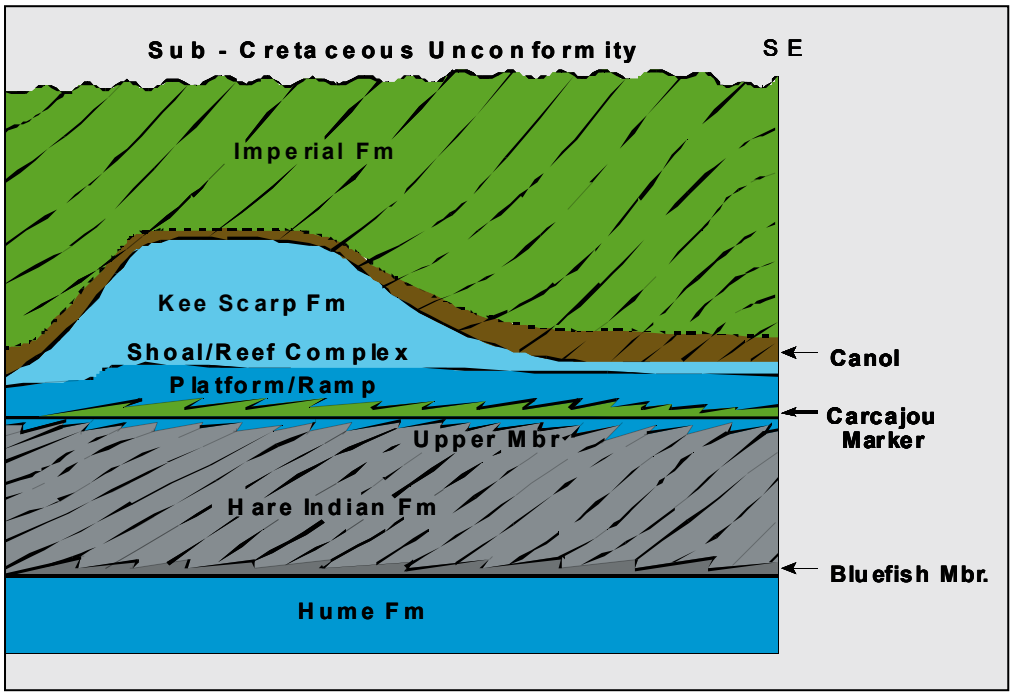

Figure 1-1: Detail of the Main Hydrocarbon Reservoir

1.5.5 Sediments

Details of the Mackenzie Valley Quaternary history are described by Mackay and Mathews (1973). The last period of glaciation (the Wisconsin) resulted in the deposition of a till veneer, as well as some pro-glacial lake and spillway deposits in portions of the area.

In the vicinity of Norman Wells, remnants of glacio-lacustrine sediments are present. These sediments may be quite variable in texture, ranging from silt and clay-sized particles to coarser sand and gravel lenses deposited during more active meltwater drainage episodes.

1.5.6 Soils

The dominant soils identified in the area of Norman Wells include Static and Turbic Cryosols, which have developed on either alluvial or morainal parent materials (Hardy Associates (1978) Ltd. 1980). Localized areas of Organic Cryosols have also been noted overlying lacustrine deposits in depressional areas or around fens and local wetland areas.

The thickness of the active layer of unfrozen groundwater is highly dependent on the time of year, aspect to the sun, proximity to buried infrastructure (e.g., underground flowlines), or degree of surface disturbance such as vegetation clearing or presence of open excavations.

1.5.7 Permafrost

The presence of discontinuous permafrost in the area has a strong influence on local groundwater flow patterns. Ice lenses and the low conductivity associated with frozen soil in the subsurface act as barriers to groundwater movement. Two groundwater bearing intervals have been identified in the Norman Wells Operational area: a shallow discontinuous interval and a deeper unconfined interval.

The Norman Wells area lies in a zone of discontinuous permafrost, where typical maximum permafrost thickness ranges from 50 to 65 m. Permafrost in the Norman Wells area is not uncommon and is regularly encountered at the Imperial site beneath roads and other locations. Significant differences in permafrost depth and thickness are evident, based on both non-intrusive (geophysical survey) and intrusive (borehole) investigations. In some areas, extensive unfrozen zones within the permafrost (taliks) have developed, separating the permafrost into ice lenses.

1.6 Natural Seepage

The presence of natural seeps in the Sahtu Settlement Area, especially around the Town of Norman Wells, is known to predate Imperial's operation. Traditional knowledge indicates seeps are regularly seen around Norman Wells particularly in the vicinity of the docks and above the town water supply, and that oil is seen when sediments are stirred up by barges (AMEC 2013). Many natural oil and gas seeps have been documented in the lower Mackenzie River Valley. In addition, several studies have been conducted to further investigate the nature and productivity of these seeps.

Information regarding the natural seeps has been included, as the influence of the seeps has the potential to appear in the groundwater chemistry of some of the GW-SNP wells in the future. In the selection of the GW-SNP wells, areas of known natural seeps were avoided. This was done to ensure the distinct chemistry of natural seeps was not confused with potential subsurface impacts from operations activities. However, groundwater is very slow moving and the effects of climate change on frozen soil are difficult to predict, so impacts from natural seeps may potentially be seen in the GW-SNP wells in the future.

The historically documented surface seeps are presented in Figure 1-2. Larger reproductions of these Figures are available in Section 9 of Imperial's 2013 Type A Water Licence Application located on the SLWB's public registry [https://mvlwb.com/registry/s13l1-007].

Natural oil and gas seepage continues to occur along the shoreline and below the riverbed in several locations, typically where upper bedrock outcrops or sub-crops under only a few meters of sediments. The surficial onshore seeps are most obvious at these specific locations:

- Along the Mackenzie shoreline upstream and downstream of the former Refinery area.
- Bosworth Creek Delta area.
- Within the Bosworth Creek downstream of where the winter road crosses the creek.
- Along the Mackenzie shoreline below the F-28X well.
- At Seepage Lake to the north.

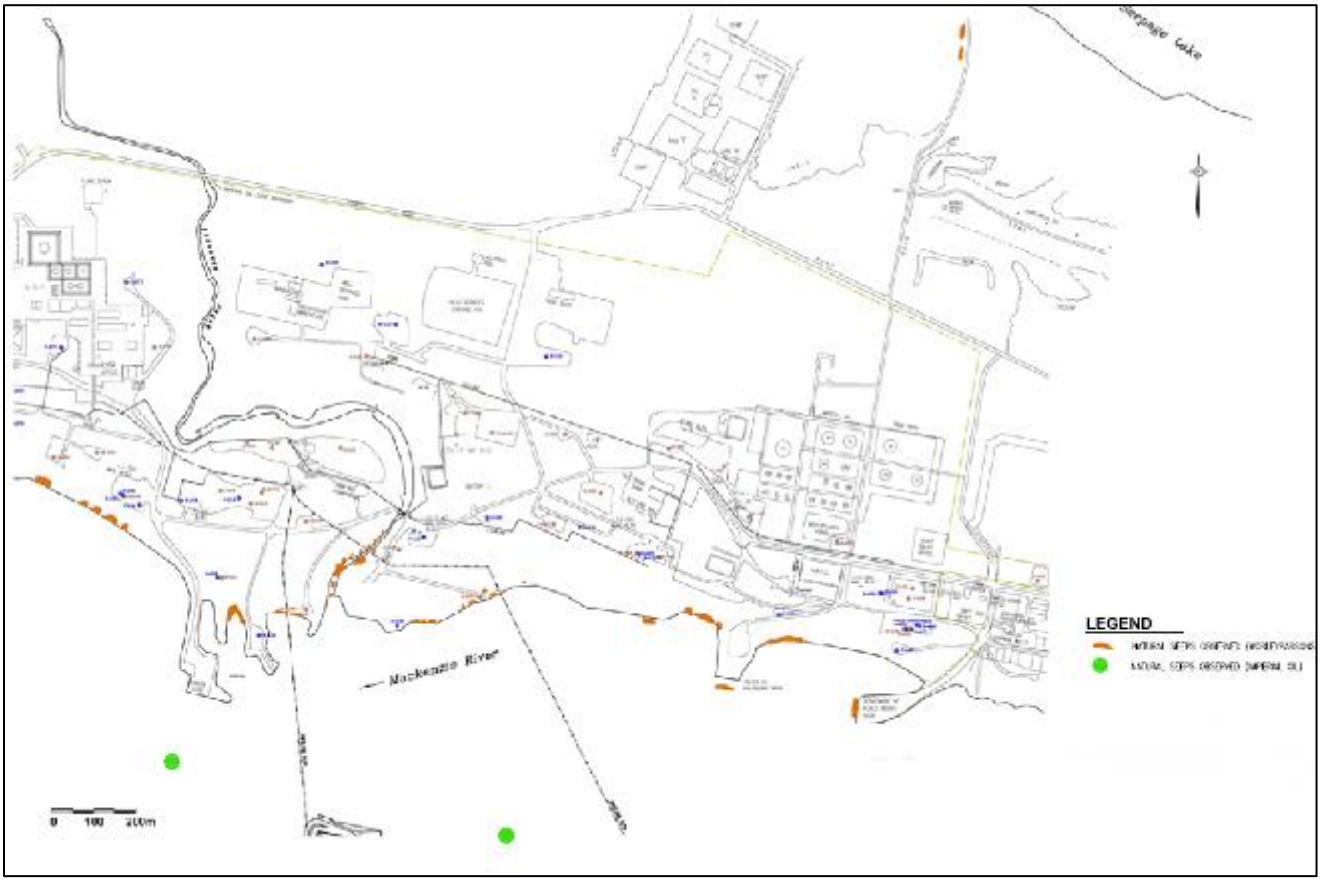

Figure 1-2: Location of Observed Seeps in the Norman Wells Area

Selected details of the chemistry of natural seepage zones are summarized in the background geochemical summary (Appendix B). The presence of natural seeps may lead to a natural source of hydrocarbons and salinity in the groundwater. Although Figure 1-2 documents the surficial expression of known seeps, it is also quite common to observe natural seep chemistry in monitoring wells more distant from the surface water bodies, where the wells are drilled into bedrock sub-cropping under the glacial overburden. Bedrock monitoring wells on the mainland area often have indications of crude oil and salinity characteristic of natural seepage.

1.7 Regional Hydrogeology

There are no known regional hydrogeologic studies that have been completed in the Norman Wells area. Therefore, results from the work commissioned to date by Imperial Oil Resources form the basis of understanding the hydrogeological setting.

The regional terrain slopes towards the Mackenzie River from the Norman Range of the Franklin Mountains, located north of the site.

Given that shallow, unconfined groundwater flow is generally controlled by topography, the inferred direction of shallow groundwater flow on the north side of the Mackenzie River would be to the south, with discharge eventually occurring to that major water body. Smaller creek valleys, such as Bosworth Creek, would also exert some control on local groundwater flow patterns, and serve as discharge areas as well.

The presence of discontinuous permafrost exerts a strong control on local groundwater flow patterns, both laterally and vertically. Ice lenses in the subsurface act as barriers to groundwater movement based on the comparatively low hydraulic conductivity associated with frozen soil. As a result, complex groundwater flow patterns are expected beneath the area. Local groundwater flow patterns may, in some cases, deviate from the site-wide general flow pattern.

1.8 Site Access

The Town of Norman Wells is accessible daily by commercial air service, barge service (for goods) in summer, and a winter road during winter.

The remote location limits the means of transportation of groundwater samples to contract laboratories due to the limitations of scheduled commercial air service (which can be weather and mechanical issues dependent). Samples will be shipped to appropriate laboratories, typically located in Edmonton, as soon as possible; however, commercial air service serving Norman Wells has been reduced in recent years.

2. Shallow Groundwater Overview

Groundwater monitoring wells have been installed at various times and have been sampled since the late 1990s and early 2000s to characterize groundwater quality, and for the purpose of early detection of groundwater changes across site.

2.1 Local Hydrogeology

2.1.1 Mainland

Groundwater surface elevations do not indicate a consistent groundwater flow direction for the Mainland area, however flow is inferred to be predominantly towards the Mackenzie River, with localized flow towards Bosworth Creek. The uppermost groundwater surface is generally identified at less than 5 mbgs, in typically fine grained silty to sandy glacial sediments.

2.1.2 Bear Island and Goose Island

Generally, groundwater surface elevations on Bear and Goose islands mimic surface topography with local flow directions inferred to be from high ground toward the closest water body. In most cases the closest water body is the Mackenzie River; however, several unnamed inland surface water bodies do exist. The uppermost groundwater surface is generally identified at less than 5 mbgs, in typically fine grained silty to sandy glacial sediments.

2.1.3 Frozen Conditions

Groundwater monitoring at Norman Wells has shown that shallow groundwater is seasonally active in some areas and frozen year-round in others. The seasonally active areas generally correspond to areas of surface disturbance, such as where removal of vegetation, constructed pads, building lots or roads are present, and in areas closer to the Mackenzie River or Bosworth Creek where a southward topographic aspect allows more solar warming of the subsurface during summer months. Undisturbed areas of denser vegetation tend to be underlain by frozen groundwater conditions throughout the year. The seasonally active period for groundwater is generally June to October.

2.1.4 Typical Groundwater Monitoring Well Installation

The installation of a groundwater monitoring well generally follows the American Society of Testing and Materials (ASTM) standards, and more specifically will follow the preferred operating practices (POPs) in Appendix E. Figure 2-1 shows a typical shallow monitoring well installation at the Imperial site. A borehole is typically completed using a solid stem auger or through direct push drilling technology. Typically, a 15 cm diameter hole is advanced through the surficial silt, clay, and sand layers. Drilling proceeds until the groundwater table is identified, or a hard layer consisting of upper bedrock and/or frozen soil (permafrost) is encountered.

The depth to groundwater is typically 2 to 4 mbgs in most areas of Imperial's Mainland and Islands facilities. This shallow groundwater zone is a seasonally unfrozen layer overlying permafrost. The depth to permafrost is locally variable and discontinuous, and is affected by vegetation cover, atmospheric temperature, and soil conditions.

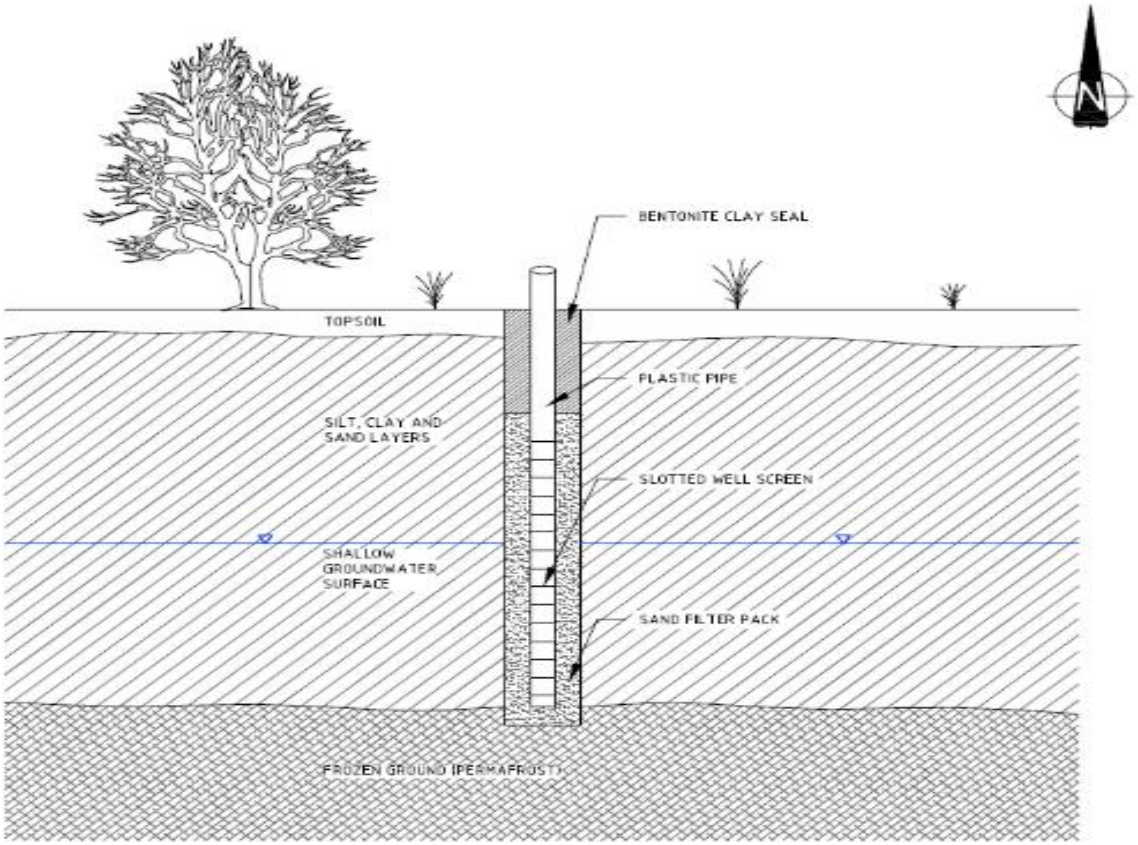

Figure 2-1: Typical Shallow Groundwater Well

The monitoring well generally consists of a 5 cm diameter plastic (PVC) pipe, with a slotted PVC well screen in the bottom 1.5 to 3.0 m of the well to allow inflow of groundwater. The machined slots are typically 0.010" to 0.020" wide openings. The annular space between the well screen and borehole wall is back filled with bags of frac sand, which act as a filter for fine sediments to prevent clogging of the well. Above the sandpack, bentonite clay pellets or chips are backfilled to ground surface to create a low permeability seal, ensuring that surface water cannot drain down the borehole and affect groundwater chemistry.

The monitoring well protrudes generally 60 to 80 cm above ground surface and is protected by a steel casing with lockable lid. In some situations, the top of casing is finished near ground surface or up to 10 cm below grade, with a flush mounted protective casing. This type of installation may be used to protect a well from vehicle traffic, or in areas prone to flooding and ice damage such as the natural islands shoreline areas.

3. Groundwater Surveillance Network Program

3.1 Groundwater Well Selection Process

The monitoring network comprises a series of linear monitoring 'fences', intended to intercept any potential historical impacts between formerly operational sources and likely receptors, to allow for timely mitigative response where necessary. The main receptors considered were waterbodies and communities, including the Mackenzie River, Bosworth Creek, and the Town of Norman Wells.

The proposed network includes both existing monitoring locations (19 wells) and new proposed monitoring locations (28 wells) which were installed in 2025-2026. There are no groundwater monitoring wells on the artificial islands.

Existing locations were selected based on many factors, including proximal location with respect to potential sources and likely receptors, quality of existing/baseline chemistry data for the location, and well completion information. Review of the existing monitoring network identified areas where coverage could be improved, and these areas were drilled between 2024 and 2026, with monitoring commencing at each new well in the year following installation.

The majority of these new installations were completed on Bear and Goose Islands, where seasonal ice scouring has historically limited the functional lifespan of previous monitoring well installations. Some of the older proposed monitoring locations (e.g., BIB98-1-3) may have been damaged or destroyed since they were last field inspected and may require replacement prior to inclusion in the GW-SNP. Field verification and assessment of proposed existing locations will therefore be required as part of the development of the monitoring network.

Existing groundwater wells with completion depths greater than 15 mbgs were not considered for inclusion in the GW-SNP, as the historic chemistry results have indicated that natural occurrences of hydrocarbons and/or saline groundwater tend to dominate in the shallow bedrock (Appendix B). In general, wells completed in the overburden and active groundwater zone overlying the permafrost, where present, are better situated to detect early changes in groundwater that may result from historical operations.

Areas of known natural hydrocarbon surface and subsurface seepage were intentionally avoided when identifying proposed GW-SNP monitoring locations. The aim of this approach is to minimize the potential for natural seepage chemistry to be confused with former operational impacts; however, it does not preclude the eventuality that geochemical influences from natural seeps may be observed in the GW-SNP wells in the future. There may also be natural seeps present around the site that have yet to be identified.

A summary of the proposed GW-SNP monitoring network is presented in Table 3-1. The selected locations for groundwater monitoring wells are illustrated on Figures 3 through 6B, and the well borehole logs (for existing monitoring locations) are provided in Appendix C.

Table 3-1: Groundwater Monitoring Well Locations and Details

Monitoring Well ID	Northing	Easting	Year Installed	Screened Interval (mbgs)	Completion Unit	Rationale
MAINLAND WEST – Central Processing Facility (CPF) and Flare Stack						
C27-16-1-3	Not Available	Not Available	2016	1.1-2.6	Surficial Sediments	Downgradient of flare stack, upgradient of Bosworth Creek
C27-16-2-3	Not Available	Not Available	2016	1.6-3.1	Surficial Sediments	Downgradient of CPF tank farm, upgradient of Bosworth Creek
C27-16-3-4	Not Available	Not Available	2016	2.8-4.3	Surficial Sediments	Downgradient of CPF tank farm, upgradient of Bosworth Creek
MW23-36	7242291.624	599048.919	2023	12.0-15.1	Shallow Bedrock	Downgradient of flare stack, upgradient of Bosworth Creek
MW23-35	7242053.778	599013.756	2023	8.7-11.7	Shallow Bedrock	Downgradient of CPF, upgradient of Bosworth Creek
CPF 97-7-5	7241852.827	599100.347	1997	1.8-4.8	Surficial Sediments / Shallow Bedrock Interface	Downgradient of CPF, upgradient of Bosworth Creek
CPF 23-1-3	7242045.02	598616.20	2023	1.9-3.9	Surficial Sediments	Downgradient of CPF, upgradient of Mackenzie River
MLW-25-01	TBD	TBD	2025	0.7-3.8	Surficial Sediments	Downgradient of flare stack, upgradient of Bosworth Creek
MLW-25-02	TBD	TBD	2025	1.2-2.7	Surficial Sediments	Downgradient of CPF, upgradient of Bosworth Creek
MLW-25-03	TBD	TBD	2025	0.7-3.8	Surficial Sediments	Downgradient of CPF, upgradient of Bosworth Creek
MAINLAND EAST – Mainland Tank Farm (MTF)						
MTF-97-1-5	7241588.497	600924.768	1997	1.7-4.7	Surficial Sediments	Between MTF and Town
MTF-97-3-5	7241459.080	600756.844	1997	1.5-4.5	Surficial Sediments	Downgradient of MTF, upgradient of River
TF 03-11-4	7241471.15	600532.22	2003	1.3-4.3	Surficial Sediments	Downgradient of MTF, upgradient of River
TF 03-12-3	7241435.32	600562.55	2003	1.0-2.8	Fill / Surficial Sediments	Downgradient of MTF, upgradient of River

Monitoring Well ID	Northing	Easting	Year Installed	Screened Interval (mbgs)	Completion Unit	Rationale
MW23-48	7242046.1366	600296.7900	2023	3.0-6.1	Shallow Bedrock	Between MTF and Town
MLE-25-01	TBD	TBD	2025	0.8-3.8	Surficial Sediments	Between MTF and Town
MLE-25-02	TBD	TBD	2025	2.5-4.0	Surficial Sediments	Downgradient of MTF, upgradient of River
MLE-26-03	TBD	TBD	2026	TBD	Surficial Sediments	Downgradient of MTF, upgradient of River
BEAR ISLAND – Bear Island Terminal 3 (B.I.T.3)						
BIB98-1-3 (R)	7238721.33	599151.92	1998	1.05-3.05	Surficial Sediments	Between BIT3 and Mackenzie River
BIT3-26-01	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT3 and Mackenzie River
BIT3-26-02	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT3 and Mackenzie River
BIT3-26-03	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT3 and Mackenzie River
BEAR ISLAND – Bear Island Terminal 4 (B.I.T.4)						
BIT4-26-01	TBD	TBD	2026	TBD	Surficial Sediments	Cross-gradient (West of BIT4)
BIT4-26-02	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT4 and Mackenzie River
BIT4-26-03	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT4 and Mackenzie River
BIT4-26-04	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT4 and Mackenzie River
BIT4-26-05	TBD	TBD	2026	TBD	Surficial Sediments	Between BIT4 and Mackenzie River
BIT4-26-06	TBD	TBD	2026	TBD	Surficial Sediments	Cross-gradient (East of Mackenzie River)
BEAR ISLAND – N-42X Pad						
BIB98-3-4	7238835.69	599204.71	1998	1.4-3.4	Surficial Sediments	Between N-42X pad and Mackenzie River
BI N42 09-1-3	7238818.681	599214.8256	2009	1.0-2.5	Surficial Sediments	Between N-42X pad and Mackenzie River/Unnamed Creek
BIN42-10-2-4	7238719	599203.7	2010	2.0-3.5	Surficial Sediments	Between N-42X pad and Unnamed Creek
N42-26-01	TBD	TBD	2026	TBD	Surficial Sediments	Between N-42X pad and Mackenzie River
N42-26-02	TBD	TBD	2026	TBD	Surficial Sediments	Between N-42X pad and Mackenzie River
N42-26-03	TBD	TBD	2026	TBD	Surficial Sediments	Between N-42X pad and Unnamed Creek

Monitoring Well ID	Northing	Easting	Year Installed	Screened Interval (mbgs)	Completion Unit	Rationale
BEAR ISLAND – Q-37X Pad						
BI-13-18-3	7238709	598235.6	2013	0.9-2.4	Surficial Sediments	Between Q-37X pad and slough
BIBT1-12-3-5	7238681.626	598041.959	2012	1.8-4.8	Surficial Sediments	Between Q-37X pad and Mackenzie River
BIBT1-15-8-4	7238696.400	598052.860	2015	2.6-4.1	Surficial Sediments	Between Q-37X pad and Mackenzie River
Q37-26-01	TBD	TBD	2026	TBD	Surficial Sediments	Between Q-37X pad and slough
Q37-26-02	TBD	TBD	2026	TBD	Surficial Sediments	Between Q-37X pad and Mackenzie River
GOOSE ISLAND – Goose Island Terminal 7 (G.I.T.7)						
GIT7-25-01	TBD	TBD	2025	0.6-3.8	Surficial Sediments	Cross-gradient (northwest of GIT7)
GIT7-25-02	TBD	TBD	2025	0.9-4.1	Surficial Sediments	Between GIT7 and Mackenzie River
GIT7-25-03	TBD	TBD	2025	0.9-2.4	Surficial Sediments	Between GIT7 and Mackenzie River
GIT7-25-04	TBD	TBD	2025	1.5-3.2	Surficial Sediments	Cross-gradient (southeast of GIT7)
GOOSE ISLAND – Goose Island Terminal 8 (G.I.T.8)						
GIT8-25-01	TBD	TBD	2025	1.5-4.5	Surficial Sediments	Cross-gradient (southwest of GIT8)
GIT8-25-02	TBD	TBD	2025	1.5-4.5	Surficial Sediments	Between GIT8 and Mackenzie River
GIT8-25-03	TBD	TBD	2025	1.5-4.5	Surficial Sediments	Between GIT8 and Mackenzie River
GIT8-25-04	TBD	TBD	2025	1.5-4.5	Surficial Sediments	Cross-gradient (northeast of GIT8)

3.1.1 Monitoring Network Maintenance

Several groundwater monitoring wells at the NWO have historically been subject to damage from ice scouring during break up, freeze-thaw cycling (e.g., frost jacking), and routine heavy equipment activities (e.g., snow clearing). Depending on seasonal conditions, a groundwater well may also be dry or frozen at the desired time of sampling. Seasonal conditions may also limit access to sampling locations. These factors may impede sampling efforts at any given time.

If a groundwater well is damaged but repairable, it will be addressed as soon as practicable. Sampling will resume at the location once the well has been repaired. If a dry groundwater well is encountered and the condition is suspected to be seasonal or temporary, sampling will be suspended at this location and will resume during the next sampling event. It is important to note that for the purposes of this groundwater surveillance network, a well proving to be consistently dry or frozen is not necessarily a negative outcome; rather, it may indicate that shallow groundwater flow is not a locally active pathway between potential sources and receptors.

Efforts will be made to repair or replace a groundwater well as soon as reasonably practicable however, delays such as seasonal brush clearing restrictions for migratory birds may factor into scheduling. The SLWB will be notified in the annual report of any changes to the groundwater monitoring network or sampling frequency at a specific location. Contingency plans related to wells repairs or replacements are also discussed in Section 5.

3.2 Groundwater Sampling Program

The groundwater monitoring network will be sampled for the parameters outlined in Table 3-2, provided below. Appendix D also summarizes the proposed analytical schedule. Primary or key indicator parameters (KIPs) are bolded within the table. Further details on the selection of primary indicator parameters can be found in Section 4.1 and Table 4-1 and Table 4-2.

The sampling program is based on the requirements outlined in Water Licence S13L1-007. It is designed to build a comprehensive and representative hydrochemical database, with parameters selected to adequately capture temporal changes in groundwater quality as a result of ongoing site activities.

Table 3-2: Sampling Parameters for All Locations[2]

Analytical Package	Parameters	Frequency
BTEX and PHC F1	**Benzene, Toluene, Ethylbenzene,** m&p-Xylene, o-Xylene, Xylenes (Total), F1 (C6-C10)	Semi-Annual
PHC F2	F2 (C10-C16)	Semi-Annual
Total Metals	Aluminium, Antimony, **Arsenic, Barium, Boron,** Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, Silver, Thallium, Tin, Titanium, Uranium, Vanadium, Zinc	Semi-Annual
Dissolved Metals	Aluminium, Antimony, **Arsenic, Barium, Boron,** Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, Silver, Thallium, Tin, Titanium, Uranium, Vanadium, Zinc	Semi-Annual
Major Ions and Routine Potability	Electrical conductivity (EC), **Total Dissolved Solids,** Alkalinity (PP and Total), Bicarbonate, Carbonate, Hydroxide, **Chloride,** Sulphate, Nitrate, Nitrite, Nitrate+Nitrite, Calcium, **Iron,** Magnesium, Manganese, Potassium, Sodium	Semi-Annual
Fluoride	Dissolved Fluoride	Semi-Annual
Field-measured	pH, temperature, and EC.	

Field parameters will also be measured at time of sampling if sufficient water is present in the monitoring well.

3.2.1 Sampling Frequency and Methodology

Semi-annual sampling (i.e., two times per calendar year) is appropriate given the slow-moving nature of groundwater at the Imperial site and the short practical field season for groundwater sampling. The timing of these semi-annual sampling events may shift slightly year-to-year, and should be scheduled to factor variability in seasonal weather and/or ground conditions. Due to freeze back of the active layer, it is inferred that flow will be minimized during the winter months in the uppermost groundwater zone. Sampling will be no-purge sampling due to the limited water recharge rate typical of shallow groundwater wells in Norman Wells.

Sampling will be conducted in accordance with the established procedures summarized in Appendix E.

3.2.2 Quality Assurance and Quality Control

All groundwater sampling will be completed in accordance with the Quality Assurance and Quality Control Plan (Appendix F). Procedures will also refer to the POP for quality review of environmental analytical laboratory data included in Appendix E.

[2] **Bold** = KIP.

4. Data Evaluation

Groundwater quality data results, analysis and interpretation will be presented in an annual report submitted to the SLWB as per the conditions of the Water Licence S13L1-007.

Imperial has identified several key indicator parameters (KIPs) of concern based on potential site inputs and findings from the Special Effects Study (Imperial 2022). A broad group of parameters will be sampled and analyzed from the GW-SNP wells, but data evaluation will focus on KIPs and certain secondary indicator parameters (SIPs). The Special Effects Study, as it evolves, and results from groundwater monitoring programs will be reviewed to inform and revise (if necessary) the list of KIPs during each data review period.

Three groups of parameters have been created, reflecting how the data will be analyzed:

- KIPs (Table 4-1).
- SIPs (Table 4-2).
- All remaining parameters.

4.1 Site Indicator Parameters

Key indicator parameters have been selected based on constituents within the former production streams at NWO and on studies of other potential Site related sources such as historical use and road materials. Secondary indicator parameters have been selected primarily to provide additional context around any noted exceedances, trends or deviations in KIP concentrations, and are not intended to capture or implicate any potential Site-related sources when considered independently. Additional parameters may be added if parameters are observed to be above environmental guidelines, background geochemical conditions, exhibiting significant increased trends or if new sources are identified. Parameters may also be elevated from secondary status to primary or key indicator parameter status (SIPs to KIPs).

4.1.1 Inorganic Parameters and Major Ions

Inorganic Parameters and major ions selected as KIPs include:

- Chloride and TDS.

These parameters can be present in produced water from oil production. Certain inorganic parameters, particularly chloride, can be mobile in the environment due to relatively high solubility and the conservative, non-reactive and non-biodegrading nature of chloride.

4.1.2 Petroleum Hydrocarbons

Light-end petroleum hydrocarbons, including benzene, toluene, ethylbenzene and xylenes (BTEX) are soluble components of crude oil which was produced, processed and shipped at Norman Wells. BTEX parameters are selected as KIPs due to their presence within the product stream, solubility and mobility in groundwater, and potential for adverse effects on the environment.

4.1.3 Dissolved Metals

Several metals have been identified as KIPs or SIPs due to their potential presence in various sources at NWO, including hydrocarbons streams, produced water and imported fill materials. Total and dissolved-phase metals will be analyzed as part of the GW-SNP. Metals KIPs include:

- Arsenic, barium, boron and iron.

4.1.4 Site Parameter Summary

Table 4-1: Key Indicator Parameter (KIP) Summary

Parameter	Rationale
Inorganics and Major Ions	
Chloride	Parameters above background and /or CCME for the potential source identified in the background analysis of the SES (Imperial 2022): • Produced water release. • Hydrocarbons only release. • Imported shale fill. • Sumps.
TDS	Overall indicator of change in water quality. Parameters above background for the potential source. identified in the background analysis of the SES (Imperial 2022): • Produced water release. • Hydrocarbons only release.
Petroleum Hydrocarbons	
BTEX	Parameters above background and /or CCME for the potential source identified in the background analysis of the SES (Imperial 2022): • Produced water release. • Hydrocarbons only release. • Imported shale fill. • Sumps.
Metals	
Arsenic	Parameters above background and /or CCME for the potential source identified in the background analysis of the SES (Imperial 2022): • Produced water release. • Sumps. • Hydrocarbons only release. • Imported shale fill.

Parameter	Rationale
Barium	Parameters above background for the potential source identified in the background analysis of the SES (Imperial 2022): • Produced water release. • Hydrocarbons only release. • Imported shale fill. • Sumps.
Boron	Identified as potential in produced water (Advisian 2022).
Iron	Parameters above background and /or CCME for the potential source identified in the background analysis of the SES (Imperial 2022): • Produced water release. • Sumps. • Hydrocarbons only release. • Imported shale fill.

Table 4-2: Secondary Indicator Parameter (SIP) Summary

Parameter	Rationale
Inorganics and Major Ions	
Calcium, Magnesium, Sulphate	Identified as part of the SES (Imperial 2022).
Metals	
Aluminum, Cadmium, Chromium, Copper, Molybdenum, Nickel, Selenium, Uranium, Zinc	Parameters above background and /or CCME for the potential source identified in the background analysis of the SES (Imperial 2022) and potentially related one or more of the following: • Produced water release. • Sumps. • Hydrocarbons only release. • Imported shale fill.

4.2 Regulatory Standards

Groundwater quality will be compared to the Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (CEQG) for the Protection of Freshwater Aquatic Life (FWAL; CCME 2012). In addition, the Federal Environmental Quality Guidelines (FEQG; ECCC 2021) will be added for some parameters where more recent data has been used in the guideline derivation compared to existing CCME guidelines.

Tabulated results will include guidelines for ready comparison. Water quality variables will be compared to the following guideline sets with guideline exceedances highlighted:

- Canadian Council of Ministers of the Environment guidelines for the protection of freshwater aquatic life (CCME FWAL; CCME 2012).
- Federal Environmental Quality Guidelines (ECCC 2021).

The Canadian Council of Ministers of the Environment is currently working on Groundwater Quality Guidelines for the Protection of Environmental and Human Health for 99 chemicals of concern. Once published, those guidelines will be incorporated into reporting and analysis where applicable.

Some parameters covered by the above-mentioned guideline documents will be modified by incorporating site-specific receiving water body criteria, including pH and hardness. These receiving water body conditions will be periodically reviewed and updated based on data collected as part of the Aquatic Effects Monitoring Program (AEMP; TRSA 2025).

It is important to note that concentrations of water quality parameters may naturally exceed applied guidelines and not be indicative of subsurface impacts potentially caused by NWO sources. These are guidelines against which data can be compared, but they do not always account for the naturally occurring local background conditions. Guideline exceedances under natural conditions may be indicative of surficial geology, surface-groundwater interactions, natural hydrocarbon seepage from underlying units, or seasonal changes (e.g., mobilization during periods of ground thawing). Groundwater background conditions are discussed further in Section 4.3.

For those parameters where no applicable guidelines exist under the CCME FWAL or FEQG, data will be compared against background and baseline (where available, for the location) data sets. Exceedances of background conditions and/or deviations from baseline conditions may warrant additional monitoring and will be assessed on a case-by-case basis. In the context of this monitoring plan, KIP and SIP parameters which do not currently have applicable CCME FWAL or FEQG values include: TDS, barium, magnesium, calcium, sulphate, and chromium.

The GW-SNP data analysis will seek to answer whether NWO is affecting measurable changes to water quality. Published environmental guidelines and comparison to local background conditions will be used as screening tools to flag potential water quality concerns; however, the program is not intended to assess overall water environmental health or act as a contaminant management or risk assessment program.

4.3 Interwell Groundwater Background Studies

The assessment of interwell (across multiple wells spread across the site) background environmental conditions at the Site commenced in 1997. As it was not the practice to collect baseline water quality data in the early 1920s when the operation started, efforts have been made since the late 1990s to establish appropriate background sample locations and evaluate background soil and groundwater chemistry. A summary of these background locations and conditions is provided in Appendix B (Advisian 2020).

Background groundwater quality is determined through analysis of water collected at locations that were geographically removed from the Imperial site and were determined to be free of facility-related impacts. The locations and corresponding groundwater wells were then divided into four groups, based on the hydrogeological zone where each of the groundwater well screens is completed. Available suitable background locations are limited by the presence of permafrost, i.e., liquid groundwater is not typically available in many undisturbed locations.

The 95th percentile analyses indicate that the following parameters may naturally exceed the applied CCME FWAL criteria in groundwater at each of the following sites:

- Mainland Sites - Overburden:
  - Iron, phenols, arsenic, cadmium, copper, selenium, uranium, and zinc.
  - Chloride and petroleum hydrocarbons can also occur above the applied guideline in natural seepage zones.
- Bear and Goose Island - Overburden:
  - Iron, phenols, cadmium, copper, selenium, uranium, and zinc.
- Bedrock Across the Imperial Site:
  - Chloride, iron, phenols, aluminium, arsenic, copper, and selenium.
  - Petroleum hydrocarbons would also be expected within areas of natural seepage in the upper bedrock across the site.

Background geochemistry values and details related to development of background geochemistry characterization, including for areas of natural hydrocarbon seepage, are provided in Appendix B.

4.4 Intrawell Baseline Determination

Baseline concentrations of KIPs and SIPs will be determined on a per well basis. Groundwater quality results from within a particular well are considered "intrawell" data for the basis of comparison. Baseline data differs from background data as it is representative of current, stable conditions, if present, for a particular location and allows for detection of local changes in water quality, rather than a comparison to field-wide background value or a published guideline. This is particularly important for older facilities such as Norman Wells, as it allows for monitoring of current potential inputs to the environment even in areas where historical impact may already exist. Furthermore, as is discussed in Section 4.2, the GW-SNP is intended to detect changes in water quality as an alert system to identify potential facility-related environmental releases or degradation, rather than to determine overall environmental health or assess and monitor existing impacts; comparison to a baseline dataset is better suited to detecting change as opposed to comparison to a fixed water quality objective.

Establishing baseline datasets on a per well basis will first require several monitoring events to establish enough data density at a particular well. Baseline data will be defined as a minimum of eight data points extending from well installation to a statistically significant change in trend or to the current reporting period (once the minimum eight points is reached; USEPA 2009). Previously collected data will be used for existing wells.

4.4.1 Calculation of Baseline Control Limits

The Baseline dataset will be used to calculate the Baseline Control Limits for each KIP and SIP for each well.

Baseline Control Limits will be calculated using the Shewhart (EPA 2009) control chart method outlined below, provided that the data meets the following conditions:

- The data set includes at least eight data points.
- Greater than or equal to 50 percent of the data are detectable.
- The Baseline data set does not include:
  - An increasing trend (determined via Mann-Kendall with modified Sen's Slope test).
  - A decreasing trend (determined via Mann-Kendall with modified Sen's Slope test).
  - Verified outliers (removed prior to defining baseline data sets).

The equations used to determine the UCL and LCL are as follows (US EPA 2009):

Equation 1: Upper and Lower Control Limit Calculation

$$UCL = \bar{x} + h \cdot s$$

$$LCL = \bar{x} - h \cdot s$$

Where:

$\bar{x} = sample\ mean\ (arithmetic)$

$s = sample\ standard\ deviation$

$h = control\ chart\ factor = 4.5$

$UCL = Upper\ Control\ Limit$

$LCL = Lower\ Control\ Limit$

4.4.2 Managing Data During Baseline Establishment

During the Baseline data establishment period (i.e., minimum eight data points, meaning a minimum 4-5 years of sampling for newly installed wells), the following scenarios may occur that will require consideration in how the data is used:

- Data below the detection limits:
  - In cases where less than 50 percent of the baseline data set are detectable, the UCL will be set to five or two times the typical RDL (as applicable) and the LCL will not be calculated (not applicable).
- Outliers:
  - An outlier is defined as a value originating from a different statistical population than the rest of the sample. Outliers will be identified using Tukey's Box Plot Method which is suitable for non-normally distributed data (USEPA 2009).

- A valid reason for removing an outlier is required before it could be removed from the data set (USEPA 2009). The following are defined as valid reasons for outlier identification and removal from the dataset:
    - Anomalous concentrations recorded during the well stabilization period, defined as the time following drilling and monitoring well installation when geochemical conditions in the groundwater around the monitoring well are adjusting following the effects of drilling and well installation.
    - An error in transcription, dilution or analytical procedure, etc. that could be identified, but the error could not be corrected.
    - The value was part of a group of parameters with one-time detections that were not replicated in subsequent follow-up verification sampling or any other sampling event.
    - Values for multiple parameters in a field duplicate sample were atypical relative to the parent sample and were not confirmed by subsequent monitoring results.
    - The value was a one-time detection that was more than one order of magnitude greater than the reportable detection limit.
    - One parameter reported over multiple samples from different wells in one sampling event was highly biased or low biased.
    - The data quality of anomalous KIP concentrations could not be verified due to historically incomplete files.
- Trends in Data:
    - Data for inclusion in the Baseline dataset will be analyzed for trends using a Mann-Kendall (Kendall 1975; Mann 1945) test. Data showing statistically significant trends will be rejected from the dataset.

If trends are observed in data during the Baseline dataset establishment period, then it will not be possible to establish well-specific Baseline Control Limits for that well. In this case, the source and environmental significance of changing groundwater will be investigated.

4.5 Data Analysis and Interpretation

All data will be presented in the annual reports (Section 6). Groundwater field and laboratory-analyzed data will be presented as described in the following section, depending on the significance of a parameter to site-related activities (i.e., KIPs, SIP, other data).

4.5.1 Data Tables with Guideline and Background Comparison

The results of all field- and laboratory-analyzed parameters will be presented in data tables with comparison to published environmental guidelines (Section 4.2) and Norman Wells background geochemistry values (Section 4.3 and Appendix B). Comparison to applied guidelines and background will be used as a screening tool to identify potential environmental concerns, and to recognize parameters that may qualify for addition to the KIP or SIP lists. Data from all years will be incorporated into the data tables.

4.5.2 Trend Charts

All KIPs will be presented in trend charts on a per well basis. Trend charts will include published environmental guidelines and background geochemistry values as well as UCL and LCL, once established. Trend charts are cumulative and will be updated annually with all data.

4.5.3 Trend Analysis

Mann-Kendall statistical trend analyses (Kendall 1975; Mann 1945) will be completed on KIPs beginning in year one (for existing monitoring wells) of the monitoring program, year 5 (to allow for establishment of data sets for new wells) and every third year thereafter. A three-year cycle for trend analysis allows for collection of a minimum of four data points for addition to the dataset and for additional time to account for missed sample events, replacement of monitoring wells, erroneous data or other such interruptions to be expected in establishing a dataset.

Statistically significant trends identified within the data will be flagged for further investigation as per the Groundwater Response Plan (Section 5). If trends are identified then additional trend charting and analysis of related SIPs will be conducted, if applicable (e.g., if trends in TDS are identified then trend analyses will be completed on additional major ions such as calcium, magnesium and sulphate to more clearly identify why TDS is changing).

4.6 Data Verification and Validation

All data will be verified and validated prior to addition to the dataset and inclusion in the annual reports through the following steps:

- All laboratory data will be subject to the QA/QC protocols outlined in Appendix F.
- Data will be compared to control limits and historical data for a particular monitoring well.
- Erroneous data will be investigated through one or more of the following methods:
  - Field data will be reviewed for possible transcription errors.
  - Field equipment calibration logs will be checked for any indications of faulty equipment.
  - Laboratory and field QA/QC results for the associated samples will be reviewed for indications of data integrity issues. Any such issues will be addressed, along with an assessment of the impact on data interpretation, in the annual report.
  - Results will be compared to other analytical results from the same sample set for indications of changing water quality or data integrity concerns.
  - If no data integrity issues are identified that suggest the data may not be accurate, the data will be reported as genuine and will be re-evaluated against subsequent years' data.
- Results found to be erroneous and not representative of actual conditions will continue to be reported but will be removed from statistical analysis.

Due to the limited period during which groundwater is active in Norman Wells and limited volume of water typically available in many wells, resampling within a given season beyond the planned two sampling events is not considered a viable option for data verification and validation.

4.7 Current Baseline Data

Appendix G provides a summary of available data from trend analysis, UCL and LCL data for all existing wells within the network. Based on the criteria listed above in Sections 4.4 to 4.6, sufficient and statistically suitable data sets were only available to determine trends and calculate baseline data for UCL and LCL on selected parameters at the following four wells:

- CPF 97-7-5 (chloride, TDS, arsenic, barium and boron);
- MTF 97-1-5 (chloride, TDS, barium and boron);
- TF 03-11-4 (chloride, BTEX, arsenic, barium, boron and iron); and
- TF 03-12-3 (chloride, TDS, arsenic, barium and boron).

Baseline data will be updated in the annual reports as per Section 4.4.

5. Groundwater Response Plan

5.1 Investigation Phase - Contingency Planning

The purpose of the GW-SNP is to install an appropriate network of wells and monitor shallow groundwater quality at key surveillance locations, sampling these locations twice per year, report findings to the SLWB and share them with the public via the SLWB's public registry. The program is also designed to trigger a groundwater response plan to manage contingencies during the Site investigation phase of the program, and when specific changes in chemistry are measured during the monitoring phase of the program.

During the Site investigation phase, including the installation of the 28 new monitoring wells in 2025-2026 and inspection of the 19 pre-existing wells chosen for inclusion in the GW-SNP program, the following scenarios in Table 5-1 are considered for contingency planning.

Table 5-1: Contingency Scenarios During Investigation Phase

Item	Scenario	Contingency Planning
1.	Desired drilling location cannot be feasibly accessed due to vegetation in the area.	• Clear the vegetation by developing a cut line, if feasible. • Move to another more suitable location in the vicinity, if feasible.
2.	Desired drilling location cannot be feasibly accessed due to topography, above-ground or buried infrastructure, wet ground, or other physical obstacles.	• Move the proposed drilling location to another more suitable location in the vicinity, if feasible.
3.	During drilling, borehole logging and monitoring well installation, unfrozen flowing groundwater is not identified.	• Install the well screen across the depth interval where an active zone of unfrozen water would be expected to develop, based on visual and/or temperature-based evidence of top of permafrost. • Even though some monitoring wells within the GW-SNP program may initially be frozen, one of the objectives of the program is to identify whether climate change affects the seasonally active zone controlling groundwater flow. Regional melting of shallow permafrost, due to climate change, in key sentinel areas downgradient of operational facilities may promote lateral migration of KIPs.
4.	During drilling, borehole logging and monitoring well installation, oily sheen, non-aqueous phase liquid (NAPL), or organic vapour analyzer (OVA) analyses on soil samples indicating strong hydrocarbon odours are identified.	• Install the monitoring well screen across the depth interval where hydrocarbon impacts are most likely to migrate with the shallow groundwater. • The intention of the GW-SNP program is not only to install downgradient sentinel wells, but to identify facility-related impacts in areas not previously investigated and determine whether there are any ongoing releases. • Based on subsequent monitoring events, evaluate whether additional wells need to be installed to laterally delineate the impacts. • Data will be transferred to Imperial's progressive reclamation team for management of legacy impacts.

Item	Scenario	Contingency Planning
5.	During ground disturbance clearance, drilling and borehole logging, evidence of buried debris or historical infrastructure is encountered.	• Undocumented buried historical debris is periodically identified in certain areas of the field during site investigations. • Consult with Imperial Operations to determine appropriate next steps. • Move the proposed drilling location to another more suitable location in the vicinity, if feasible. • Notify the progressive reclamation group of the possible area of concern.
6.	During inspection of the pre-existing wells, a well is determined to be damaged or otherwise unsuitable for future sampling.	• Repair the pre-existing well, if feasible. • Abandon the existing well and replace with a new installation in the vicinity.

5.2 Monitoring Phase - Contingency Planning

The GW-SNP program is being designed to incorporate the concept of adaptive monitoring, which is an approach that responds to a measurement of a potential effect by triggering further confirmation steps, which may include changing the analytical schedule, triggering lateral delineation drilling, or modifying other program parameters. The process and steps that serve as a response framework are described in the following section.

The following scenarios in Table 5-2 are considered for contingency planning during the monitoring phase of the GW-SNP program.

Table 5-2: Contingency Scenarios During Monitoring Phase

Item	Scenario	Contingency Planning
1.	Detection of primary KIPs at concentrations above baseline and/or background, but below applied regulatory guidelines (where available).	• Continue summer-fall sampling as planned. • Evaluate whether the situation is stable, based on statistical trend analysis. • If increasing statistical trends in KIPs and/or SIPs are identified, consider the need for additional site characterization to laterally delineate the issue, if feasible. • For parameters where regulatory guidelines are not available, background and baseline ranges will be used as screening criteria (e.g., TDS, dissolved Ba).
2.	Detection of primary KIPs at concentrations exceeding both baseline and/or background and applied regulatory guidelines.	• Continue summer-fall sampling as planned. • Verify data integrity by reviewing sampling field notes, laboratory QA/QC reports, field QA/QC sample results, and Chain of Custody documentation. • Evaluate whether the situation is stable, based on statistical trend analysis. • If increasing statistical trends in KIPs/SIPs are identified, plan for additional site characterization within 3 years to laterally delineate the area, if feasible. • Consider expansion of the analytical schedule parameters for this well, if necessary, to clarify potential risks.

Item	Scenario	Contingency Planning
3.	Detection of background/baseline exceedance and/or increasing trend in one or more SIPs at a well.	• Review of chemistry data to confirm presence of statistically relevant increasing trend. • Consider additional characterization to determine relevance of increasing trend in context of local site/groundwater conditions (this may include expanded analytical suite in subsequent sampling events, review of adjacent monitoring well chemistry, etc.).
4.	Physical damage to a GW-SNP monitoring well affecting the ability to conduct future sampling events at that well.	• Attempt to repair the existing well during the next GW-SNP sampling program. • Plan for abandonment of the existing well, and installation a replacement well in the vicinity within 3 years, if feasible.
5.	GW-SNP monitoring wells are found to be dry, frozen, and/or consistently do not provide enough groundwater for sampling.	• Continue summer-fall measurements as planned, to verify whether the frozen/dry conditions are temporally stable or changing over time. • In particular, the potential effects of a warming climate on thawing of the active zone above permafrost is an important metric to evaluate in sentinel areas downgradient from potential sources. Intact shallow permafrost is considered an effective hydraulic barrier to groundwater flow and primary KIP migration from sources toward receptors.
6.	First-time detection of hydrocarbon KIPs at a monitoring location	• Verify data integrity by reviewing sampling field notes, laboratory QA/QC reports, field QA/QC sample results, and Chain of Custody documentation. • Additional sampling and/or analyses may be required to assist with differentiation between natural hydrocarbon seepage and/or NWO-related hydrocarbon impacts to shallow groundwater.

Note that adaptive monitoring and the contingencies presented herein are specific to how the monitoring program and data analysis may change.

6. Reporting

All data will be reported annually to the SLWB on or before March 31st of the year following data collection as per Part B(13) of Water Licence S13L1-007A summary of the GW-SNP will be submitted to the SLWB as part of the Annual Water Use Report.

6.1 Annual Reports

Annual reports will include:

- A summary of the field work conducted, and methods employed.
- A summary of any scope deviations or deficiencies in the program.
- Water monitoring data tables including groundwater surface elevations, well installation details and hydraulic conductivity testing results, where available.
- Analytical data tables comparing results to regulatory guidelines, background and historic data:
  - Data tables will include all field- and laboratory-analyzed data.
  - All historic data will be presented in data tables.
- Copies of the laboratory certificates of analysis.
- Trend charts where KIPs will be presented on a per-well basis; UCL and LCL will be included once established.
- Shewert and Mann-Kendall statistical trend analysis will be completed on KIPs as outlined in Section 4.5.3.
- A summary of field and laboratory QA/QC results and an interpretation of the impact of any QA/QC issues on data quality and interpretation:
  - Data will be verified and validated using QA/QC protocols outlined in Appendix F.
- Results will be reviewed in the context of the response framework outlined in Section 6.
- Figures depicting the site, the monitoring locations and infrastructure being monitored.
- Monitoring well logs for the full well network.
- A summary of any well maintenance, abandonment or replacement work conducted.
- Recommendations for any changes to the monitoring program.

6.2 Trend Analysis

New datasets are being established with the addition of a large number of new or recently drilled monitoring wells. As such, trend analysis will be limited in the first years of sampling. For Year 1, existing well data sets will have trend analysis completed. Trend analysis will be completed in Year 5 for the full network of wells and repeated every three years after that. Raw data sets (i.e., unformatted Excel tables) will accompany each year's submission.

6.3 Community Engagement

The Community Based Monitoring Program shared the importance of bringing the results back in the community in a meaningful way. Imperial will continue to engage with Sahtu communities to ensure that community stakeholders are informed in a meaningful way (i.e., equating water quality results to how they related to expressed community concerns) and will have the opportunity to provide feedback.

7. Closure

We trust that this report satisfies your current requirements and provides suitable documentation for your records. If you have any questions or require further details, please contact the undersigned at any time.

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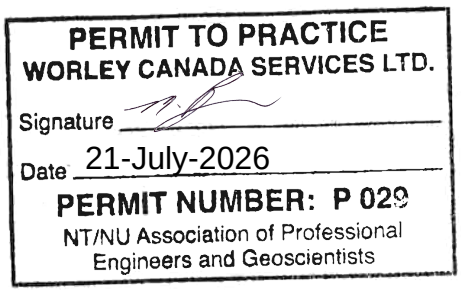

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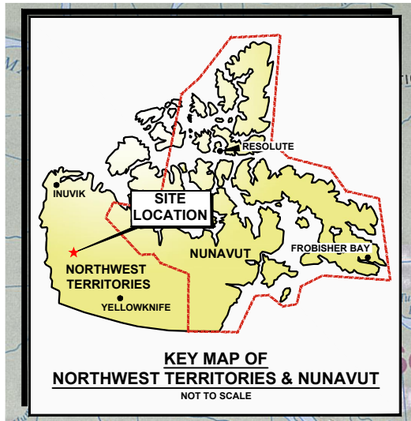
Figures



KEY MAP OF
NORTHWEST TERRITORIES & NUNAVUT
NOT TO SCALE

SITE LOCATION

NORTHWEST TERRITORIES

Settlement Area

GREAT BEAR LAKE

Smith Arm

McTavish Arm

Keith Arm

McVicar Arm

Leith Peninsula

Deerpass Bay

Russel Bay

Jupiter Bay

Cloud Bay

Neiland Bay

Sawmill Bay

Cape MacDonnel

Workman Island

Ekka Island

Ikanyo Island

Knife Point

Mackintosh Bay

Douglas Bay

Etacho Point

Kokéragi Point

Point Leith

Richardson Island

Echo Bay

Dowdell Point

Sayoyue and Ehdacho Historic Site (Ehdacho Unit)

Sayoyue and Ehdacho Historic Site (Sayoyue Unit)

Fox Point

Deline

Deline Fishery and Fort Franklin Historic Site

Manitou Island

Bell Island

Norman Wells

Perty Island

Judith Island

Ogilvie Island

Tulita

Police Island

Great Bear River

Winter Road

Sr. Charles Creek

Porcupine River

Three Day Lake

Big Smith Creek

Lac Ste-Thérèse

Lac Tache

Lac Grandin

Birch Lake

Hoe River

Tate Lake

Stewart Lake

Keller Lake

Blackwater Lake

Tseepantee Lake

Fish Lake

Greasy Lake

Highland Lake

Bulmer Lake

Lac Levis

Lac La Martre

Wha Ti

Rae Lakes

Rae

Rae-Edzo

Edzo

Wekweti

Yellowknife

North Arm Territorial Park

Prelude Lake Territorial Park

Fred Henne Territorial Park

Bras d'Or Lake

Checkbuttelo Lake

Clive Lake

Bartlett Lake

Windflower Lake

Raccoon Lake

Weyburn Lake

Hottah Lake

Zebulon Lake

Longtom Lake

Ellington Lake

Wipmay Lake

Grant Lake

Mesa Lake

Grenville Lake

Rawalpindi Lake

Whitewolf Lake

Abaiyesseh Lake

Little Forehead Lake

Humpy Lake

Roulante Lake

Snare Lake

Wecho Lake

Indin Lake

Mattberry Lake

Basler Lake

Ghost Lake

Kwejinne Lake

Armi Lake

Upper Carp Lake

Rocknest Lake

Redrock Lake

Scotstown Lake

Samandré Lake

Itchen Lake

Point Lake

Lac Ste-Croix

Margaret Lake

Black Lichen Lake

Castor Lake

Rebesca Lake

Beaverlodge Lake

Lac Malfait

Hardisty Lake

Taka Lake

Rae Lake

Faber Lake

Saddle Lake

Sarah Lake

Mazenod Lake

Hislop Lake

Slemon Lake

Mosher Lake

Russell Lake

Stagg Lake

Marian Lake

James Lake

Zinto Lake

Ingray Lake

Lac Granville

Lac Taché

Lac La Martre

CARTAGE MOUNTAINS

North Slave Region

Winter Road

Rae-Edzo

Edzo

Yellowknife

Norman Wells Range

Franklin Mountains

Canyon Ranges

Mackenzie Mountains

McConnell Range

Camsell Range

Ebbutt Range

Mt. Wilson 2276m

Christie Pass

Mt. Pike

Mt. Sir

Ferry (Seasonal)

Heritage Trail

Canol Road

Mackenzie River

Great Bear River

Keele River

Ramparts River

Redstone River

Wrigley Lake

Wrigley

Fish Lake

Camsell Bend

Nahanni River

Root River

Ochre River

Blackwater River

Dahadinni River

Johnson River

Throuh River

Ravens River

Natla River

Silverberry Creek

Thunderstone Creek

Landry Creek

English Creek

Chief River

Moose Horn River

Tetcho River

Keele River

Wrigley Lake

Redstone

MAINLAND WEST

MAINLAND CENTRAL

MAINLAND SUMPS

MAINLAND EAST

MAINLAND WEST - MTF

MAINLAND EAST - MTF

SEEPAGE LAKE

GOOSE ISLAND - GIT7

GOOSE ISLAND - GIT8

GOOSE ISLAND

BEAR ISLAND - BIT4

BEAR ISLAND - BIT3

BEAR ISLAND - N-45X

BEAR ISLAND - Q-37X

BEAR ISLAND

ISLAND 5

ISLAND 6

MACKENZIE RIVER

LEASE No. 96 E/7-29

LEASE No. 76 E/7-16

LEASE No. 96 E/7-26-4

LEASE No. L-2825T

LEASE No. L-2824T

LEASE No. L-3175T

LOT 8 REMAINDER GROUP 1158
PLAN 52019 C.L.S.R.

SANDBAR

SOUTH BOUNDARY OF LOT 8 PLAN 52019 C.L.S.R. (NOT ESSO'S LEASE BOUNDARY)

O.H.W.M. PLAN NO. 52015 C.L.S.R.

O.H.W.M. PLAN NO. 52016 C.L.S.R.

O.H.W.M. PLAN NO. 52005 C.L.S.R.

ISLAND 3 (DEHCHO)

19 EXISTING WELLS	INJECTION WELLS
I- 22X K-24X	J-19X L-19X
L-24X M-19X	J-21X L-21X
F-17X M-20X	J-23X L-23X
K-20X M-22X	
K-22X M-24X	

ISLAND 4 (EKWE)

SPACING WELLS	INJECTION WELLS
I-29X K-29X	H-29-1X L-25X
I-30X K-30X	J-25X L-27X
I-32X M-28X	J-27X L-29X
K-7 &8 M-28X	J-29-1X L-31X
M-26X	

ISLAND 1 (BAYUNA)

PRODUCING WELLS	INJECTION WELLS
G-34X G-40X	F-37X H-35X
G-36X I-36X	F-39X H-37X
G-38X I-38X	H-33X H-39X

ISLAND 2 (RAMPART)

PRODUCING WELLS	INJECTION WELLS
E-42X G-46X	F-41X H-43X
E-44X G-48X	F-43X H-45X
E-46X I-44X	F-45X H-47X
E-48X I-46X	F-47X H-49X
G-44X I-48X	H-41X
F-52X (PROPOSED)	H-52X (PROPOSED)

PLAN 69807 C.L.S.R. (L.T.O. No. 1732)
LOT 1007 LEASE No. 96 E/7-15-2
ISLAND 5 (ITEH KEE)

PRODUCING WELLS	INJECTION WELLS
M-31X K-36X	J-31X L-33X
M-32X K-37X	J-32X L-34X
M-34X I-32X	J-35X L-35X
K-32X I-34X	J-36X L-36X
K-33X I-35X	L-37X
K-34X	

PLAN 69807 C.L.S.R. (L.T.O. No. 1732)
LOT 1008 LEASE No. 96 E/7-14-2
ISLAND 6 (LITTLE BEAR)

PRODUCING WELLS	INJECTION WELLS
I-40X K-40X	J-37X J-43X
I-42X K-42X	J-39X L-39X
K-38X M-40X	J-41X L-41X

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- ESSO LEASE BOUNDARY
- UTILIDOR LOCATION
- PIPELINE R/W
- O/H POWERLINE
- LEASE BOUNDARY (D.H.W.M.)
- REGISTERED PLAN BOUNDARY
- OPERATIONAL APECs

SOURCE:
SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010164101 (REV 0 DATED 95-10-16) AND 98100093 (REV 1 DATED 98-10-08)

NAD27 UTM ZONE 9

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1:10000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

SITE PLAN

Date:	04-MAR-24	Drawn by:	OTHERS	Edited by:	BMF	Appr'd by:	MB

Project No.: 417085-49223

FIG No.: 2

REV.: 2

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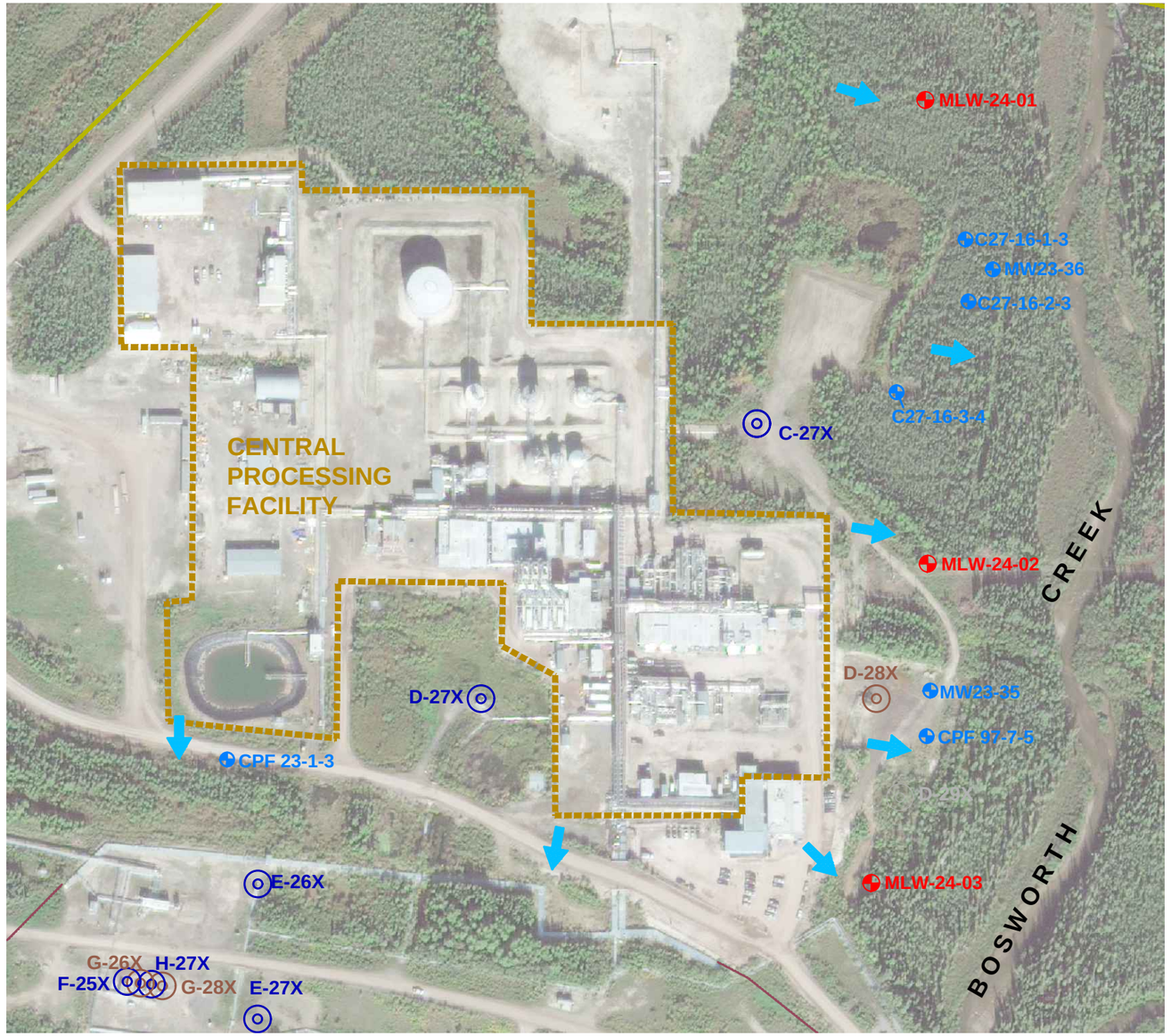

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- ESSO LEASE BOUNDARY
- LEASE BOUNDARY (O.H.W.M.)
- REGISTERED PLAN BOUNDARY
- MONITORING WELL LOCATION
- 2024 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

MAINLAND WEST PROPOSED SNP LOCATIONS

Date:	Drawn by:	Edited by:	App'd by:
22-APR-25	OTHERS	DLC	MB

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FIG No 3 | REV 2

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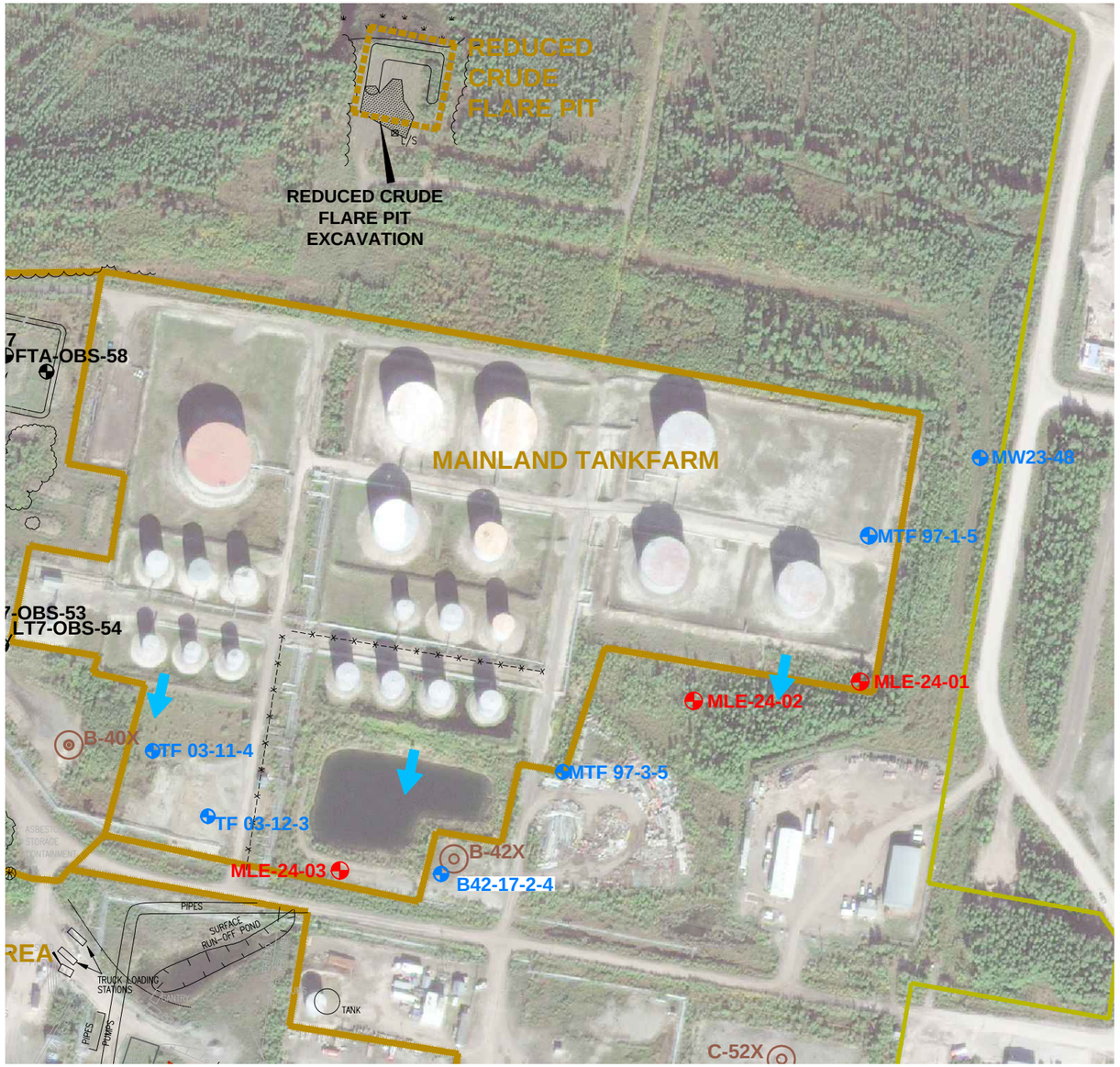

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- ESSO LEASE BOUNDARY
- LEASE BOUNDARY (O.H.W.M.)
- REGISTERED PLAN BOUNDARY
- MONITORING WELL LOCATION
- 2024 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

MAINLAND EAST PROPOSED SNP LOCATIONS

Date:	Drawn by:	Edited by:	App'd by:
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FIG No 4 | REV 2

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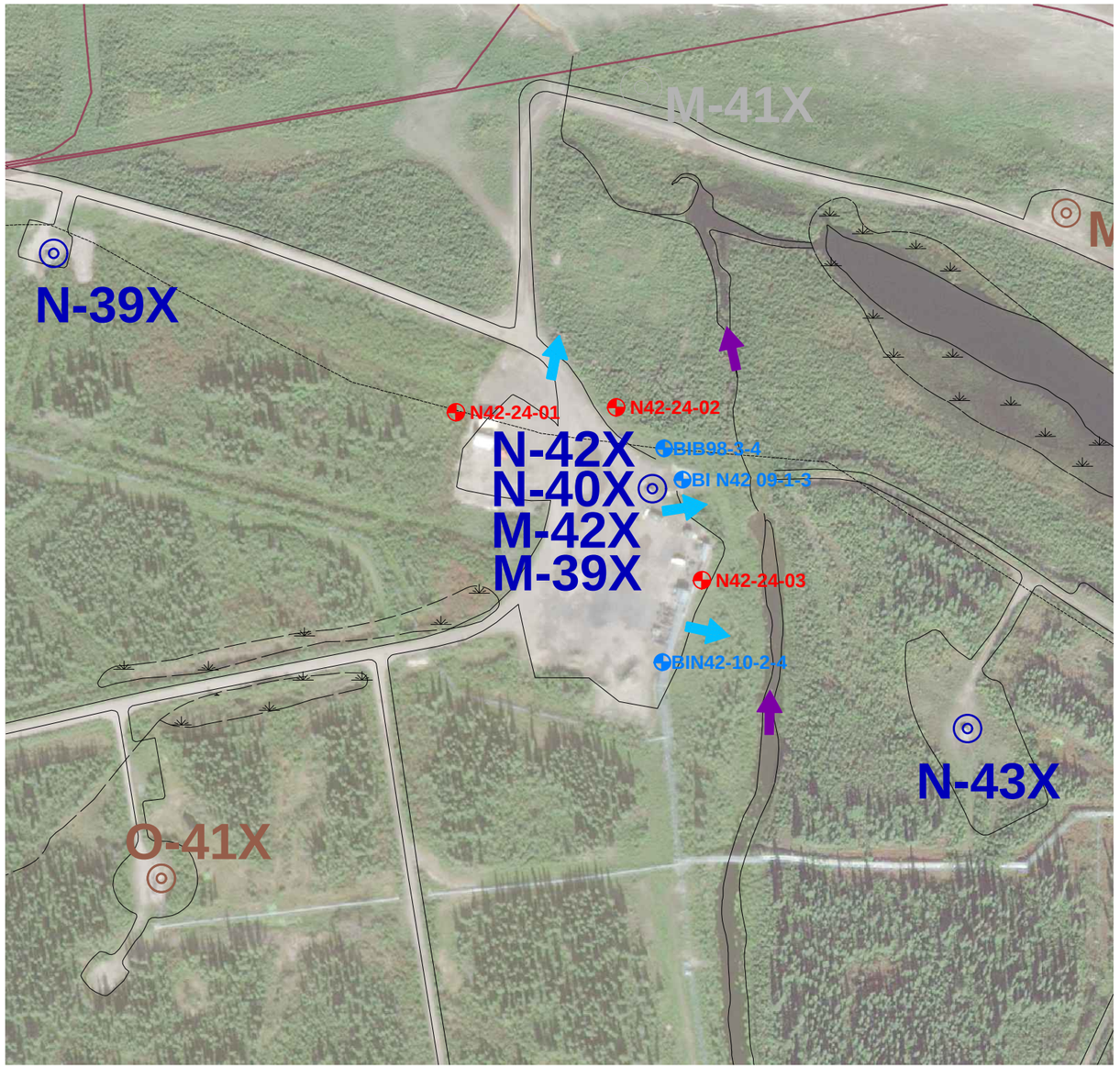

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- REGISTERED PLAN BOUNDARY
- MONITORING WELL LOCATION
- 2025 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION
- UNNAMED CREEK FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

BEAR ISLAND N-42X PROPOSED SNP LOCATIONS

Date:	Drawn by:	Edited by:	App'd by:
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FIG No **5A** | REV **2**

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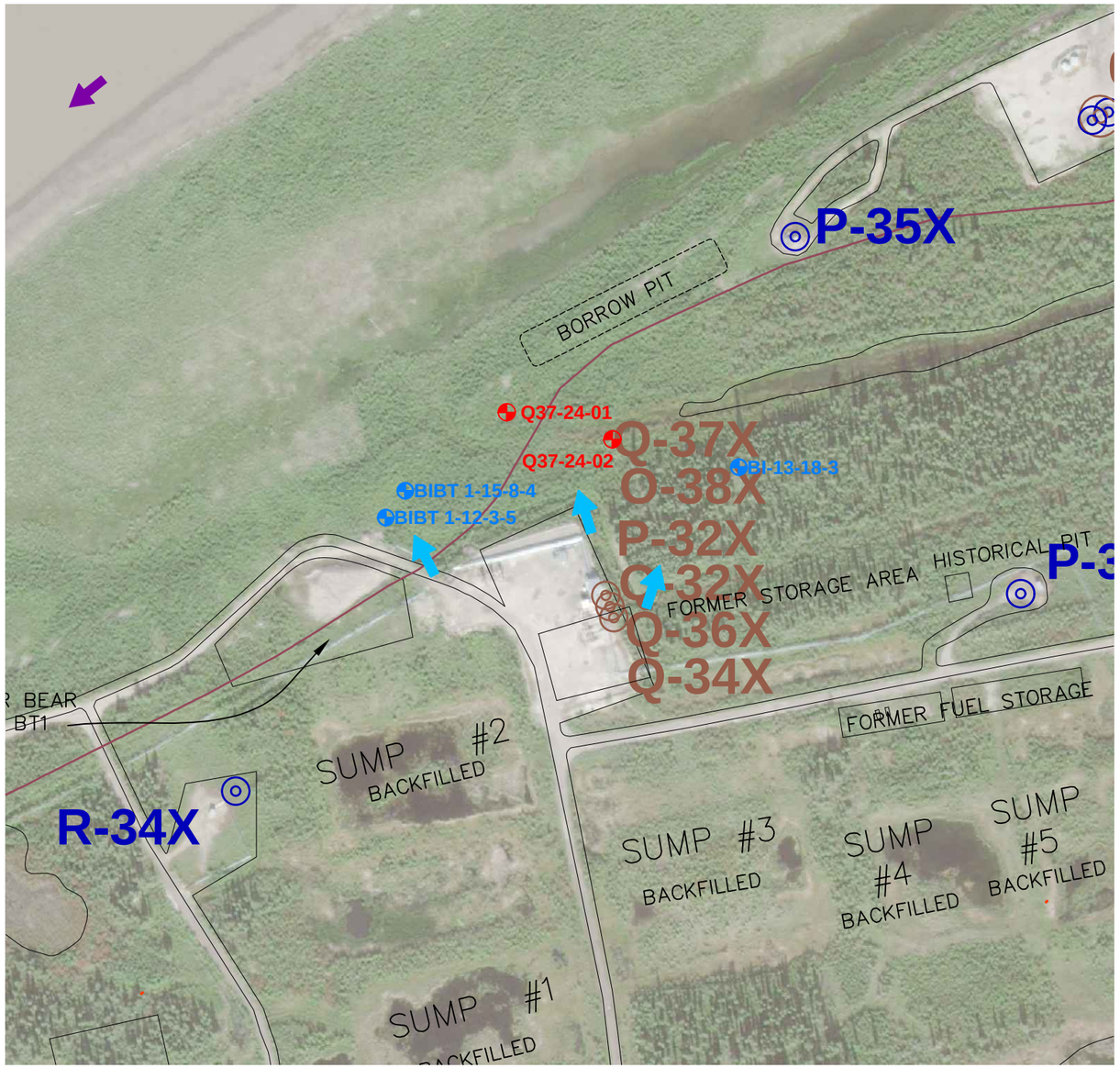

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- REGISTERED PLAN BOUNDARY
- MONITORING WELL LOCATION
- 2025 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION
- MACKENZIE RIVER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

BEAR ISLAND Q-37X PROPOSED SNP LOCATIONS

Date:	Drawn by:	Edited by:	App'd by:
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FIG No **5B** REV **2**

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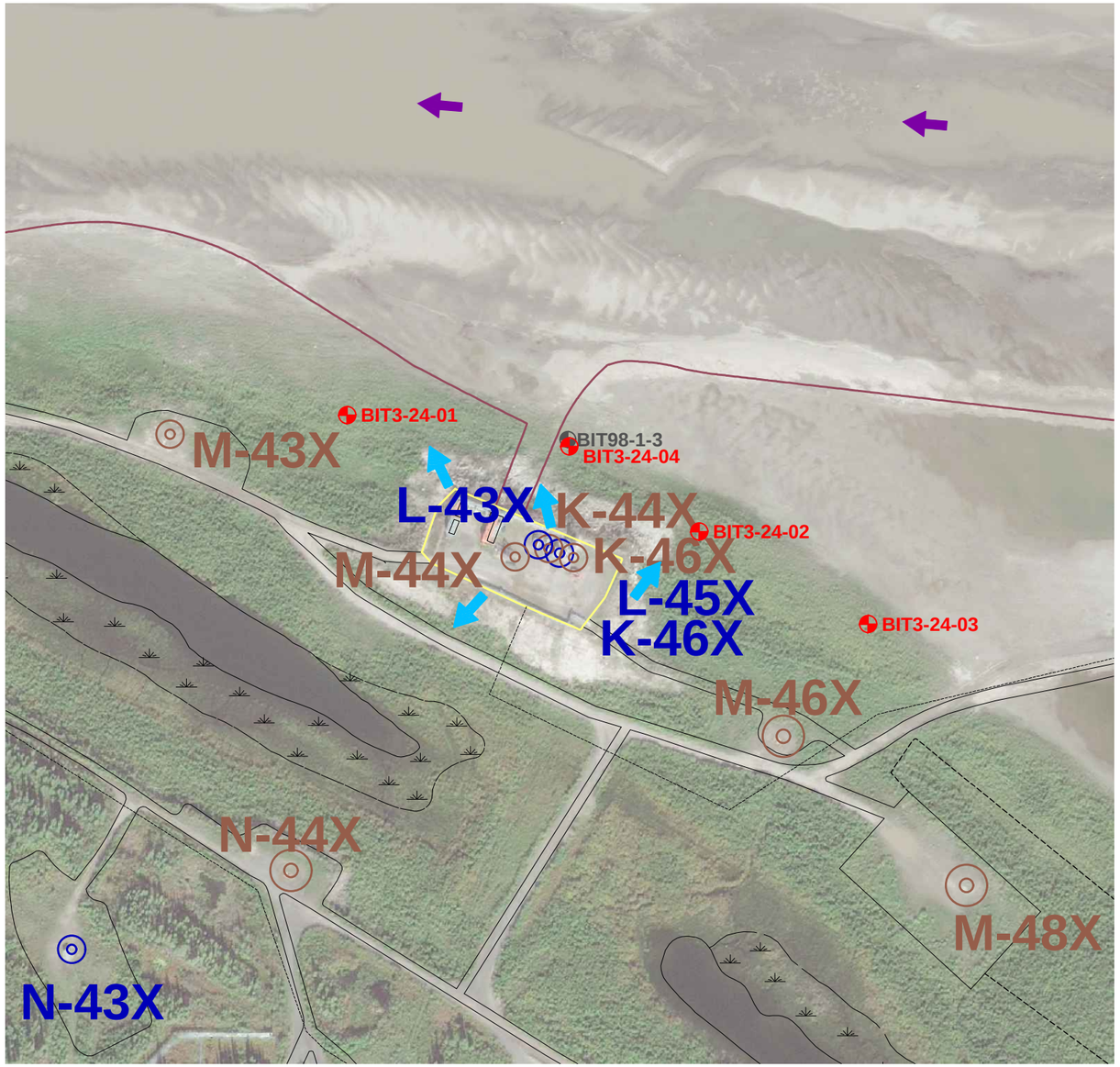

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- REGISTERED PLAN BOUNDARY
- MONITORING WELL LOCATION
- ABANDONED MONITORING WELL LOCATION (TO BE REPLACED)
- 2025 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION
- MACKENZIE RIVER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

BEAR ISLAND B.I.T.3 PROPOSED SNP LOCATIONS

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FIG No **5C** REV **2**

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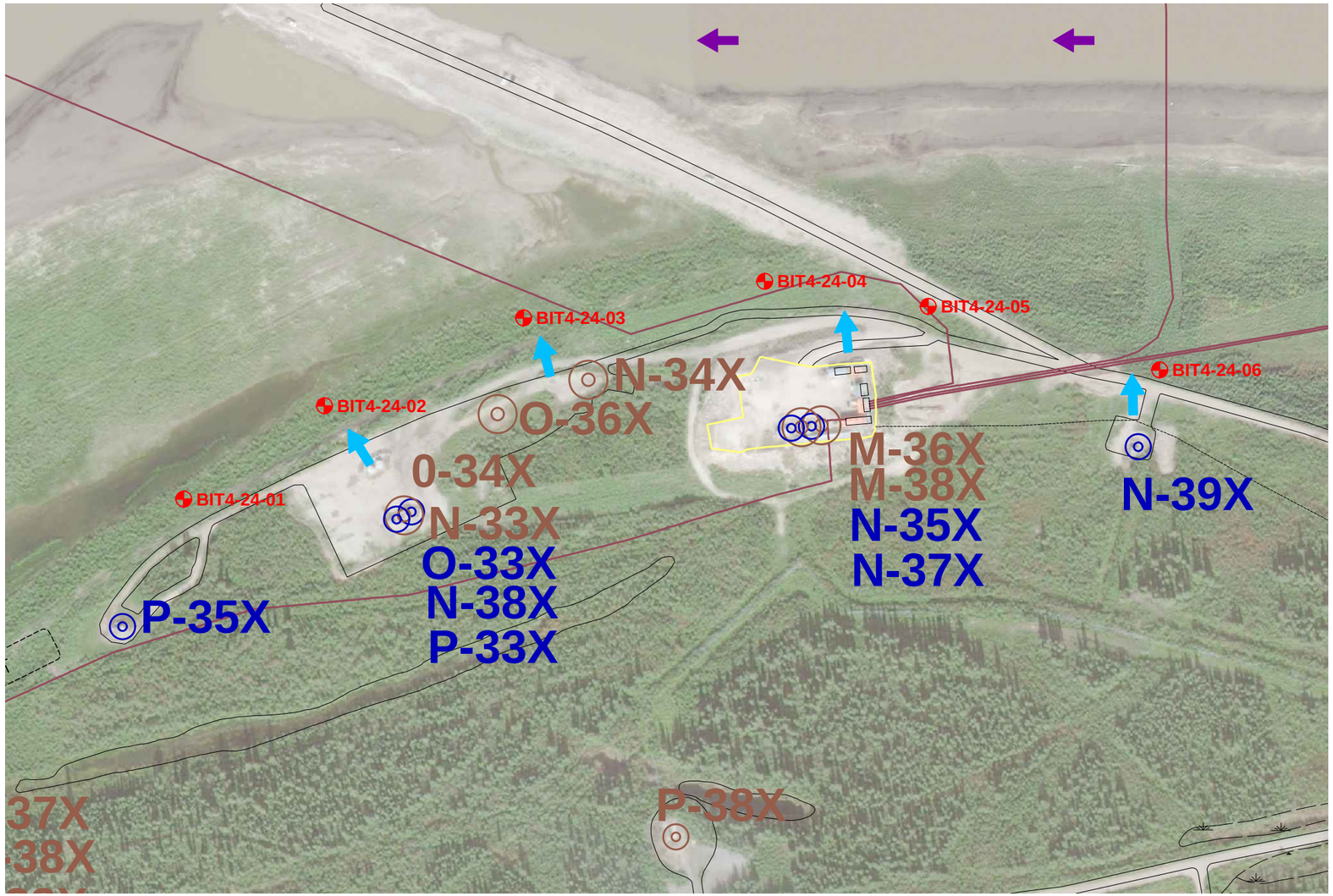

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- REGISTERED PLAN BOUNDARY
- 2025 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION
- MACKENZIE RIVER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

BEAR ISLAND B.I.T.4 PROPOSED SNP LOCATIONS

Date:	22-APR-25	Drawn by:	OTHERS	Edited by:	DLC	App'd by:	MB

TSS Advision

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FIG No **5D** | REV **2**

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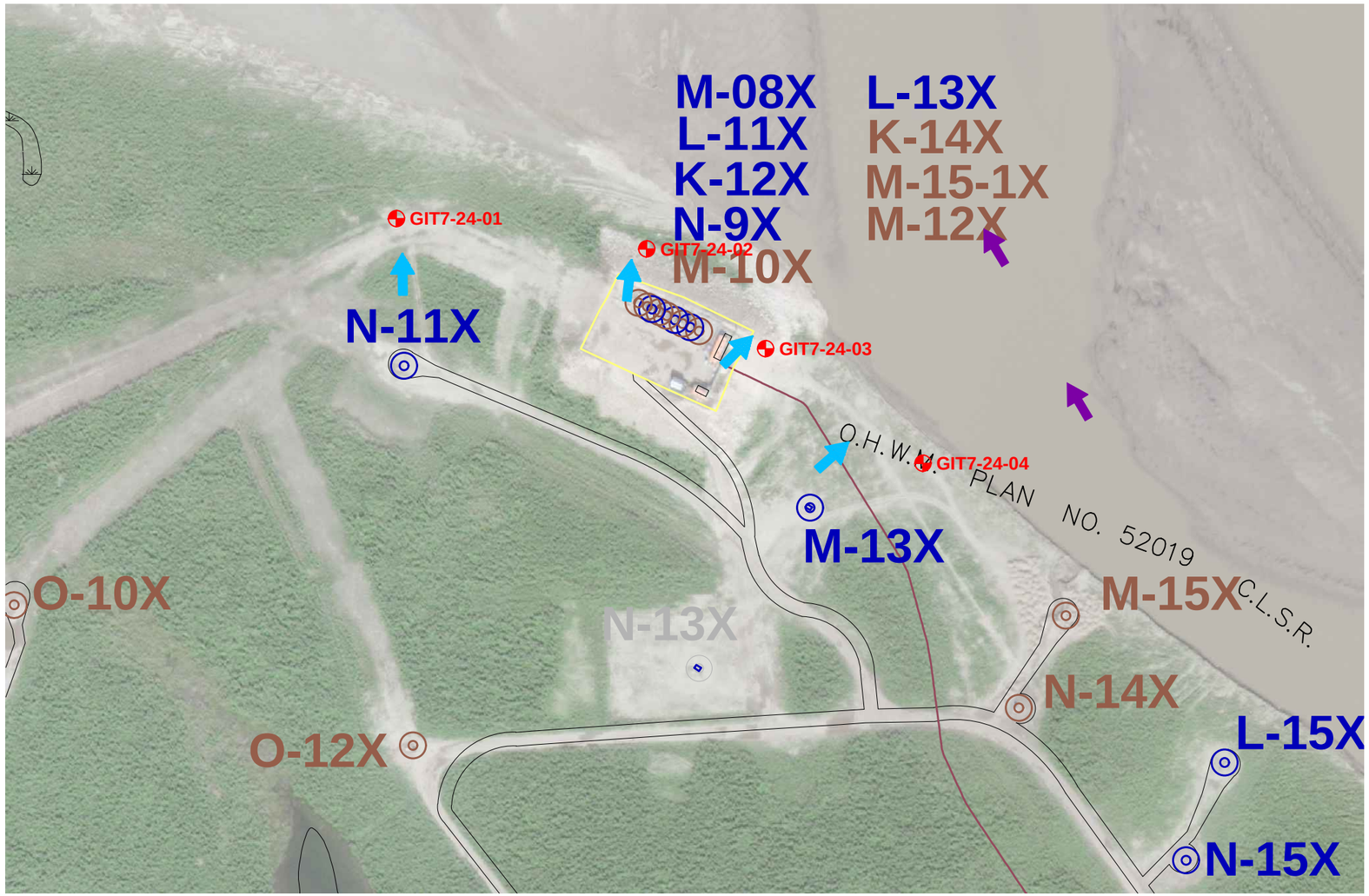

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- REGISTERED PLAN BOUNDARY
- 2024 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION
- MACKENZIE RIVER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

GOOSE ISLAND G.I.T.7 PROPOSED SNP LOCATIONS

Date:	Drawn by:	Edited by:	App'd by:
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FIG No: 6A
REV: 2

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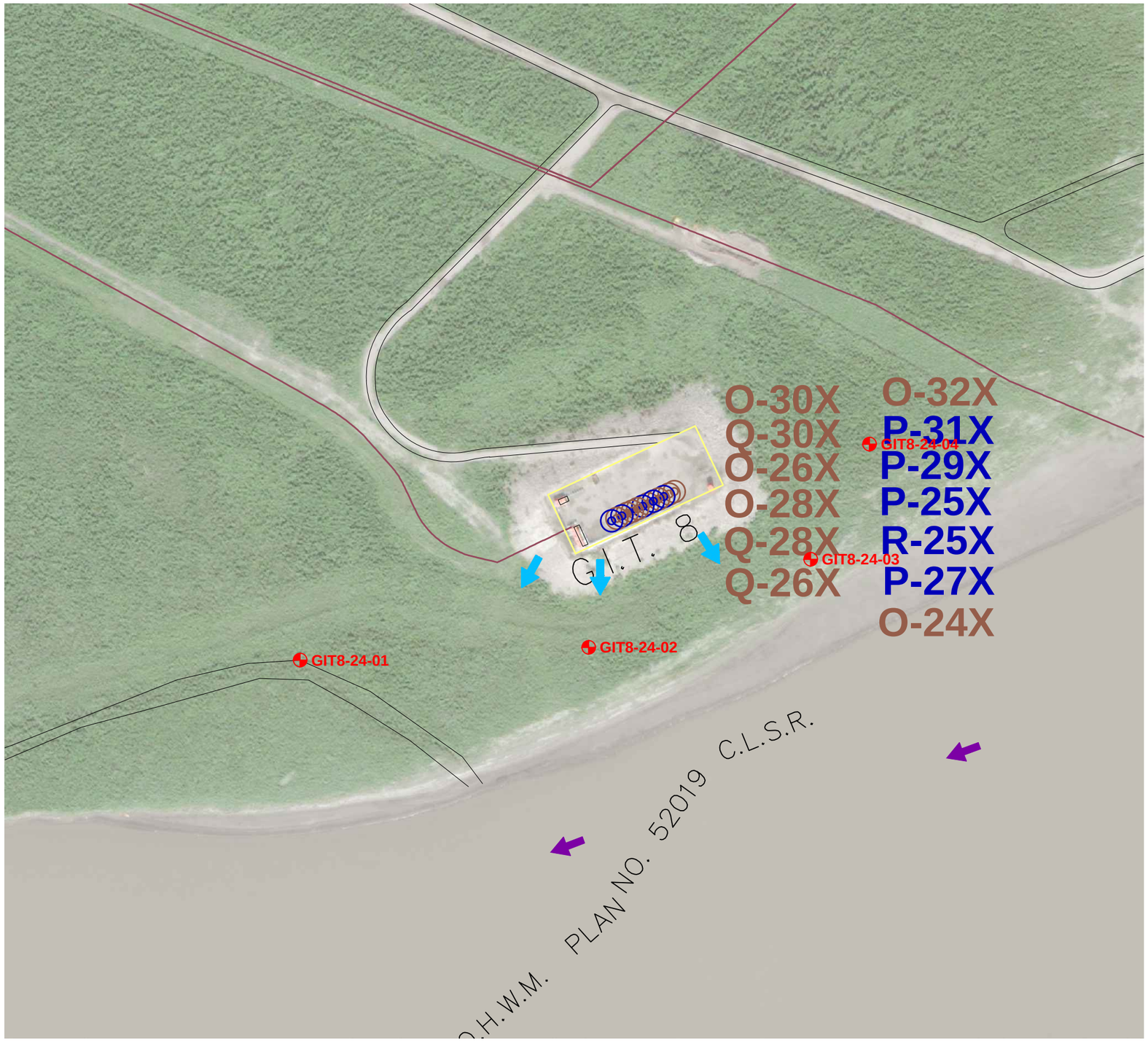

LEGEND

- INJECTION WELL LOCATION
- PRODUCTION WELL LOCATION
- REGISTERED PLAN BOUNDARY
- 2024 PROPOSED MONITORING WELL LOCATION
- INFERRED SHALLOW GROUNDWATER FLOW DIRECTION
- MACKENZIE RIVER FLOW DIRECTION

SOURCES:
1. SITE PLAN AS PER UMA ENGINEERING LTD. FILES 010166101 (REV 0 DATED 95-10-16) AND 98100003 (REV 1 DATED 98-10-08)
2. WORLEYPARSONS SURVEY 2009, 2010, 2012, 2013.

NAD27 UTM ZONE 9

m 0 50 100 150 m

1:3000

IMPERIAL
GROUNDWATER MANAGEMENT PLAN
NORMAN WELLS OPERATIONS

GOOSE ISLAND G.I.T.8 PROPOSED SNP LOCATIONS

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FIG No **6B** | REV **2**

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Appendix A. Limitation of Liability, Scope of Report, and Third-Party Reliance

Limitation of Liability, Scope of Report, and Third-Party Reliance

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The investigation undertaken by TRSA with respect to this report and any conclusions or recommendations made in this report reflect TRSA' s judgment based on the site conditions observed at the time of the site inspection on the date(s) set out in this report and on information available at the time of preparation of this report. This report has been prepared for the specific application to this site and it is based, in part, upon visual observation of the site, subsurface investigation at discrete locations and depths, and specific analysis of specific chemical parameters and materials during a specific time interval, all as described in this report. Unless otherwise stated, the findings cannot be extended to previous or future site conditions, portions of the site which were unavailable for direct investigation, subsurface locations which were not investigated directly, or chemical parameters, materials or analysis which were not addressed. Substances other than those addressed by the investigation described in this report may exist within the site, substances addressed by the investigation may exist in areas of the site not investigated and concentrations of substances addressed which are different than those reported may exist in areas other than the locations from which samples were taken.

If site conditions or applicable standards change or if any additional information becomes available at a future date, modifications to the findings, conclusions, and recommendations in this report may be necessary.

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Appendix B. Background Geochemical Statistical Summary

Imperial

Background Geochemical Statistical Summary (Appendix 3)

Norman Wells, NT

28 May 2020

407011-00622 – CA-REP-0006

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Calgary, AB T3B 6B7 CANADA
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Worley Group

THIS REPORT CONTAINS PROVISIONS LIMITING LIABILITY, THE SCOPE OF THE REPORT AND THIRD PARTY RELIANCE

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Project No. 407011-00622-CA-REP-0006 - Background Geochemical Statistical Summary (Appendix 3): Norman Wells, NT

Rev	Description	Originator Approval	Reviewer Approval	Project Manager Approval	Date
0	Issued as Final	M. Brown	A. Glatiotis	S. Gibb	28-May-20

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Table 13 Groundwater Statistical Source Data (1998-2019) – Dissolved Metals

1. Introduction and Methodology

1.1 Introduction

Soil, bedrock, and groundwater analytical results from numerous Phase II Environmental Site Assessments (ESAs) conducted to date within the Norman Wells Field (the Site) have indicated that there are concentrations of select hydrocarbon, salt and metals parameters in certain lithologic/stratigraphic units that are naturally elevated above generic federal and territorial environmental quality guidelines. Understanding background (pre-industrial disturbance) environmental quality is required to properly evaluate site characterization data and determine appropriate site remediation objectives and endpoints for the Norman Wells Field. The evaluation of background geochemical conditions is complicated by the presence of natural crude oil, gas, and saline water seepage in several Mainland areas of the Site.

This document includes a summary review and assessment of available data with the objective of determining background soil, bedrock and groundwater geochemical conditions, both within the natural seepage areas and outside of them, for the primary near surface (i.e. upper 20 metres [m]) lithologic/stratigraphic units present within the Norman Wells Field. To provide context the statistically evaluated results are compared to appropriate CCME federal regulatory guidelines for soil and groundwater quality, as summarized in the main text of this report.

1.2 Background Sampling Location Selection

1.2.1 Soil and Bedrock

The majority of the background soils/bedrock data was collected between 1998 and 2016. Data were collected for a range of environmental projects and it is possible that a location considered suitable for background purposes for a groundwater or subsurface soils investigation may not necessarily provide suitable background surface soils data due to disturbance of surface soils, or due to the presence of shale fill material. Only data from those background locations considered to have minimal or no potential industrial impact were included in the background assessment.

Background soil and bedrock sampling locations are shown on Figures 1 and 2 and summarized on Table 1. For the purposes of the Norman Wells environmental background assessment, soil and bedrock background locations were summarized into the following general categories/stratigraphic units:

- Surface organic soil generally above 0.5 metres below ground surface (mbgs):
  - Mainland (17 locations, 17 samples);
  - Mainland Seeps (4 locations, 4 samples); and
  - Islands (4 locations, 5 samples).
- Surface mineral soil (generally upper 0.5 m of soil profile):
  - Mainland (15 locations, 18 samples);
  - Mainland Seeps (5 locations, 8 samples); and

  - Islands (14 locations, 14 samples).
- Subsurface mineral soil (> 0.5 mbgs to bedrock contact):
  - Mainland (28 locations, 53 samples);
  - Mainland Seeps (4 locations, 8 samples); and
  - Islands (19 locations, 45 samples).
- Bedrock:
  - Siltstone on Mainland (10 locations, 11 samples);
  - Mainland Seeps (2 locations, 4 samples); and
  - Shale Fill Material from Quarry (4 locations, 4 samples).

There were no natural seepage areas identified on the Islands and no bedrock was encountered or sampled during intrusive investigations on the Islands.

1.2.2 Groundwater

Background monitoring wells would ideally be installed in an undisturbed, up-gradient area, isolated from any potential sources of anthropogenic impact. However, these locations tend to be heavily influenced by permafrost in the vicinity of Norman Wells. Previous attempts to install background wells in up-gradient areas of the lease, removed from the Imperial facilities and in areas of natural vegetation, have resulted in rapidly frozen groundwater monitoring wells that consistently remain frozen. As such, the use of the term "background" in this report does not necessarily mean the groundwater monitoring well is installed in an undisturbed, up-gradient area. Rather, the term is used for locations inferred to be removed from site facilities and free of facility-related impacts.

Background groundwater sampling locations are shown on Figures 3 and 4 and summarized on Table 2. These background wells are separated into five groups, as follows. These groups are based on the hydrogeological zone where the monitoring well screen is completed, as well as evidence for the presence or absence of natural seepage in the vicinity:

- Surficial sediments on Mainland (14 wells, total of 75 samples);
- Surficial sediments on Natural Islands (10 wells, total of 63 samples);
- Shallow bedrock on Mainland inferred to represent natural saline water and hydrocarbon seepage (7 wells, total of 81 samples);
- Surficial sediments on Mainland inferred to represent natural saline water and hydrocarbon seepage (5 wells, total of 27 samples); and
- Surficial sediments on Mainland inferred to represent natural gas seepage without saline water (4 wells, total of 34 samples).

1.3 Analytical Data Compilation & Screening

1.3.1 Statistical Trend Analyses

Statistics were evaluated generally following protocols in U.S. EPA Unified Guidance (2009). Statistical trend analyses were used to evaluate temporal changes in key parameters at background locations for groundwater samples. A similar analysis could not be done on soil/bedrock data since these results do not have a temporal history, as they are derived from one-time drilling and sampling events. The presence of statistically significant temporal trends would suggest facility-related water quality impacts, meaning that the monitoring well in question may not be suitable as a background location. Key parameters considered for trend analyses were benzene, toluene, ethylbenzene, arsenic, copper, cadmium, iron and chloride.

The analysis was performed using the non-parametric Mann-Kendall trend test (Mann 1945; Kendall 1975; Gilbert 1987). The purpose of the Mann-Kendall (MK) test is to statistically assess if there is an upward or downward trend of the variable of interest over time. In each case, the trend analysis was conducted using the available data series from 2007 to 2013. The Mann-Kendall test was performed on data sets where at least four data points were available. To identify potentially significant trends, the trend analysis data was filtered using the probability of the trend: a probability of 95% or greater was used as the first level of screening, based on the statistical convention of $p < 0.05$ for rejection of the null hypothesis of "no trend".

1.3.2 Outliers Assessment

High outliers were reviewed for each sample group. High outliers were defined as data points which exist at three times the interquartile range (IQR) of the data set above the 75th percentile (> P75+3*IQR) for one of the analyzed parameters (AMSRP 2008). The IQR is the 75th percentile minus the 25th percentile (P75-P25).

Samples detected as high outliers were reassessed by checking against the borehole log, location, other samples from the location, typographical error, and laboratory error. Samples deemed to be not impacted (false outliers) were still considered for the calculation of background statistical values while real outliers (potentially impacted or not reliable) were removed.

1.3.3 Statistical Analysis of Data

One of the key aspects of the statistical calculations is the method of dealing with results reported below the laboratory method detection limit (MDL), which is a frequent occurrence with some of the dissolved trace metals and hydrocarbons in particular. In order to calculate statistical values, a real number is required rather than a "less than" result. In the background statistical calculations analytical results reported below the MDL were conservatively considered as real numbers at the MDL value.

A geometric mean, minimum, maximum, and 95th percentile value for each parameter of interest was determined for each of the soil, bedrock and groundwater groups of interest. The source data used for statistical analyses are included in Tables 9 through 15.

2. Summary of Key Findings

2.1 Soil Statistical Background

Based on the review of the available statistical background data, the following general trends were inferred from data summarized on Table 3:

- Concentrations of one or more metals/trace elements (As, Mo, Ni, Se and Tl) exceeding CCME Industrial use guidelines have been confirmed in background organic surface soil and mineral subsurface soil on the Mainland.
- Above guideline SAR values have been measured/calculated for a limited number of mineral subsurface soil samples on the Mainland.
- In the Island soils, background metals concentrations in surface mineral soil are typically below CCME Parkland use guidelines. However, Mo may be present at concentrations above guidelines in the subsurface soil.
- EC levels above CCME Parkland use guidelines (2 dS/m) may be present in both organic and mineral soil on the Islands. The EC is typically associated with concentrations of sulphate, calcium and magnesium ions (considered to be naturally occurring) rather than chloride (considered to be an indicator of industrial activities).
- One or more BTEX and PHC F1 through F4 parameter concentrations above detection limits but generally below CCME guidelines have been reported in all strata and may be associated with organic matter and/or hydrocarbon seeps at the bedrock/soil interface, particularly in close proximity to the Mackenzie River.
- Background data sets for the organic and mineral surface soil on the Islands and natural seeps areas on the Mainland are limited and should be interpreted/referenced with caution.

2.2 Bedrock Statistical Background

General trends in bedrock geochemistry are based on a limited data set, and the following conclusions are derived from the data in Table 3:

- Concentrations of one or more metals/trace elements (As and Ni) exceeding CCME Industrial use guidelines have been confirmed in siltstone bedrock on the Mainland.
- Concentrations of As, Mo, Se and Tl exceeding CCME Industrial use guidelines have also been confirmed in shale bedrock samples collected from the Town of Norman Wells quarry. This shale material is used as fill throughout the Site and the adjacent Town.
- Above CCME Industrial use guideline SAR values have been measured/calculated for a limited number of siltstone bedrock samples from the Mainland.
- Background data sets for the bedrock are limited and should be interpreted/referenced with caution.

2.3 Groundwater Statistical Background

In terms of groundwater geochemistry, key characteristics noted for groundwater background locations in surficial sediments on both the Mainland and Islands areas are summarized below. Characteristics related to natural seepage areas are considered separately in Section 2.4 below:

- nitrate, nitrite and phenols levels were close to or exceeded the applied CCME Freshwater Aquatic Life (FWAL) guidelines in the near surface groundwater (Table 5);
- concentrations of several metals/trace elements (As, Cd, Cu, Fe, Pb, Hg, Se, Ag, Tl, U, Zn) exceeding CCME FWAL guidelines have been confirmed in shallow groundwater at Mainland locations (Table 6);
- at Islands background locations, a shorter list of metals/trace elements with groundwater concentrations exceeding CCME FWAL guidelines (Cd, Cu, Fe, U) is identified (Table 6);
- concentrations of PHC and/or PAH parameters are generally non-detectable in shallow groundwater background locations on the Islands and at Mainland locations which are not identified as natural seepage zones (Tables 7, 8).

2.4 Natural Seepage Zones Statistical Background

General trends in soil and bedrock geochemistry for natural seeps areas are based on a limited data set, and include the following preliminary conclusions as summarized in Table 4:

- Soil/bedrock concentrations of one or more metals/trace elements (As and Ni) exceeding CCME Industrial use guidelines have been confirmed in natural seeps organic surface soil and mineral subsurface soil and/or bedrock on the Mainland.
- One or more natural seeps soil samples contained concentrations of benzene, PHC F1, PHC F2, PHC F3, and/or select PAHs (fluorene, naphthalene, phenanthrene) exceeding CCME guidelines for industrial and/or parkland use. Hydrocarbon concentrations appear to increase with depth in the natural seep areas.
- SAR levels in one or more natural seep mineral subsurface soil samples exceeded CCME parkland use guidelines.

In terms of groundwater geochemistry, key characteristics noted for the natural seepage zones are summarized below:

- chloride and phenols levels exceeded the applied CCME FWAL guidelines in the natural oil seeps in both upper bedrock and surficial sediments (Table 5);
- seeps identified as related to natural gas without saline water also exceeded the phenols guideline, but had chloride levels more typical of background non-seep surficial sediments (Table 5);
- concentrations of several metals/trace elements (Al, As, Cd, Cu, Fe, Pb, Hg, Se, Tl, U, Zn) exceeding CCME FWAL guidelines have been confirmed in groundwater near natural oil and gas seeps from both upper bedrock and surficial sediments (Table 6); and
- concentrations of several PHC and PAH parameters are detected in groundwater near natural oil and gas seeps, with toluene, anthracene, benzo(a)anthracene, benzo(a)pyrene, fluoranthene, naphthalene,

phenanthrene and pyrene exceeding CCME FWAL guidelines based on the statistical analyses. Benzene may also exceed the applied guideline in the inferred natural gas seeps but is generally lower in the oil-related seeps (Tables 7 and 8).

3. References

AMSRP (Abandoned Military Site Remediation Protocol), 2008. Abandoned Military Site Remediation Protocol. Vol II – Technical Supporting Documentation. Indian and Northern Affairs Canada (INAC) Contaminated Site Program. December 2008.

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Figures

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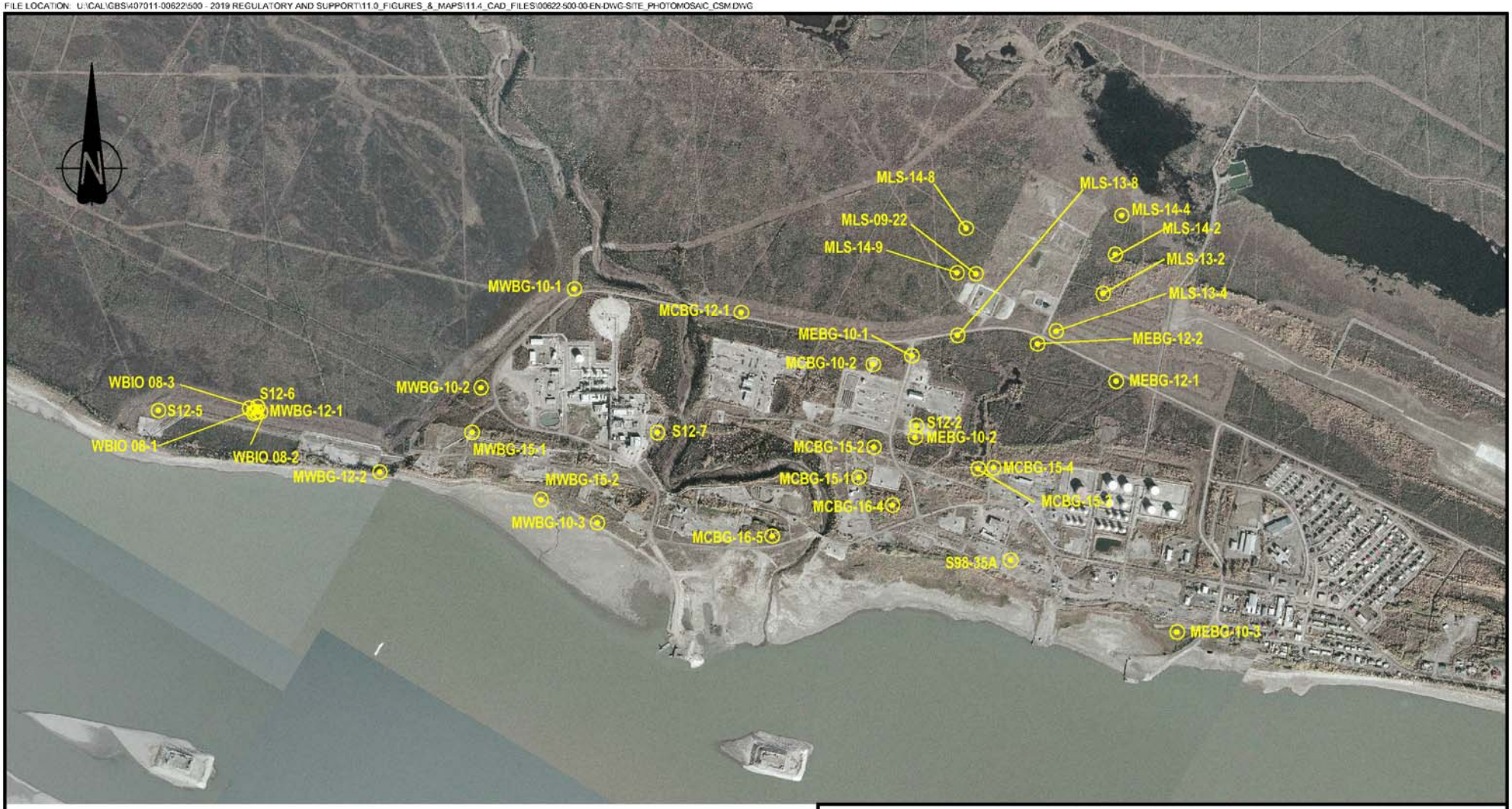

LEGEND

- BACKGROUND SOIL/BEDROCK SAMPLE LOCATION

NAD27 UTM ZONE 9N

m 0 500 1000 m

1:20000

IMPERIAL

APPENDIX 3 - BACKGROUND GEOCHEMICAL STATISTICAL SUMMARY

NORMAN WELLS, NT

BACKGROUND SOIL/BEDROCK SAMPLING LOCATIONS (MAINLAND)

Date:	Drawn by:	Edited by:	App'd by:
01-MAY-19	MYT	B.M.F.	

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FIG No 1

REV A

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LEGEND

- BACKGROUND SOIL/BEDROCK SAMPLE LOCATION

NAD27 UTM ZONE 9N

m 0 500 1000 2500 m

1:50000

IMPERIAL

APPENDIX 3 - BACKGROUND GEOCHEMICAL STATISTICAL SUMMARY

NORMAN WELLS, NT

BACKGROUND SOIL/BEDROCK SAMPLING LOCATIONS (ALL AREAS)

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FIG No 2 REV A

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LEGEND

- BACKGROUND MONITORING WELL LOCATION

NAD27 UTM ZONE 9N

m 0 500 1000 m

1:20000

IMPERIAL

APPENDIX 3 - BACKGROUND GEOCHEMICAL STATISTICAL SUMMARY

NORMAN WELLS, NT

BACKGROUND MONITORING WELL LOCATIONS (MAINLAND)

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FIG No: 3 REV: A

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LEGEND

- BACKGROUND MONITORING WELL LOCATION

NAD27 UTM ZONE 9N

m 0 500 1000 1500 m

1:25000

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APPENDIX 3 - BACKGROUND GEOCHEMICAL STATISTICAL SUMMARY

NORMAN WELLS, NT

BACKGROUND MONITORING WELL LOCATIONS (ISLANDS)

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FIG No: 4

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Tables

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Table 1
Background Soil / Bedrock Locations (1998-2019)

AREA	LOCATIONS							
	Organic Surface Soil		*Mineral Surface Soil*		*Mineral Subsurface Soil*		*Bedrock*	
	Borehole ID	Sample Depths	Borehole ID	Sample Depths	Borehole ID	Sample Depths	Borehole ID	Sample Depth
Mainland	P98-35A	0.0-0.15 m	MCBG-12-1	0.1-0.5 m	CLAY PIT#1	Surface	**SILTSTONE**	
	MCBG-10-02	0.3-0.6 m	MLS-09-22	0.0-0.4 m	CLAY PIT#2	Surface	MEBG-12-2	3.5-4.0 m
	MEBG-10-01	0.0-0.3 m	MWBG-12-2	0.3-0.6 m	A45X OVERBURDEN 1	Surface	MWBG-10-01	2.4-2.7 m
	MEBG-12-1	0.0-0.3 m	S12-2D	0.3-0.35 m	A45X OVERBURDEN 2	Surface	MWBG-12-2	2.0-2.2 m
	MEBG-12-2	0.2-0.5 m	S12-2E	0.3-0.35 m	WBIO 08-1	0.76-1.5, 2.3-3.0 m	MLS-13-4	2.0-2.2 m; 2.8-3.0 m
	MWBG-10-01	0.0-0.3 m	S12-2F	0.3-0.35 m	WBIO 08-2	0.76-1.5, 2.3-3.0 m	MLS-14-4	3.0 m
	MWBG-10-02	0.0-0.3 m	S12-5D	0.5-0.6 m	WBIO 08-3	0.76-1.5, 3.0-3.8 m	MLS-14-8	3.0 m
	MWBG-12-1	0.0-0.4 m	S12-6D	0.1-0.2; 0.3-0.4 m	MCBG-10-02	0.6-1.0 m; 1.5-2.0 m	MLS-14-9	3.0 m
	S12-2D	0.15-0.3 m	S12-6E	0.1-0.2; 0.3-0.4 m	MCBG-12-1	0.6-0.9 m; 1.0-1.5 m; 1.7-2.1 m	MWBG-15-2	2.4-3.0 m
	S12-2E	0.15-0.3 m	S12-6F	0.1-0.2; 0.3-0.4 m	MEBG-10-01	0.3-0.6 m; 0.6-1.0 m; 2.5-3.0 m	MLS-14-2	2-2.5 m
	S12-2F	0.15-0.3 m	MCBG-15-2	0.1-0.3 m	MEBG-10-2	0.3-0.6 m; 0.6-1.0 m; 1.8-2.3 m; 2.5-3.0 m	P98-35A	2.0-3.0 m
	S12-5D	0.1-0.2 m	MWBG-15-1	0.1-0.3 m	MEBG-12-1	1.5-2.0 m; 3.0-3.4 m		
	MLS-13-8	0.5-0.7 m	MWBG-10-01	0.3-0.6 m	MEBG-12-2	1.0-1.5 m; 2.0-2.5 m		
	MLS-14-4	1.0 m	MWBG-10-02	0.3-0.6 m	MWBG-10-01	0.6-1.0 m		
	MWBG-15-1	0.0-0.1 m	MLS-14-2	1 m	MWBG-10-02	0.6-1.0 m; 2.4-2.7 m		
	MCBG-15-2	0.0-0.1 m			MLS-09-22	1.0-1.3 m		
	MEBG-10-2	0.0-0.3 m			MWBG-12-1	0.4-0.8 m; 1.5-2.0 m		
					MLS-13-2	1.5-1.7 m; 2.0-2.2 m		
					MLS-13-4	1.2-1.5 m	**SHALE**	
					MLS-13-8	1.3-1.5 m; 2.8-3.0 m	S12-Quarry 1	Surface
					MLS-14-4	2.0 m	S12-Quarry 2	Surface
					MLS-14-8	1.0 m; 2.0 m	S12-Quarry 3	Surface
					MLS-14-9	1.0 m; 2.0 m	SHALE-1	Surface
					MCBG-15-2	0.3-0.5 m; 2.4-3.0 m		
					MWBG-15-1	0.3-0.8 m; 1.8-2.4 m		
					MLS-14-2	2 m		
					MCBG-16-4	0.7-1.1 m; 2.4-3.0 m; 4.0-4.5 m		
					MEBG-16-5	0.6-1.2 m; 2.5-3.0 m; 4.2-4.8 m		
Mainland Natural Seepage Zones	MEBG-10-3	0.0-0.3 m	MCBG-15-1	0.1-0.3 m; 0.3-0.5 m	MWBG-10-03	0.6-1.0; 2.2-2.7 m; 4.0-4.5 m	MCBG-15-1	4.2-4.8 m
	MCBG-15-1	0.0-0.1 m	MWBG-10-03	0.0-0.3 m; 0.3-0.6 m	MEBG-15-3	0.5-1.2 m; 2.4-3.0 m	MEBG-10-3	0.3-0.6 m; 0.6-1.0 m; 2.5-3.0 m
	MEBG-15-3	0.0-0.1 m	MEBG-15-3	0.1-0.5 m	MEBG-15-4	0.5-0.8 m; 1.8-2.4 m		
	MEBG-15-4	0.0-0.2 m	MEBG-15-4	0.2-0.5 m	MWBG-15-2	2.4-3.0 m		
			MWBG-15-2	0.0-0.15 m; 0.15-0.6 m				
Bear / Frenchy's/Goose Islands	BI 08-01	0.0-0.3 m	BIBG-10-3	0.0-0.3 m	BI 08-01	0.8-1.2 m; 2.0-2.4 m	NA	NA
	BIBG-15-1	0.0-0.05 m; 0.05-0.4 m	BIBG-10-2	0.0-0.3 m	BIBG-10-3	0.3-0.6 m; 0.6-1.0 m; 1.8-2.1 m; 4.2-4.5 m		
	BIBG-15-2	0.0-0.4 m	FIBG-10-1	0.0-0.3 m	BIBG-10-2	0.3-0.6 m; 0.6-1.0 m; 2.5-3.0 m; 4.0-4.5 m		
	BIBG-15-3	0.0-0.2 m	GIBG-10-1	0.0-0.3 m	BIBG-10-1	0.9-1.2 m; 1.2-1.5 m; 1.5-1.8 m; 4.0-4.3 m		
			GIBG-10-2	0.0-0.3 m	BIBG-12-1	0.5-0.8 m; 2.7-3.0 m; 4.2-4.5 m; 6.0-6.5 m; 7.0-7.5 m		
			S12-8D	0.1-0.2 m	BIBG-12-2	1.0-1.5 m; 3.5-4.0 m; 4.5-5.0 m		
			S12-9D	0.2-0.3 m	FIBG-10-1	0.3-0.6 m; 0.6-1.0 m; 2.3-2.8 m		
			BIBG-15-1	0.4-0.8 m	GIBG-10-1	0.3-0.6 m; 0.6-1.0 m; 2.5-3.0 m		
			BIBG-15-2	0.4-0.8 m	GIBG-10-2	0.3-0.6 m; 0.6-1.0 m; 1.8-2.3 m; 3.0-3.3 m		
			BIBG-15-3	0.2-0.5 m	S12-8D	0.5-0.6 m		
			GIBG-15-13	0.6 m	BIBG-15-1	1.8-2.4 m		
			GIBG-15-14	0.3 m	BIBG-15-2	1.8-2.4 m		
			GIBG-15-15	1.0 m	BIBG-15-3	0.5-1.0 m		
			GIBG-15-16	0.3 m	BIBG-15-3	1.8-2.4 m		
					GIBG-15-13	0.8 m; 4.8 m		
					GIBG-15-14	1.8 m; 3.6 m		
					GIBG-15-15	3.5 m		
					GIBG-15-16	1.8 m; 3.2 m		
					BIBG-16-12	1.0-1.3 m		

Notes:
NA = not applicable. No bedrock or seeps observed/sampled on Natural Islands.

Table 2
Background Groundwater Sampling Locations (1997-2019)

Monitoring Well	Original Location Code (soil borehole / piezometer)	Depth Interval of Sandpack (m bgs)	Hydrogeologic Unit	Lithology Within Screened Interval
Background – Surficial Sediments - Not Associated with Natural Seepage Zones				
Mainland Locations - Surficial Sediments				
B38 93-2-4	B38 93-2-4	less than 4 m	Surficial sediment	no borehole log
BT3 97-2-5	BT3 97-2-5	1.10 - 4.60	Surficial sediment	Silt
MCBG-10-1-3	MCBG-10-02 / 10-1-3	0.80 - 2.50	Surficial sediment	Clayey Silt / Peat / Silty Clay
MCBG-12-1-2	MCBG-12-1 / BH-12-1-2	0.50 - 3.00	Surficial sediment	Topsoil, Sand, Silty Clay
MEBG-10-1-3	MEBG-10-2 / 10-1-3	1.00 - 3.00	Surficial sediment	Silty Sand / Clayey Silt
MEBG-12-2-3	MEBG-12-2 / 12-2-3	0.80 - 3.00	Surficial sediment	Silty Clay and Bedrock
MLS 09-6-2	MLS 09-06-2	0.80 - 2.20	Surficial sediment	Silty clay and bedrock
MLS-13-9-3	MLS-13-9 / MLS-13-9-3	0.90 - 2.40	Surficial sediment	
MLS-14-3-3	MLS14-3 / MLS-14-3-3	1.50 - 3.00	Surficial sediment	Silt
MLS-14-4-3	MLS14-4 / MLS-14-4-3	1.50 - 3.00	Surficial sediment	Clayey silt, silt and gravel
MLS-14-8-3	MLS14-8 / MLS-14-8-3	1.50 - 3.00	Surficial sediment	Clayey silt
MWBG-10-1-3	MWBG-10-02 / 10-1-3	0.80 - 2.70	Surficial sediment	Silt / Clay
MWBG-12-1-3	MWBG-12-2 / 12-1-3	1.20 - 3.00	Surficial sediment	Silt and Siltstone
WBIO 08-1-2	WBIO 08-1-2	0.60 - 2.40	Surficial sediment	Sandy clay / Silty sand
Bear and Frenchy's Island Locations - Surficial Sediments				
BI 08-1-4	BI 08-1-4	0.60 - 2.40	Surficial sediment	Silty clay
BI-13-6-2	BI-13-6 / 13-6-2.4	0.60 - 2.70	Surficial sediment	Silt and Clayey silt
BI-14-8-3	BI-14-8 / 14-8-3	1.66 - 3.16	Surficial sediment	Silty clay
BIBG-10-1-4	BIBG-10-3 / 10-1-4	0.78 - 4.10	Surficial sediment	Silty Clay / Sand
BIBG-10-2-4	BIBG-10-2 / 10-2-4	0.50 - 3.77	Surficial sediment	Sand
BIBG-12-1-7	BIBG-12-1 / 12-1-7	3.80 - 7.50	Surficial sediment	Silty Sand / Sandy Silt
BIBG-12-2-4	BIBG-12-02 / 12-2-4	0.70 - 4.20	Surficial sediment	Silty Clay / Sandy Silt
FIBG-10-1-4	FIBG-10-1 / 10-1-4	0.69 - 3.97	Surficial sediment	Silty Clay / Sand
Goose Island Locations - Surficial Sediments				
GIBG-10-1-5	GIBG-10-1 / 10-1-5	1.20 - 4.50	Surficial sediment	Sandy Silt
GIBG-10-2-3	GIBG-10-2 / 10-2-3	1.30 - 3.00	Surficial sediment	Sand

Monitoring Well	Original Location Code (soil borehole / piezometer)	Depth Interval of Sandpack (m bgs)	Hydrogeologic Unit	Lithology Within Screened Interval
Background – Surficial Sediments and Bedrock - Associated with Natural Seepage Zones				
Background – Shallow Bedrock - Inferred to Represent Natural Hydrocarbon and Saline Water Seepage				
NWR 98-18-15	NWR 98-18-15	11.00 - 14.70	Shallow bedrock	Siltstone
NWR 99-16-17	NWR 99-16-17	12.60 - 17.00	Shallow bedrock	Siltstone
RB 02-3-2	RB 02-3-2	0.60 - 3.30	Shallow bedrock	Siltstone / Shale
NWR-09-1-20	NWR-09-1-20	16.50 - 20.00	Shallow bedrock	Shale / Siltstone / Sandstone
NWR-09-3-20	NWR-09-3-20	16.10 - 20.20	Shallow bedrock	Sandstone
NWR-09-4-17	NWR-09-4-17	15.24 - 17.30	Shallow bedrock	Siltstone
BT3-99-21-12	BT3-99-21-12	8.50 - 12.20	Shallow bedrock	Siltstone
Background – Surficial Sediments - Inferred to Represent Natural Hydrocarbon and Saline Water Seepage				
NWR 03-38-3	NWR 03-38-3	0.50 - 3.00	Surficial sediment	Sand and clay
RB-13-2-2.4	RB-13-2 / RB-13-2-2.4	0.60 - 2.55	Surficial sediment	Gravelly Sand and Clay
RB-13-4-3	RB-13-4 / RB-13-4-3	1.20 - 3.30	Surficial sediment	Sandy Gravel
RB-13-5-2.4	RB-13-5 / RB-13-5-2.4	0.60 - 2.55	Surficial sediment	Sandy Clay and Siltstone
RB-13-8-1.5	RB-13-8 / RB-13-8-1.5	0.16 - 1.50	Surficial sediment	Sandy Clay
Background – Surficial Sediments - Inferred to Represent Natural Gas Seepage Without Saline Water				
MEBG-15-4-3	MEBG-15-4	1.50 - 3.60	Surficial sediment	Silty Clay
MLS-14-2-3	MLS14-2 / MLS-14-2-3	1.00 - 2.50	Surficial sediment	Silty Clay and Siltstone
B38 02-33-3	B38X-02-2 / B38X 02-33-3	1.10 - 3.10	Surficial sediment	Sandy Silt
B38 02-34-3	B38X-02-3 / B38X 02-34-3	1.50 - 3.50	Surficial sediment	Clayey Silt

Table 3
Soil and Bedrock Background Geochemical Statistical Summary (1998-2019)

Background Geochemical Statistics for Soil and Bedrock: Salinity Parameters

Imperial - Norman Wells

	pH (pH units)	EC (dS/m)	SAR (ratio)
CCME Residential/Parkland Fine Surface (Islands)	6 - 8	2	5
CCME Industrial Fine Surface (Mainland)	6 - 8	4	12
95th Percentile Background - Organic Surface Soil (Mainland)	7.52	1.13	1.38
Maximum Background - Organic Surface Soil (Mainland)	7.57	1.5	1.5
95th Percentile Background - Organic Surface Soil (Islands)	7.83	2.9	0.7
Maximum Background - Organic Surface Soil (Islands)	7.9	3.3	0.75
95th Percentile Background - Mineral Surface Soil (Mainland)	7.49	0.71	1.65
Maximum Background - Mineral Surface Soil (Mainland)	7.61	0.73	2
95th Percentile Background - Mineral Surface Soil (Islands)	7.76	2.9	1.04
Maximum Background - Mineral Surface Soil (Islands)	7.77	2.9	1.4
95th Percentile Background - Mineral Subsurface Soil (Mainland)	8.04	1.91	5.68
Maximum Background - Mineral Subsurface Soil (Mainland)	8.1	2.4	22
95th Percentile Background - Mineral Subsurface Soil (Islands)	7.76	2.5	0.64
Maximum Background - Mineral Subsurface Soil (Islands)	7.81	2.9	1.1
95th Percentile Background - Bedrock (Mainland Siltstone)	7.67	1.52	22.85
Maximum Background - Bedrock (Mainland Siltstone)	7.72	1.26	26
95th Percentile Background - Bedrock (Mainland Shale)	NC	NC	NC
Maximum Background - Bedrock (Mainland Shale)	NC	NC	NC

NA	Denotes guideline not available
NC	Denotes parameters not measured / not calculated
	Shading indicates parameters above most restrictive guidelines selected

Background Geochemical Statistics for Soil and Bedrock: Metals and Trace Elements

Imperial - Norman Wells

	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water Soluble) (mg/kg)	Cadmium (mg/kg)	Chromium (6+) (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
CCME Residential/Parkland Fine Surface (Islands)	20	12	500	4	---	10	0.4	64	50	63	140	6.6	10	50	1	1	23	130	200
CCME Industrial Fine Surface (Mainland)	40	12	2000	8	---	22	1.4	87	300	91	600	50	40	50	2.9	1	300	130	360
95th Percentile Background - Organic Surface Soil (Mainland)	2	9.05	471	0.83	2.64	1.01	0.15	51	10.7	22.7	12	0.13	17.2	33.8	1.62	1.26	4.2	45.7	90.2
Maximum Background - Organic Surface Soil (Mainland)	2	11	515	0.9	3	1.03	0.15	86.4	12	26	14	0.14	44	39	2.7	2.5	4.5	47	100
95th Percentile Background - Organic Surface Soil (Islands)	1	9.7	356	0.8	0.45	0.94	0.14	16.4	8.9	20.6	10.6	0.1	2.1	28.2	1	0.36	0.8	26.2	116
Maximum Background - Organic Surface Soil (Islands)	1	10	380	0.8	0.45	1	0.15	17	9	21	11	0.1	2.2	29	1	0.4	0.9	27	120
95th Percentile Background - Mineral Surface Soil (Mainland)	1	12.6	397	0.84	1.13	0.89	0.15	29.8	14	26	13.2	0.08	2.6	41.6	0.89	0.3	1.5	46.1	142
Maximum Background - Mineral Surface Soil (Mainland)	1	19	402	0.87	1.2	1.09	0.15	37	18	35	14	0.09	2.8	56	0.9	0.3	1.9	50	150
95th Percentile Background - Mineral Surface Soil (Islands)	1	8.8	353	0.62	0.31	0.9	0.15	21.5	9.54	21.8	12.6	0.07	3.2	29.6	0.88	0.3	1	29.4	108.5
Maximum Background - Mineral Surface Soil (Islands)	1	9.4	360	0.63	0.31	1.32	0.15	30	9.8	23	13.9	0.08	4.1	32	1.01	0.3	1.2	29.5	140
95th Percentile Background - Mineral Subsurface Soil (Mainland)	1	25.2	398	1.06	1.86	0.89	0.18	35	18.9	37.8	18.4	0.11	5.58	60.4	1.28	0.7	2	48.6	148
Maximum Background - Mineral Subsurface Soil (Mainland)	2	49	660	1.4	3.7	2	0.3	39	24.7	45	25.6	0.33	11	127	2.7	1	2.3	66	350
95th Percentile Background - Mineral Subsurface Soil (Islands)	1	9.25	368	0.6	0.52	0.7	0.15	18	9.4	22.9	11	0.06	2.4	29.9	0.8	0.3	1	30	99.9
Maximum Background - Mineral Subsurface Soil (Islands)	2	9.9	408	0.8	0.58	0.9	0.15	20	10	25	12	0.1	14	31	1	1	2	36	120
95th Percentile Background - Bedrock (Mainland Siltstone)	1	23.8	454	0.93	3	0.12	0.15	41.8	21.8	50	14.8	0.11	0.74	63.2	0.5	0.3	1	62.2	148
Maximum Background - Bedrock (Mainland Siltstone)	1	24	500	0.95	3.1	0.12	0.15	42	22	53	15	0.12	0.81	64	0.5	0.3	1	64	150
95th Percentile Background - Bedrock (Mainland Shale)	NC	39.6	NC	0.65	NC	0.74	NC	51.2	6.97	42.5	10.8	0.284	64.7	49.2	7.56	2.29	NC	125.7	106.2
Maximum Background - Bedrock (Mainland Shale)	NC	42.9	NC	0.66	NC	0.82	NC	53.6	7.16	43.6	11	0.312	66.4	49.6	7.9	2.33	NC	129	108

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Table 3
Soil and Bedrock Background Geochemical Statistical Summary (1998-2019)

Background Geochemical Statistics for Soil and Bedrock: Petroleum Hydrocarbon Parameters

Imperial - Norman Wells

	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes (Total) (mg/kg)	PHC-F1 (-BTEX) (mg/kg)	PHC-F2 (mg/kg)	PHC-F3 (mg/kg)	PHC-F4 (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo(a)anthracene (mg/kg)	Benzo(a)pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
CCME Residential/Parkland Fine Surface (Islands)	2.1	110	120	65	210	150	1300	5600	0.28	320	2.5	1	0.6	1	6.2	1	15.4	0.25	1	0.013	0.046	7.7
CCME Industrial Fine Surface (Mainland)	2.8	330	430	230	320	260	2500	6600	0.28	320	32	10	72	10	NA	10	180	0.25	10	0.013	0.046	100
95th Percentile Background - Organic Surface Soil (Mainland)	0.018	0.073	0.036	0.144	43.3	111.5	831.5	195.5	0.016	0.016	0.012	0.02	0.02	0.02	0.15	0.0158	0.0196	0.026	0.0196	0.0226	0.3224	0.0476
Maximum Background - Organic Surface Soil (Mainland)	0.019	0.076	0.038	0.15	45	150	1200	200	0.019	0.019	0.015	0.02	0.02	0.02	0.23	0.019	0.02	0.03	0.02	0.025	0.52	0.066
95th Percentile Background - Organic Surface Soil (Islands)	0.0234	0.0704	0.0436	0.288	25.2	41.2	422	157	0.005	0.005	0.004	0.005	0.005	0.0145	0.008	0.005	0.0078	0.0069	0.005	0.0301	0.035	0.0135
Maximum Background - Organic Surface Soil (Islands)	0.028	0.083	0.052	0.35	27	44	440	160	0.005	0.005	0.004	0.005	0.005	0.015	0.008	0.005	0.0083	0.0072	0.005	0.033	0.037	0.014
95th Percentile Background - Mineral Surface Soil (Mainland)	0.011	0.044	0.022	0.088	14.1	33.8	277	118	0.005	0.005	0.004	0.01	0.01	0.014	0.01	0.005	0.01	0.018	0.01	0.0117	0.0289	0.0134
Maximum Background - Mineral Surface Soil (Mainland)	0.012	0.046	0.023	0.092	15	38	310	120	0.005	0.005	0.004	0.01	0.01	0.015	0.01	0.005	0.01	0.019	0.01	0.012	0.031	0.014
95th Percentile Background - Mineral Surface Soil (Islands)	0.0182	0.0656	0.047	0.34	29.2	43.8	274	90	0.005	0.005	0.004	0.008	0.008	0.0255	0.0176	0.007	0.012	0.01	0.011	0.0395	0.0379	0.0192
Maximum Background - Mineral Surface Soil (Islands)	0.038	0.095	0.089	0.72	52	72	370	96	0.005	0.005	0.004	0.009	0.009	0.029	0.019	0.008	0.014	0.011	0.012	0.05	0.04	0.021
95th Percentile Background - Mineral Subsurface Soil (Mainland)	0.015	0.02	0.016	0.081	18.3	83.7	536.5	209.5	0.006	0.006	0.004	0.006	0.009	0.022	0.025	0.006	0.011	0.013	0.01	0.018	0.045	0.02
Maximum Background - Mineral Subsurface Soil (Mainland)	0.02	0.18	0.059	0.34	42	180	1800	830	0.01	0.01	0.004	0.01	0.01	0.027	0.026	0.01	0.012	0.03	0.01	0.022	0.063	0.022
95th Percentile Background - Mineral Subsurface Soil (Islands)	0.005	0.02	0.01	0.04	15.5	27	207	86	0.005	0.005	0.004	0.005	0.005	0.019	0.034	0.005	0.008	0.005	0.0064	0.025	0.059	0.0164
Maximum Background - Mineral Subsurface Soil (Islands)	0.02	0.048	0.021	0.04	30	79	380	96	0.005	0.005	0.004	0.005	0.005	0.02	0.059	0.005	0.008	0.005	0.009	0.028	0.11	0.019
95th Percentile Background - Bedrock (Mainland)	0.0775	0.4	0.96	6.08	96.8	825.5	1265	288	0.034	0.023	0.004	0.023	0.0065	0.027	0.122	0.007	0.014	0.236	0.005	0.048	0.771	0.08
Maximum Background - Bedrock (Mainland)	0.15	0.78	1.9	12.1	140	920	1400	410	0.037	0.025	0.004	0.025	0.0067	0.027	0.13	0.007	0.014	0.26	0.005	0.05	0.83	0.086

Table 4

Natural Seeps Soil and Bedrock Background Geochemical Statistical Summary (1998-2019)

Background Geochemical Statistics for Natural Seeps Soil and Bedrock: Salinity Parameters

Imperial - Norman Wells

	pH (pH units)	EC (dS/m)	SAR (ratio)
CCME Industrial Fine Surface	6 - 8	4	12
95th Percentile Background - Organic Surface Soil (Mainland)	7.45	1.32	1.27
Maximum Background - Organic Surface Soil (Mainland)	7.49	1.4	1.4
95th Percentile Background - Mineral Surface Soil (Mainland)	7.72	0.79	0.64
Maximum Background - Mineral Surface Soil (Mainland)	7.72	0.8	0.7
95th Percentile Background - Mineral Subsurface Soil (Mainland)	7.78	0.98	7.28
Maximum Background - Mineral Subsurface Soil (Mainland)	7.8	1.1	11
95th Percentile Background - Bedrock (Mainland Siltstone)	7.75	0.9	2.84
Maximum Background - Bedrock (Mainland Siltstone)	7.78	0.97	2.9

NA Denotes guideline not available
NC Denotes parameters not measured / not calculated
Shading indicates parameters above most restrictive guidelines selected

Background Geochemical Statistics for Natural Seeps Soil and Bedrock: Metals and Trace Elements

Imperial - Norman Wells

	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water Soluble) (mg/kg)	Cadmium (mg/kg)	Chromium (6+) (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
CCME Industrial Fine Surface	40	12	2000	8	---	22	1.4	87	300	91	600	50	40	50	2.9	1	300	130	360
95th Percentile Background - Organic Surface Soil (Mainland)	1	10.4	476.5	0.8	3.1	1.35	0.14	29.5	14.4	23.7	20.7	0.11	12.5	45.1	1.08	0.55	2.83	43	127
Maximum Background - Organic Surface Soil (Mainland)	1	11	520	0.8	3.5	1.5	0.15	33	16	24	21	0.11	14	49	1.1	0.6	3	46	130
95th Percentile Background - Mineral Surface Soil (Mainland)	1	11.6	419.5	0.83	0.68	0.9	0.15	23.55	10.3	18.6	13.6	0.08	2.23	29.6	0.91	0.3	1.6	41.8	113
Maximum Background - Mineral Surface Soil (Mainland)	1	13	430	0.85	0.7	1.1	0.15	26	11	19	14	0.1	2.3	31	1	0.3	1.6	46	120
95th Percentile Background - Mineral Subsurface Soil (Mainland)	1	20.2	360	0.87	1.65	0.96	0.15	33.6	17.4	41.8	15.4	0.05	2.84	52.2	0.98	0.3	1.28	46.8	154
Maximum Background - Mineral Subsurface Soil (Mainland)	1	25	380	0.99	2.3	1.2	0.15	42	21	49	17	0.05	3	63	1.1	0.3	1.4	54	170
95th Percentile Background - Bedrock (Mainland Siltstone)	1	21	194	0.61	1.2	0.1	0.15	36.4	18.7	30.1	11	0.076	0.4	55.1	0.5	0.3	1	86.8	135.5
Maximum Background - Bedrock (Mainland Siltstone)	1	21	200	0.65	1.2	0.1	0.15	37	19	31	11	0.08	0.4	56	0.5	0.3	1	94	140

Table 4

Natural Seeps Soil and Bedrock Background Geochemical Statistical Summary (1998-2019)

Background Geochemical Statistics for Natural Seeps Soil and Bedrock: Petroleum Hydrocarbon Parameters

Imperial - Norman Wells

	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes (Total) (mg/kg)	PHC-F1 (-BTEX) (mg/kg)	PHC-F2 (mg/kg)	PHC-F3 (mg/kg)	PHC-F4 (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo(a)anthracene (mg/kg)	Benzo(a)pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
CCME Industrial Fine Surface	2.8	330	430	230	320	260	2500	6600	0.28	320	32	10	72	10	NA	10	180	0.25	10	0.013	0.046	100
95th Percentile Background - Organic Surface Soil (Mainland)	0.011	0.044	0.022	0.09	18	150.7	4645	3019	0.01	0.01	0.008	0.01	0.0117	0.029	0.121	0.0117	0.011	0.0117	0.011	0.015	0.254	0.019
Maximum Background - Organic Surface Soil (Mainland)	0.011	0.044	0.022	0.09	19	160	5200	3400	0.01	0.01	0.008	0.01	0.012	0.032	0.14	0.012	0.011	0.012	0.011	0.016	0.29	0.019
95th Percentile Background - Mineral Surface Soil (Mainland)	0.009	0.037	0.184	0.074	12.6	215.5	4750	3135	0.0165	0.011	0.009	0.013	0.026	0.016	0.107	0.009	0.019	0.017	0.012	0.034	0.045	0.043
Maximum Background - Mineral Surface Soil (Mainland)	0.012	0.046	0.023	0.092	13	240	5100	3800	0.02	0.012	0.01	0.014	0.032	0.017	0.15	0.01	0.024	0.021	0.013	0.047	0.052	0.059
95th Percentile Background - Mineral Subsurface Soil (Mainland)	2.655	0.078	2.96	18.55	973	2706.5	4438.5	1691.5	0.149	0.02	0.004	0.076	0.005	0.065	0.633	0.006	0.034	0.646	0.005	1.386	2.366	0.286
Maximum Background - Mineral Subsurface Soil (Mainland)	2.9	0.097	4.3	21	1400	3900	6500	2500	0.21	0.026	0.004	0.11	0.005	0.091	0.95	0.006	0.048	0.93	0.005	2.1	3.5	0.43
95th Percentile Background - Bedrock (Mainland)	0.034	0.02	0.018	0.06	139.5	1185	2780	1035.5	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Maximum Background - Bedrock (Mainland)	0.039	0.02	0.02	0.063	150	1200	2900	1100	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

Table 5

Groundwater Indicator Parameters - Background Geochemical Statistical Summary (1997-2019)

PROJECT No.: 417011-00096

Monitoring Station	Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
CCME 2015. CEQG Freshwater Aquatic Life	---	---	---	120	---	---	---	3	0.06	(6.5 - 9)	0.004	---	---	---	---	---
Background - Surficial Sediments																
Mainland Locations - Surficial Sediments - 95th Percentile Background	1000	312	1	17	2300	1241	1	0.4	0.03	8.1	0.013	5.2	1.0	161	700	1620
Mainland Locations - Surficial Sediments - Maximum Background	1100	400	5	26	2800	1600	5	36.0	0.11	8.1	0.021	12.0	5.0	180	980	2200
Bear, Goose, and Frenchy's Islands - Surficial Sediments - 95th Percentile Background	975	477	1	23	2600	1600	1	2.4	0.03	8.0	0.014	4.5	1.0	100	930	2255
Bear, Goose, and Frenchy's Islands - Surficial Sediments - Maximum Background	1200	540	1	25	3000	1800	1	23.0	0.17	8.1	0.048	5.3	1.0	520	1200	2700
Background - Shallow Bedrock - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage																
Shallow Bedrock - Natural Saline Water & Oil Seepage - 95th Percentile Background	1570	198	25	715	3397	788	0.5	1.0	0.06	8.5	0.020	7.6	20.5	747	117	2402
Shallow Bedrock - Natural Saline water & Oil Seepage - Maximum Background	1680	474	40	1500	5880	1580	1	4.0	0.26	8.6	0.025	16.8	33.0	848	185	3130
Background - Surficial Sediments - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage																
Surficial Sediments - Natural Saline Water & Oil Seepage - 95th Percentile Background	1220	350	62	280	2780	1200	1	0.2	0.06	8.7	0.020	7.5	51.0	440	990	2015
Surficial Sediments - Natural Saline Water & Oil Seepage - Maximum Background	1300	390	200	291	2800	1300	1	0.4	0.06	10.1	0.023	8.6	160	680	1000	2300
Background - Surficial Sediments - Inferred to Represent Natural Gas Seepage without Saline Water																
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - 95th Percentile Background	876	266	1	12	1384	740	1	0.2	0.06	7.7	0.062	6.9	1.0	47	201	920
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - Maximum Background	950	330	1	13	1600	750	1	0.2	0.10	7.9	0.072	10.0	1.0	72	330	1200

NA Denotes guideline not available
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Table 6

Groundwater Dissolved Metals - Background Geochemical Statistical Summary (1997-2019)

PROJECT No.: 417011-00096

Monitoring Station	Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Uranium (mg/L)	Zinc (mg/L)
CCME 2015, CEQG Freshwater Aquatic Life	**0.1**	**0.005**	**---**	**1.5**	**0.00009**	**0.0089**	**0.004**	**0.3**	**0.007**	**---**	**0.000026**	**0.073**	**0.15**	**0.001**	**0.00025**	**0.0008**	**0.015**	**0.03**
Background - Surficial Sediments																		
Mainland Locations - Surficial Sediments - 95th Percentile Background	0.13	0.01	0.53	0.27	0.00200	0.0070	0.01	6.11	0.023	3.01	0.000288	0.005	0.03	0.002	0.01000	0.0200	0.039	0.03
Mainland Locations - Surficial Sediments - Maximum Background	3.70	0.07	0.88	0.34	0.00200	0.0100	0.02	11.00	0.100	3.66	0.000940	0.005	0.05	0.030	0.01000	0.0300	1.000	0.15
Bear, Goose, and Frenchy's Islands - Surficial Sediments - 95th Percentile Background	0.03	0.00	0.22	0.04	0.00045	0.0010	0.01	7.50	0.001	5.44	0.000003	0.026	0.02	0.001	0.00010	0.0002	0.024	0.03
Bear, Goose, and Frenchy's Islands - Surficial Sediments - Maximum Background	0.05	0.00	0.23	0.09	0.00073	0.0100	0.01	64.00	0.002	10.00	0.000003	0.041	0.04	0.002	0.00100	0.0020	0.082	0.03
Background - Shallow Bedrock - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage																		
Shallow Bedrock - Natural Saline Water & Oil Seepage - 95th Percentile Background	0.34	0.05	8.40	1.33	0.00200	0.0070	0.01	4.08	0.030	0.64	0.000170	0.008	0.02	0.005	0.00021	0.0300	0.079	0.03
Shallow Bedrock - Natural Saline water & Oil Seepage - Maximum Background	5.35	0.07	23.69	1.37	0.00200	0.0070	0.02	12.40	0.100	1.30	0.000580	0.031	0.04	0.030	0.01000	0.0300	1.000	0.21
Background - Surficial Sediments - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage																		
Surficial Sediments - Natural Saline Water & Oil Seepage - 95th Percentile Background	0.07	0.03	1.39	1.13	0.00140	0.0070	0.01	25.00	0.042	2.80	0.000050	0.020	0.02	0.001	0.00015	0.0012	0.411	1.40
Surficial Sediments - Natural Saline Water & Oil Seepage - Maximum Background	0.12	0.04	2.01	1.40	0.00200	0.0070	0.01	28.00	0.100	2.80	0.000050	0.020	0.02	0.002	0.00020	0.0016	1.000	1.70
Background - Surficial Sediments - Inferred to Represent Natural Gas Seepage without Saline Water																		
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - 95th Percentile Background	0.07	0.02	1.53	0.16	0.00102	0.0070	0.01	29.50	0.032	5.99	0.000050	0.006	0.02	0.002	0.00010	0.0008	0.308	0.02
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - Maximum Background	0.16	0.02	2.70	0.28	0.00200	0.0070	0.01	64.00	0.100	6.40	0.000050	0.006	0.03	0.003	0.00021	0.0008	1.000	0.04

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Table 7
Groundwater PHCs - Background Geochemical Statistical Summary (1997-2019)

PROJECT No.: 417011-00096

Monitoring Station	Benzene (mg/L)	Ethylbenzene (mg/L)	PHC F1 (C6-C10) - BTEX (mg/L)	PHC F2 (C10-C16) (mg/L)	Toluene (mg/L)	Xylenes-Total (mg/L)
CCME 2015. CEQG Freshwater Aquatic Life	**0.37**	**0.09**	**---**	**---**	**0.002**	**---**
Background - Surficial Sediments						
Mainland Locations - Surficial Sediments - 95th Percentile Background	0.0005	0.0005	0.10	0.10	0.0005	0.000923
Mainland Locations - Surficial Sediments - Maximum Background	0.0050	0.0050	0.19	0.20	0.0050	0.01
Bear, Goose, and Frenchy's Islands - Surficial Sediments - 95th Percentile Background	0.0004	0.0004	0.10	0.10	0.0004	0.00089
Bear, Goose, and Frenchy's Islands - Surficial Sediments - Maximum Background	0.0004	0.0004	0.10	0.10	0.0004	0.0009
Background - Shallow Bedrock - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage						
Shallow Bedrock - Natural Saline Water & Oil Seepage - 95th Percentile Background	0.0630	0.0025	0.88	28.8	0.0033	0.0100
Shallow Bedrock - Natural Saline water & Oil Seepage - Maximum Background	0.1700	0.0500	3.90	130	0.0500	0.1000
Background - Surficial Sediments - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage						
Surficial Sediments - Natural Saline Water & Oil Seepage - 95th Percentile Background	0.0911	0.0022	0.24	1.60	0.0009	0.0144
Surficial Sediments - Natural Saline Water & Oil Seepage - Maximum Background	0.1000	0.0032	0.60	3.00	0.0014	0.080
Background - Surficial Sediments - Inferred to Represent Natural Gas Seepage without Saline Water						
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - 95th Percentile Background	0.9630	0.0757	1.58	1.90	0.0131	0.3875
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - Maximum Background	1.2500	0.3100	2.20	2.80	0.0250	0.450

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NC Denotes parameters not measured / not calculated
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Table 8
Groundwater PAHs - Background Geochemical Statistical Summary (1997-2019)

PROJECT No.: 417011-00096

Monitoring Station	Acenaphthene (mg/L)	Acridine (mg/L)	Anthracene (mg/L)	Benzo[a]anthracene (mg/L)	Benzo[a]pyrene (mg/L)	Fluoranthene (mg/L)	Fluorene (mg/L)	Naphthalene (mg/L)	Phenanthrene (mg/L)	Pyrene (mg/L)	Quinoline (mg/L)
CCME 2015. CEQG Freshwater Aquatic Life	**0.0058**	**0.0044**	**0.000012**	**0.000018**	**0.000015**	**0.00004**	**0.003**	**0.0011**	**0.0004**	**0.000025**	**0.0034**
Background - Surficial Sediments											
Mainland Locations - Surficial Sediments - 95th Percentile Background	0.00010	0.00005	0.000010	0.000009	0.000008	0.00003	0.00005	0.0001	0.0001	0.000030	0.0002
Mainland Locations - Surficial Sediments - Maximum Background	0.00010	0.00005	0.000032	0.000068	0.000008	0.00039	0.00005	0.0001	0.0004	0.000280	0.0002
Bear, Goose, and Frenchy's Islands - Surficial Sediments - 95th Percentile Background	0.00010	0.00005	0.000010	0.000009	0.000008	0.00001	0.00005	0.0001	0.0001	0.000020	0.0002
Bear, Goose, and Frenchy's Islands - Surficial Sediments - Maximum Background	0.00010	0.00005	0.000010	0.000009	0.000008	0.00001	0.00005	0.0001	0.0001	0.000020	0.0002
Background - Shallow Bedrock - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage											
Shallow Bedrock - Natural Saline Water & Oil Seepage - 95th Percentile Background	0.00044	0.00005	0.000011	0.000082	0.000032	0.00006	0.00140	0.0049	0.0035	0.000228	0.0002
Shallow Bedrock - Natural Saline water & Oil Seepage - Maximum Background	0.00096	0.00005	0.000034	0.000110	0.000077	0.00009	0.00220	0.0066	0.0047	0.000490	0.0002
Background - Surficial Sediments - Inferred to Represent Natural Saline Water & Hydrocarbon Seepage											
Surficial Sediments - Natural Saline Water & Oil Seepage - 95th Percentile Background	0.00042	NC	0.000024	0.000009	0.000008	0.00006	0.00182	0.0031	0.0017	0.000201	NC
Surficial Sediments - Natural Saline Water & Oil Seepage - Maximum Background	0.00062	NC	0.000076	0.000016	0.000008	0.00006	0.00200	0.0038	0.0037	0.000210	NC
Background - Surficial Sediments - Inferred to Represent Natural Gas Seepage without Saline Water											
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - 95th Percentile Background	0.00015	0.00005	0.000045	0.000035	0.000012	0.00027	0.00014	0.0157	0.0004	0.000199	0.0002
Surficial Sediments - Natural Gas & Non-Saline Water Seepage - Maximum Background	0.00016	0.00005	0.000051	0.000040	0.000013	0.00032	0.00016	0.0160	0.0004	0.000230	0.0002

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Table 9
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Salinity Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Electrical Conductivity (dS/m)	pH (pH units)	Sodium Adsorption Ratio (none)
MAINLAND - Organic Surface Soil					
P98-35A	23-Aug-1998	0.0 - 0.15m	0.764	7.5	0.62
MCBG-10-02	14-Aug-2010	0.3 - 0.6m	0.33	7.4	0.4
MEBG-10-01	15-Aug-2010	0.3 - 0.6m	0.4	6.11	0.4
MEBG-12-1	16-Jul-2012	0.0 - 0.3m	0.25	6.19	0.1
MEBG-12-2	16-Jul-2012	0.2 - 0.5m	0.3	6.27	0.21
MWBG-10-01	01-Aug-2010	0.0 - 0.3m		7.45	0.4
MWBG-10-02	01-Aug-2010	0.0 - 0.3m		7.51	0.5
MWBG-12-1	03-Aug-2012	0.0 - 0.4m	0.31	6.99	0.1
S12-2D	18-Sep-2012	0.15 - 0.3m		6.39	
S12-2E	18-Sep-2012	0.15 - 0.3m		6.96	
S12-2F	18-Sep-2012	0.15 - 0.3m		6.74	
S12-5D	19-Sep-2012	0.1 - 0.2m		6.55	
MLS-13-8	25-Aug-2013	0.5 - 0.7m	0.25	5.49	1.5
MLS-14-4	28-Feb-2014	1.0m	0.24	6.93	1.3
MWBG-15-1	23-Sep-2015	0.0 - 0.1m	0.58	5.8	0.25
MCBG-15-2	23-Sep-2015	0.0 - 0.1m	0.44	6.14	0.19
MEBG-10-2	16-Aug-2010	0.0 - 0.3m	1.5	7.57	0.4
MAINLAND - Mineral Surface Soil					
MC-BG-12-1	03-Aug-2012	0.1 - 0.5m	0.36	6.98	0.15
MLS-09-22	01-Aug-2009	0.0 - 0.4m	0.64	7.16	2
MWBG-12-2	17-Jul-2012	0.3 - 0.6m	0.36	7.36	0.27
S12-2D	18-Sep-2012	0.3 - 0.35m		7.21	
S12-2E	18-Sep-2012	0.3 - 0.35m		7.25	
S12-2F	18-Sep-2012	0.3 - 0.35m		7.12	
S12-5D	19-Sep-2012	0.5 - 0.6m		6.6	
S12-6D	19-Sep-2012	0.1 - 0.2m		6.49	
	19-Sep-2012	0.3 - 0.4m		7.29	
S12-6E	19-Sep-2012	0.1 - 0.2m		6.72	
	19-Sep-2012	0.3 - 0.4m		7.23	
S12-6F	19-Sep-2012	0.1 - 0.2m		6.63	
	19-Sep-2012	0.3 - 0.4m		7.19	
MCBG-15-2	23-Sep-2015	0.1 - 0.3m	0.24	6.15	0.25
MWBG-15-1	23-Sep-2015	0.1 - 0.3m	0.73	6.25	0.34
MWBG-10-01	01-Aug-2010	0.3 - 0.6m		7.61	0.7
MWBG-10-02	01-Aug-2010	0.3 - 0.6m		7.47	0.5
MLS-14-2	27-Feb-2014	1.0m	0.15	7.36	1

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Table 9
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Salinity Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Electrical Conductivity (dS/m)	pH (pH units)	Sodium Adsorption Ratio (none)
MAINLAND - Mineral Subsurface Soil					
CLAY PIT#1	08-Sep-2003				
	08-Sep-2003		0.93	7.7	0.39
CLAY PIT#2	08-Sep-2003				
	08-Sep-2003		1.8	7.7	0.33
A45X OVERBURDEN 1	15-Aug-2010		2.4	7.7	0.6
A45X OVERBURDEN 2	15-Aug-2010		0.79	7.72	0.5
WBIO 08-1-2	30-Jul-2008	0.76 - 1.5m	0.91	8.1	0.6
	30-Jul-2008	2.3 - 3.0m	1.1	8	0.6
WBIO 08-2	29-Jul-2008	0.76 - 1.5m	0.54	8	0.5
	29-Jul-2008	2.3 - 3.0m	0.7	8.1	0.7
WBIO 08-3	29-Jul-2008	0.76 - 1.5m	0.55	8.1	0.7
	29-Jul-2008	3.0 - 3.8m	1.4	7.9	0.6
MCBG-10-02	14-Aug-2010	0.6 - 1.0m	0.29	7.5	0.4
(Duplicate)	14-Aug-2010	0.6 - 1.0m	0.29	7.56	0.4
	14-Aug-2010	1.5 - 2.0m	0.26	7.32	1
MC-BG-12-1	03-Aug-2012	0.6 - 0.9m	0.87	7.13	0.19
	03-Aug-2012	1.0 - 1.5m	2.2	6.99	0.42
(Duplicate)	03-Aug-2012	1.0 - 1.5m	2	7	0.4
	03-Aug-2012	1.7 - 2.1m	0.42	7.07	0.93
MEBG-10-01	15-Aug-2010	0.3 - 0.6m	0.4	6.11	0.4
	15-Aug-2010	0.6 - 1.0m	0.43	6.95	0.5
	15-Aug-2010	2.5 - 3.0m	0.44	7.61	0.7
MEBG-10-2	16-Aug-2010	0.3 - 0.6m	0.73	7.66	0.4
	16-Aug-2010	0.6 - 1.0m	0.41	7.43	0.3
	16-Aug-2010	1.8 - 2.3m	0.29	7.8	0.5
	16-Aug-2010	2.5 - 3.0m	0.53	7.8	0.5
MEBG-12-1	16-Jul-2012	1.5 - 2.0m	0.53	7.21	1.9
	16-Jul-2012	3.0 - 3.4m	0.72	7.44	22
MEBG-12-2	16-Jul-2012	1.0 - 1.5m	0.51	7.06	0.41
	16-Jul-2012	2.0 - 2.5m	0.4	7.12	9.1
MWBG-10-01	01-Aug-2010	0.6 - 1.0m		7.61	0.8
MWBG-10-02	01-Aug-2010	0.6 - 1.0m		7.5	0.5
	01-Aug-2010	2.4 - 2.7m		7.63	1.7
MWBG-12-1	03-Aug-2012	0.4 - 0.8m	0.28	7.28	0.17
	03-Aug-2012	1.5 - 2.0m	0.57	7.15	0.28
(Duplicate)	03-Aug-2012	1.5 - 2.0m	0.73	7.05	0.32
MLS-13-4	23-Aug-2013	1.2 - 1.5m	0.21	7.33	1.7
MLS-13-8	25-Aug-2013	1.3 - 1.5m	0.67	6.94	0.57
	25-Aug-2013	2.8 - 3.0m	0.47	7.19	1.1
MLS-14-4	28-Feb-2014	2.0m	0.32	7.41	4.6
MLS-14-8	03-Mar-2014	1.0m	0.27	7.42	0.97
	03-Mar-2014	2.0m	0.42	7.4	0.81
MLS-14-9	02-Mar-2014	1.0m	0.2	7.1	1.4
	02-Mar-2014	2.0m	0.44	7.41	7.3
MCBG-15-2	23-Sep-2015	0.3 - 0.5m	0.28	7.23	0.63
	23-Sep-2015	2.4 - 3.0m	0.46	7.13	0.53
MWBG-15-1	23-Sep-2015	0.3 - 0.8m	0.54	6.93	0.16
	23-Sep-2015	1.8 - 2.4m	1.2	6.99	1.1
MCBG-16-4	09-Mar-16	0.7 - 1.1m	0.59	6.55	0.38
	09-Mar-16	2.4 - 3.0 m	0.44	6.87	0.82
	09-Mar-16	4.0 - 4.5 m	0.5	7.17	1
MEBG-16-5	10-Mar-16	0.6 - 1.2 m	0.76	6.83	0.33
	10-Mar-16	2.5 - 3.0 m	0.8	6.96	0.36
	10-Mar-16	4.0 - 4.5 m	0.69	7.24	0.54
MLS-14-2	27-Feb-2014	2.0m	0.43	7.05	0.51

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Table 9
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Salinity Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Electrical Conductivity (dS/m)	pH (pH units)	Sodium Adsorption Ratio (none)
MAINLAND - BEDROCK-Siltstone					
MEBG-12-2	16-Jul-2012	3.5 - 4.0m	0.92	7.72	26
MWBG-10-01	01-Aug-2010	2.4 - 2.7m		6.98	1.5
MWBG-12-2	17-Jul-2012	2.0 - 2.5m	0.3	7.54	0.6
MLS-13-4	23-Aug-2013	2.0 - 2.2m	0.26	6.97	9.7
	23-Aug-2013	2.8 - 3.0m	1.1	7.22	7.5
MLS-14-4	28-Feb-2014	3.0m	0.48	7.24	11
MLS-14-8	03-Mar-2014	3.0m	0.28	7.6	1.3
MLS-14-9	03-Mar-2014	3.0m	1	7.53	19
P98-35A	23-Aug-1998	2.0 - 3.0m	1.26	7.2	0.73
MLS-14-2	27-Feb-2014	2.5m	1.7	7.52	0.53
MAINLAND - BEDROCK-Shale					
S12 - QUARRY 1	23-Sep-2012			3.24	
S12 - QUARRY 2	23-Sep-2012			3.18	
S12 - QUARRY 3	23-Sep-2012			3.46	
Bear/Frenchy's/Goose Islands					
BEAR/FRENCHY'S/GOOSE ISLANDS -Organic Surface Soil					
BI 08-01	26-Jul-2008	0.0 - 0.3m	1.3	7.9	0.5
BIBG-15-1	30-Sep-2015	0.0 - 0.05m	0.53	7.22	0.21
	30-Sep-2015	0.05 - 0.4m	0.63	7.56	0.22
BIBG-15-2	30-Sep-2015	0.0 - 0.4m	3.3	7.24	0.75
BIBG-15-3	30-Sep-2015	0.0 - 0.2m	0.69	6.83	0.2
Bear/Frenchy's/Goose Islands					
BEAR/FRENCHY'S/GOOSE ISLANDS - Mineral Surface Soil					
BIBG-10-3	28-Aug-2010	0.0 - 0.3m	0.54	7.77	0.3
BIBG-10-2	29-Aug-2010	0.0 - 0.3m	0.49	7.65	0.3
FIBG-10-1	30-Aug-2010	0.0 - 0.3m	2.9	7.74	0.8
(Duplicate)	30-Aug-2010	0.0 - 0.3m	2.9	7.76	0.7
GIBG-10-1	31-Aug-2010	0.0 - 0.3m	0.62	7.73	0.4
GIBG-10-2	01-Sep-2010	0.0 - 0.3m	1.8	7.5	0.2
S12-8D	20-Sep-2012	0.1 - 0.2m		7.39	
S12-9D	20-Sep-2012	0.2 - 0.3m		7.2	
BIBG-15-1	30-Sep-2015	0.4 - 0.8m	0.9	7.13	0.39
BIBG-15-2	30-Sep-2015	0.4 - 0.8m	2.5	7.16	0.43
BIBG-15-3	30-Sep-2015	0.2 - 0.5m	0.47	7.19	0.29
GIBG-15-13	03-Oct-2015	0.6m	0.64	7.1	0.42
GIBG-15-14	03-Oct-2015	0.3m	2.4	7.23	0.25
GIBG-15-15	03-Oct-2015	1.0m	2.7	7.25	0.3
GIBG-15-16	03-Oct-2015	0.3m	0.71	7.13	1.4

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Table 9
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Salinity Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Electrical Conductivity (dS/m)	pH (pH units)	Sodium Adsorption Ratio (none)
BEAR/FRENCHY'S/GOOSE ISLANDS - Mineral Subsurface Soil					
BI 08-01	26-Jul-2008	0.8 - 1.2m	1.3	7.8	0.3
	26-Jul-2008	2.0 - 2.4m	1.4	7.6	0.3
BIBG-10-3	28-Aug-2010	0.6 - 1.0m	0.84	7.65	0.2
	28-Aug-2010	1.8 - 2.1m	1.1	7.57	0.2
	28-Aug-2010	4.2 - 4.5m	0.89	7.76	0.3
BIBG-10-2	29-Aug-2010	0.3 - 0.6m	0.51	7.7	0.4
	29-Aug-2010	0.6 - 1.0m	0.72	7.6	0.3
	29-Aug-2010	2.5 - 3.0m	0.4	7.58	0.3
	29-Aug-2010	4.0 - 4.5m	0.57	7.49	0.2
BIBG-10-1	29-Aug-2010	1.2 - 1.5m	1	7.73	0.4
	29-Aug-2010	1.5 - 1.8m	2.7	7.76	0.3
	29-Aug-2010	4.0 - 4.3m	1.8	7.63	0.3
BIBG-12-1	22-Jul-2012	0.5 - 0.8m	0.5	7.21	0.21
	22-Jul-2012	2.7 - 3.0m	1.7	6.86	0.33
	22-Jul-2012	4.2 - 4.5m	2	7.4	0.41
	22-Jul-2012	6.0 - 6.5m	1	6.95	0.26
	22-Jul-2012	7.0 - 7.5m	0.46	7.34	0.54
BIBG-12-2	25-Jul-2012	1.0 - 1.5m	0.48	6.97	0.36
(Duplicate)	25-Jul-2012	1.0 - 1.5m	0.38	7	0.4
	25-Jul-2012	3.5 - 4.0m	1.5	6.96	0.21
	25-Jul-2012	4.5 - 5.0m	1.5	7.06	0.18
FIBG-10-1	30-Aug-2010	0.3 - 0.6m	0.97	7.81	0.4
	30-Aug-2010	0.6 - 1.0m	0.89	7.76	0.3
	30-Aug-2010	2.3 - 2.8m	0.77	7.7	0.4
GIBG-10-1	31-Aug-2010	0.3 - 0.6m	0.61	7.66	0.4
	31-Aug-2010	0.6 - 1.0m	1.1	7.62	0.5
(Duplicate)	31-Aug-2010	0.6 - 1.0m	1.6	7.63	0.4
	31-Aug-2010	2.5 - 3.0m	2.5	7.53	0.2
GIBG-10-2	01-Sep-2010	0.3 - 0.6m	0.67	7.6	0.2
	01-Sep-2010	0.6 - 1.0m	0.57	7.64	0.3
	01-Sep-2010	1.8 - 2.3m	0.35	7.34	0.2
S12-8D	20-Sep-2012	0.5 - 0.6m		7.27	
BIBG-15-1	30-Sep-2015	1.8 - 2.4m	2.9	7.03	0.43
BIBG-15-2	30-Sep-2015	1.8 - 2.4m	1.4	7.58	0.39
BIBG-15-3	30-Sep-2015	0.5 - 1.0m	1.2	6.91	0.28
	30-Sep-2015	1.8 - 2.4m	1.5	7.05	0.68
GIBG-15-13	03-Oct-2015	0.6m	0.64	7.1	0.42
	03-Oct-2015	4.8m	0.79	7.17	0.43
GIBG-15-14	03-Oct-2015	1.8m	1.6	7.56	0.29
	03-Oct-2015	3.6m	1.3	7.14	0.39
GIBG-15-15	03-Oct-2015	3.5m	1	7.58	0.64
GIBG-15-16	03-Oct-2015	1.8m	0.88	7.02	0.64
	03-Oct-2015	3.2m	1.1	7.06	1.1
(Duplicate)	03-Oct-2015	3.2m			
BIBG-16-12	03-Mar-2016	1.0 - 1.3m	2.5	7.08	0.41

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Table 9
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Salinity Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Electrical Conductivity (dS/m)	pH (pH units)	Sodium Adsorption Ratio (none)
MAINLAND - SEEPS					
MAINLAND SEEPS - Organic Surface Soil					
MCBG-15-1	23-Sep-2015	0.0 - 0.1m	0.75	4.09	0.42
MEBG-10-3	21-Aug-2010	0.0 - 0.3m	0.27	7.49	1.4
MEBG-15-3	24-Sep-2015	0.0 - 0.1m	1.4	7.25	0.55
MEBG-15-4	24-Sep-2015	0.0 - 0.2m	0.84	6.59	0.2
MAINLAND SEEPS - Mineral Surface Soil					
MCBG-15-1	23-Sep-2015	0.1 - 0.3m	0.77	6.86	0.39
	23-Sep-2015	0.3 - 0.5m	0.5	6.58	0.31
MWBG-10-03	05-Aug-2010	0.0 - 0.3m	0.78	7.72	0.7
	05-Aug-2010	0.3 - 0.6m	0.77	7.72	0.5
MEBG-15-3	24-Sep-2015	0.1 - 0.5m	0.8	7.24	0.54
MEBG-15-4	24-Sep-2015	0.2 - 0.5m	0.21	6.37	0.49
MWBG-15-2	24-Sep-2015	0.0 - 0.15m	0.64	7.05	0.28
	24-Sep-2015	0.15 - 0.6m	0.55	7.22	0.39
MAINLAND SEEPS - Mineral Subsurface Soil					
MWBG-10-03	05-Aug-2010	0.6 - 1.0m	0.8	7.7	0.4
(Duplicate)	05-Aug-2010	0.6 - 1.0m	0.79	7.75	0.4
	05-Aug-2010	2.2 - 2.7m	0.71	7.8	1.7
	05-Aug-2010	4.0 - 4.5m	0.41	7.41	0.9
MEBG-15-3	24-Sep-2015	0.5 - 1.2m	0.25	7.2	0.71
	24-Sep-2015	2.4 - 3.0m	0.38	6.98	0.43
MEBG-15-4	24-Sep-2015	0.5 - 0.8m	0.3	6.97	0.57
	24-Sep-2015	1.8 - 2.4m	0.53	6.79	0.31
MWBG-15-2	24-Sep-2015	2.4 - 3.0m	1.1	7.74	11
MAINLAND SEEPS - Bedrock					
MCBG-15-1	23-Sep-2015	4.2 - 4.8m	0.53	7.58	0.62
MEBG-10-3	21-Aug-2010	0.3 - 0.6m	0.24	7.41	2.1
	21-Aug-2010	0.6 - 1.0m	0.24	7.48	2.5
	21-Aug-2010	2.5 - 3.0m	0.97	7.78	2.9

Table 9
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Salinity Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Electrical Conductivity (dS/m)	pH (pH units)	Sodium Adsorption Ratio (none)

Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Hydrocarbon Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes-Total (mg/kg)	PHC F1 (C6-C10) - BTEX (mg/kg)	PHC F2 (C10-C16) (mg/kg)	PHC F3 (C16-C34) (mg/kg)	PHC F4 (C34-C50) (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo[a]anthracene (mg/kg)	Benzo[a]pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Benzo[g,h,i]perylene (mg/kg)	Benzo[k]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
MAINLAND - Organic Surface Soil																										
P98-35A	23-Aug-1998	0.0 - 0.15m																								
MCBG-10-02	14-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	10	52		0.005	0.005	0.004	0.005	0.005	0.009	0.013	0.005	0.018	0.005	0.005	0.005	0.005	0.005	0.017	0.0087
MEBG-10-01	15-Aug-2010	0.3 - 0.6m	0.018	0.071	0.035	0.14	42	40	530		0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.025	0.005	0.005	0.03	0.005	0.005	0.022	0.005
MEBG-12-1	16-Jul-2012	0.0 - 0.3m	0.019	0.076	0.038	0.15	45	38	290		0.019	0.019	0.015	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
MEBG-12-2	16-Jul-2012	0.2 - 0.5m	0.011	0.044	0.022	0.088	26	15	370		0.011	0.011	0.0088	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
MWBG-10-01	01-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	10	110		0.005	0.005	0.004	0.005	0.005	0.0083	0.0066	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.016	0.005
MWBG-10-02	01-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	10	110		0.005	0.005	0.004	0.005	0.005	0.0058	0.0068	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0098	0.026	0.0067
MWBG-12-1	03-Aug-2012	0.0 - 0.4m	0.005	0.02	0.01	0.04	12	10	53																	
MLS-13-8	25-Aug-2013	0.5 - 0.7m	0.017	0.07	0.03	0.13	40	33	470	170																
MLS-14-4	28-Feb-2014	1.0m	0.005	0.02	0.01	0.04	12	10	50	50																
MWBG-15-1	23-Sep-2015	0.0 - 0.1m	0.013	0.05	0.025	0.1	20	27	430	130	0.005	0.005	0.004	0.015	0.015	0.015	0.015	0.015	0.015	0.005	0.015	0.015	0.015	0.015	0.015	0.015
MCBG-15-2	23-Sep-2015	0.0 - 0.1m	0.017	0.068	0.034	0.14	31	80	1200	200	0.0051	0.005	0.0049	0.02	0.02	0.02	0.02	0.02	0.02	0.0063	0.02	0.02	0.02	0.005	0.02	0.02
MEBG-10-2	16-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	18	150	310		0.005	0.005	0.004	0.005	0.005	0.018	0.0087	0.005	0.23	0.005	0.012	0.005	0.005	0.025	0.52	0.066
MAINLAND - Mineral Surface Soil																										
MC-BG-12-1	03-Aug-2012	0.1 - 0.5m	0.005	0.02	0.01	0.04	12	10	59																	
MWBG-12-2	17-Jul-2012	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	38	110																	
MCBG-15-2	23-Sep-2015	0.1 - 0.3m	0.01	0.04	0.02	0.08	15	20	310	100	0.005	0.005	0.004	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.01	0.019	0.01	0.01	0.01	0.01
MWBG-15-1	23-Sep-2015	0.1 - 0.3m	0.012	0.046	0.023	0.092	12	24	200	120	0.005	0.005	0.004	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.01	0.01	0.01	0.01	0.015	0.01
MWBG-10-01	01-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	10	48		0.005	0.005	0.004	0.005	0.005	0.0092	0.0065	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.017	0.0053
MWBG-10-02	01-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	10	74		0.005	0.005	0.004	0.005	0.005	0.015	0.019	0.005	0.005	0.005	0.0087	0.005	0.005	0.012	0.031	0.014
MLS-14-2	27-Feb-2014	1.0m	0.005	0.02	0.01	0.04	12	12	74	50																

Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Hydrocarbon Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes-Total (mg/kg)	PHC F1 (C6-C10) - BTEX (mg/kg)	PHC F2 (C10-C16) (mg/kg)	PHC F3 (C16-C34) (mg/kg)	PHC F4 (C34-C50) (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo[a]anthracene (mg/kg)	Benzo[a]pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Benzo[g,h,i]perylene (mg/kg)	Benzo[k]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
MAINLAND - Mineral Subsurface Soil																										
A45X OVERBURDEN 1	15-Aug-2010		0.005	0.02	0.01	0.04	12	10	31	11																
A45X OVERBURDEN 2	15-Aug-2010		0.005	0.02	0.01	0.04	12	10	29	12																
MCBG-10-02	14-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	34	10	0.005	0.005	0.004	0.005	0.005	0.0085	0.012	0.005	0.015	0.005	0.005	0.005	0.005	0.005	0.013	0.0086
	14-Aug-2010	1.5 - 2.0m	0.005	0.02	0.01	0.04	12	10	63	16	0.005	0.005	0.004	0.005	0.005	0.015	0.024	0.005	0.026	0.005	0.0076	0.005	0.005	0.011	0.025	0.014
MC-BG-12-1	03-Aug-2012	0.6 - 0.9m	0.005	0.02	0.01	0.04	12	10	200	60																
	03-Aug-2012	1.0 - 1.5m	0.005	0.02	0.01	0.04	12	10	80	33																
(Duplicate)	03-Aug-2012	1.0 - 1.5m	0.005	0.02	0.01	0.04	12	10	87	36																
	03-Aug-2012	1.7 - 2.1m	0.005	0.02	0.01	0.04	12	10	55	26																
MEBG-10-01	15-Aug-2010	0.3 - 0.6m	0.018	0.071	0.035	0.14	42	40	530	220	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.025	0.005	0.005	0.03	0.005	0.005	0.022	0.005
	15-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	12	87	27	0.005	0.005	0.004	0.005	0.005	0.011	0.017	0.005	0.022	0.005	0.0091	0.005	0.005	0.005	0.02	0.013
	15-Aug-2010	2.5 - 3.0m	0.005	0.02	0.01	0.04	12	10	50	13																
MEBG-10-2	16-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	35	320	100																
	16-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	77	23																
	16-Aug-2010	1.8 - 2.3m	0.019	0.18	0.059	0.34	12	10	49	14																
	16-Aug-2010	2.5 - 3.0m	0.005	0.02	0.01	0.04	12	13	120	22																
MEBG-12-1	16-Jul-2012	1.5 - 2.0m	0.005	0.02	0.01	0.04	12	23	240	93																
	16-Jul-2012	3.0 - 3.4m	0.005	0.02	0.01	0.04	12	72	500	190																
MEBG-12-2	16-Jul-2012	1.0 - 1.5m	0.005	0.02	0.01	0.04	12	10	36	10																
	16-Jul-2012	2.0 - 2.5m	0.005	0.02	0.01	0.04	12	46	200	56																
MWBG-10-01	01-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	38	12	0.005	0.005	0.004	0.005	0.005	0.013	0.0084	0.005	0.005	0.005	0.005	0.005	0.005	0.0058	0.017	0.0065
MWBG-10-02	01-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	69	17	0.005	0.005	0.004	0.005	0.0054	0.021	0.023	0.005	0.005	0.005	0.012	0.005	0.0058	0.017	0.041	0.02
	01-Aug-2010	2.4 - 2.7m	0.005	0.02	0.01	0.04	12	12	130	63	0.005	0.005	0.004	0.005	0.005	0.013	0.017	0.005	0.005	0.005	0.0056	0.005	0.005	0.012	0.033	0.011
MLS-09-22	01-Aug-2009	1.0 - 1.3m	0.005	0.02	0.01	0.04	12	10	10	10																
MWBG-12-1	03-Aug-2012	0.4 - 0.8m	0.005	0.02	0.01	0.04	12	10	41	24																
	03-Aug-2012	1.5 - 2.0m	0.005	0.02	0.01	0.04	12	10	58	29																
(Duplicate)	03-Aug-2012	1.5 - 2.0m	0.005	0.02	0.01	0.04	12	10	59	30																
MLS-13-2	23-Aug-2013	1.5 - 1.7m	0.005	0.02	0.01	0.083	12	90	540	120																
	23-Aug-2013	2.0 - 2.2m	0.005	0.02	0.01	0.04	12	180	940	220																
MLS-13-4	23-Aug-2013	1.2 - 1.5m	0.005	0.02	0.01	0.04	12	10	89	50																
MLS-13-8	25-Aug-2013	1.3 - 1.5m	0.005	0.02	0.01	0.04	19	16	160	50																
	25-Aug-2013	2.8 - 3.0m	0.005	0.02	0.01	0.04	17	10	50	50																
MLS-14-4	28-Feb-2014	2.0m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.0082	0.0074	0.005	0.0091	0.005	0.005	0.005	0.005	0.005	0.018	0.005
(Duplicate)	28-Feb-2014	2.0m	0.005	0.02	0.01	0.04	12	13	50	50																
MLS-14-8	03-Mar-2014	1.0m	0.005	0.02	0.01	0.04	12	10	50	50																
	03-Mar-2014	2.0m	0.005	0.02	0.01	0.04	12	33	160	50																
MLS-14-9	02-Mar-2014	1.0m	0.005	0.02	0.01	0.04	12	10	66	50																
	02-Mar-2014	2.0m	0.005	0.02	0.01	0.04	12	10	50	50																
MCBG-15-2	23-Sep-2015	0.3 - 0.5m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.0064	0.0059	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	23-Sep-2015	2.4 - 3.0m	0.005	0.02	0.01	0.04	12	10	55	50	0.005	0.005	0.004	0.005	0.0061	0.017	0.023	0.005	0.0077	0.005	0.0075	0.005	0.0059	0.01	0.024	0.013
MWBG-15-1	23-Sep-2015	0.3 - 0.8m	0.005	0.02	0.01	0.04	12	10	58	50	0.005	0.005	0.004	0.005	0.0065	0.021	0.029	0.005	0.011	0.005	0.0089	0.005	0.0068	0.012	0.031	0.016
	23-Sep-2015	1.8 - 2.4m	0.005	0.02	0.01	0.04	12	11	68	50	0.005	0.005	0.004	0.005	0.0088	0.027	0.038	0.005	0.013	0.005	0.011	0.0063	0.01	0.022	0.041	0.022
MCBG-16-4	09-Mar-16	0.7 - 1.1m	0.02	0.02	0.019	0.076	23	28	160	100	0.01	0.01	0.004	0.01	0.01	0.014	0.025	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.022	0.014
	09-Mar-16	2.4 - 3.0 m	0.011	0.02	0.01	0.04	12	15	98	50	0.005	0.005	0.004	0.005	0.005	0.013	0.023	0.005	0.0058	0.005	0.0072	0.007	0.006	0.005	0.019	0.014
	09-Mar-16	4.0 - 4.5 m	0.005	0.02	0.01	0.04	12	15	78	50	0.005	0.005	0.004	0.005	0.005	0.013	0.024	0.005	0.006	0.005	0.0064	0.005	0.0065	0.005	0.015	0.012
MEBG-16-5	10-Mar-16	0.6 - 1.2 m	0.005	0.02	0.01	0.04	12	19	150	50	0.005	0.005	0.004	0.005	0.005	0.008	0.0096	0.005	0.01	0.005	0.005	0.005	0.005	0.005	0.035	0.0068
	10-Mar-16	2.5 - 3.0 m	0.005	0.02	0.01	0.04	12	17	83	50	0.005	0.005	0.004	0.005	0.005	0.014	0.021	0.005	0.012	0.005	0.0056	0.005	0.005	0.0077	0.042	0.012
	10-Mar-16	4.0 - 4.5 m	0.005	0.02	0.01	0.04	12	25	65	50	0.005	0.005	0.004	0.005	0.005	0.009	0.0094	0.005	0.018	0.005	0.005	0.005	0.005	0.005	0.063	0.0094
MLS-14-2	27-Feb-2014	2.0m	0.005	0.02	0.01	0.04	12	170	1800	830																

Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Hydrocarbon Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes-Total (mg/kg)	PHC F1 (C6-C10) - BTEX (mg/kg)	PHC F2 (C10-C16) (mg/kg)	PHC F3 (C16-C34) (mg/kg)	PHC F4 (C34-C50) (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo[a]anthracene (mg/kg)	Benzo[a]pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Benzo[g,h,i]perylene (mg/kg)	Benzo[k]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
MAINLAND - BEDROCK-Siltstone																										
MEBG-12-2	16-Jul-2012	3.5 - 4.0m	0.005	0.02	0.01	0.04	28	340	740																	
MWBG-10-01	01-Aug-2010	2.4 - 2.7m	0.005	0.02	0.01	0.04	12	44	700		0.005	0.005	0.004	0.005	0.005	0.0093	0.0075	0.005	0.005	0.005	0.0088	0.005	0.005	0.027	0.24	0.013
MWBG-12-2	17-Jul-2012	2.0 - 2.5m	0.005	0.02	0.01	0.04	44	230	700																	
MLS-13-4	23-Aug-2013	2.0 - 2.2m	0.005	0.02	0.01	0.04	12	98	160																	
	23-Aug-2013	2.8 - 3.0m	0.005	0.02	0.01	0.04	12	140	310																	
MLS-14-4	28-Feb-2014	3.0m	0.005	0.02	0.01	0.04	12	72	130		0.005	0.0052	0.004	0.01	0.0067	0.027	0.017	0.005	0.046	0.007	0.012	0.024	0.005	0.011	0.13	0.024
MLS-14-8	03-Mar-2014	3.0m	0.005	0.02	0.01	0.063	29	710	1100																	
MLS-14-9	03-Mar-2014	3.0m	0.005	0.02	0.01	0.04	12	410	730																	
(Duplicate)	03-Mar-2014	3.0m	0.005	0.02	0.01	0.04	12	370	770																	
P98-35A	23-Aug-1998	2.0 - 3.0m	0.15	0.78	1.9	12.1																				
MLS-14-2	27-Feb-2014	2.5m	0.005	0.02	0.015	0.04	140	920	1400		0.037	0.025	0.004	0.025	0.005	0.023	0.02	0.005	0.13	0.005	0.014	0.26	0.005	0.05	0.83	0.086
BEAR/FRENCHY'S/GOOSE ISLANDS -Organic Surface Soil																										
BI 08-01	26-Jul-2008	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	14	10																	
BIBG-15-1	30-Sep-2015	0.0 - 0.05m	0.005	0.02	0.01	0.04	18	30	440	140	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.011	0.016	0.005
	30-Sep-2015	0.05 - 0.4m	0.028	0.083	0.052	0.35	27	16	79	50	0.005	0.005	0.004	0.005	0.005	0.015	0.021	0.005	0.0084	0.005	0.0083	0.0072	0.005	0.033	0.037	0.014
BIBG-15-2	30-Sep-2015	0.0 - 0.4m	0.005	0.02	0.01	0.04	12	10	74	50	0.005	0.005	0.004	0.005	0.005	0.012	0.018	0.005	0.0067	0.005	0.005	0.005	0.005	0.014	0.025	0.011
BIBG-15-3	30-Sep-2015	0.0 - 0.2m	0.005	0.02	0.01	0.04	12	44	350	160	0.005	0.005	0.004	0.005	0.005	0.005	0.011	0.005	0.005	0.005	0.005	0.005	0.005	0.0085	0.014	0.005
BEAR/FRENCHY'S/GOOSE ISLANDS - Mineral Surface Soil																										
BIBG-10-3	28-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	10	100		0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.019	0.005	0.005	0.005	0.005	0.005	0.021	0.005
BIBG-10-2	29-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	20	73																	
FIBG-10-1	30-Aug-2010	0.0 - 0.3m	0.005	0.02	0.019	0.087	12	72	370																	
(Duplicate)	30-Aug-2010	0.0 - 0.3m																								
GIBG-10-1	31-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	14	10	130																	
GIBG-10-2	01-Sep-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	11	90																	
BIBG-15-1	30-Sep-2015	0.4 - 0.8m	0.038	0.095	0.089	0.72	52	25	77	50	0.005	0.005	0.004	0.005	0.005	0.012	0.018	0.005	0.0069	0.005	0.0064	0.011	0.005	0.05	0.04	0.012
BIBG-15-2	30-Sep-2015	0.4 - 0.8m	0.005	0.02	0.01	0.04	12	10	72	50	0.005	0.005	0.004	0.005	0.005	0.014	0.019	0.005	0.007	0.005	0.0074	0.005	0.005	0.017	0.027	0.013
BIBG-15-3	30-Sep-2015	0.2 - 0.5m	0.005	0.02	0.01	0.04	12	11	87	50	0.005	0.005	0.004	0.005	0.005	0.012	0.016	0.005	0.005	0.005	0.005	0.005	0.005	0.014	0.023	0.011
GIBG-15-13	03-Oct-2015	0.6m	0.005	0.02	0.01	0.04	12	13	190	79	0.005	0.005	0.004	0.005	0.0051	0.019	0.027	0.005	0.01	0.005	0.0085	0.005	0.009	0.02	0.031	0.015
(Duplicate)	03-Oct-2015	0.6m	0.005	0.02	0.01	0.04	12	13	210	96																
GIBG-15-14	03-Oct-2015	0.3m	0.005	0.02	0.01	0.04	12	10	51	50	0.005	0.005	0.0042	0.0094	0.0089	0.029	0.031	0.0078	0.015	0.0084	0.014	0.0073	0.012	0.018	0.034	0.021
GIBG-15-15	03-Oct-2015	1.0m	0.005	0.02	0.01	0.04	12	10	78	50	0.005	0.005	0.004	0.005	0.005	0.018	0.026	0.005	0.01	0.005	0.0084	0.005	0.0073	0.017	0.029	0.016
GIBG-15-16	03-Oct-2015	0.3m	0.005	0.046	0.01	0.04	12	11	69	50	0.005	0.005	0.004	0.005	0.005	0.016	0.023	0.005	0.0087	0.005	0.0084	0.005	0.0058	0.013	0.027	0.015

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Table 10

Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Hydrocarbon Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes-Total (mg/kg)	PHC F1 (C6-C10) - BTEX (mg/kg)	PHC F2 (C10-C16) (mg/kg)	PHC F3 (C16-C34) (mg/kg)	PHC F4 (C34-C50) (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo[a]anthracene (mg/kg)	Benzo[a]pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Benzo[g,h,i]perylene (mg/kg)	Benzo[k]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
BEAR/FRENCHY'S/GOOSE ISLANDS - Mineral Subsurface Soil																										
BI 08-01	26-Jul-2008	0.8 - 1.2m	0.005	0.02	0.01	0.04	12	15	10																	
	26-Jul-2008	2.0 - 2.4m	0.005	0.02	0.01	0.04	12	21	26																	
BIBG-10-3	28-Aug-2010	0.6 - 1.0m	0.005	0.02	0.02	0.04	12	79	210		0.005	0.005	0.004	0.005	0.005	0.02	0.02	0.005	0.059	0.005	0.005	0.005	0.005	0.028	0.11	0.019
	28-Aug-2010	1.8 - 2.1m	0.005	0.02	0.01	0.04	12	10	38		0.005	0.005	0.004	0.005	0.005	0.014	0.019	0.005	0.021	0.005	0.005	0.005	0.005	0.013	0.024	0.011
	28-Aug-2010	4.2 - 4.5m	0.005	0.02	0.01	0.04	12	10	19		0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.0063	0.005	0.005	0.005	0.005	0.005	0.005	0.005
BIBG-10-2	29-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	10	28																	
	29-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	22																	
	29-Aug-2010	2.5 - 3.0m	0.005	0.02	0.01	0.04	12	10	14																	
	29-Aug-2010	4.0 - 4.5m	0.005	0.02	0.01	0.04	12	10	51																	
BIBG-10-1	29-Aug-2010	1.2 - 1.5m	0.005	0.02	0.021	0.04	30	60	92																	
	29-Aug-2010	1.5 - 1.8m	0.005	0.02	0.01	0.04	12	28	57																	
	29-Aug-2010	4.0 - 4.3m	0.005	0.02	0.01	0.04	16	19	29																	
BIBG-12-1	22-Jul-2012	0.5 - 0.8m	0.005	0.02	0.01	0.04	12	10	38																	
	22-Jul-2012	2.7 - 3.0m	0.005	0.02	0.01	0.04	12	10	35																	
	22-Jul-2012	4.2 - 4.5m	0.005	0.02	0.01	0.04	12	10	11																	
	22-Jul-2012	6.0 - 6.5m	0.005	0.02	0.01	0.04	12	10	13																	
	22-Jul-2012	7.0 - 7.5m	0.005	0.02	0.01	0.04	12	10	10																	
BIBG-12-2	25-Jul-2012	1.0 - 1.5m	0.005	0.02	0.01	0.04	12	12	66																	
(Duplicate)	25-Jul-2012	1.0 - 1.5m	0.005	0.02	0.01	0.04	12	10	63																	
	25-Jul-2012	3.5 - 4.0m	0.005	0.02	0.01	0.04	12	10	33																	
	25-Jul-2012	4.5 - 5.0m	0.005	0.02	0.01	0.04	12	13	42																	
FIBG-10-1	30-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	19	59																	
	30-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	46																	
	30-Aug-2010	2.3 - 2.8m	0.005	0.02	0.01	0.04	12	10	27																	
GIBG-10-1	31-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	18	10	380																	
	31-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	13	10	100																	
	31-Aug-2010	2.5 - 3.0m	0.005	0.02	0.01	0.04	13	10	24																	
GIBG-10-2	01-Sep-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	10	44																	
	01-Sep-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	10	30																	
	01-Sep-2010	1.8 - 2.3m	0.005	0.02	0.01	0.04	12	10	10																	
	01-Sep-2010	3.0 - 3.3m	0.005	0.02	0.01	0.04	12	10	15																	
BIBG-15-1	30-Sep-2015	1.8 - 2.4m	0.02	0.048	0.01	0.04	12	10	62	50	0.005	0.005	0.004	0.005	0.005	0.013	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.023	0.027	0.012
BIBG-15-2	30-Sep-2015	1.8 - 2.4m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.0074	0.011	0.005	0.005	0.005	0.005	0.005	0.005	0.0066	0.013	0.0069
BIBG-15-3	30-Sep-2015	0.5 - 1.0m	0.005	0.02	0.01	0.04	12	10	61	50	0.005	0.005	0.004	0.005	0.005	0.012	0.018	0.005	0.005	0.005	0.005	0.005	0.005	0.012	0.021	0.011
	30-Sep-2015	1.8 - 2.4m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.012	0.017	0.005	0.005	0.005	0.005	0.005	0.005	0.013	0.021	0.01
GIBG-15-13	03-Oct-2015	0.6m	0.005	0.02	0.01	0.04	12	13	190	79	0.005	0.005	0.004	0.005	0.0051	0.019	0.027	0.005	0.01	0.005	0.0085	0.005	0.009	0.02	0.031	0.015
(Duplicate)	03-Oct-2015	0.6m	0.005	0.02	0.01	0.04	12	13	210	96																
	03-Oct-2015	4.8m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.012	0.014	0.005	0.0078	0.005	0.0063	0.005	0.005	0.011	0.021	0.011
GIBG-15-14	03-Oct-2015	1.8m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.008	0.0085	0.005	0.005	0.005	0.005	0.005	0.005	0.0055	0.011	0.0054
	03-Oct-2015	3.6m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0094	0.005
GIBG-15-15	03-Oct-2015	3.5m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0072	0.005
GIBG-15-16	03-Oct-2015	1.8m	0.005	0.02	0.01	0.04	12	10	59	50	0.005	0.005	0.004	0.005	0.005	0.014	0.018	0.005	0.0086	0.005	0.0071	0.005	0.005	0.013	0.023	0.013
	03-Oct-2015	3.2m	0.005	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.005	0.0066	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.011	0.0057
(Duplicate)	03-Oct-2015	3.2m	0.005	0.02	0.01	0.04	12	10	50	50																
BIBG-16-12	03-Mar-16	1.0-1.3m	0.005	0.02	0.01	0.04	12	11	86	50																

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Table 10

Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Hydrocarbon Parameters

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes-Total (mg/kg)	PHC F1 (C6-C10) - BTEX (mg/kg)	PHC F2 (C10-C16) (mg/kg)	PHC F3 (C16-C34) (mg/kg)	PHC F4 (C34-C50) (mg/kg)	Acenaphthene (mg/kg)	Acenaphthylene (mg/kg)	Anthracene (mg/kg)	Benzo[a]anthracene (mg/kg)	Benzo[a]pyrene (mg/kg)	Benzo[b&j]fluoranthene (mg/kg)	Benzo[g,h,i]perylene (mg/kg)	Benzo[k]fluoranthene (mg/kg)	Chrysene (mg/kg)	Dibenzo[a,h]anthracene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Indeno[1,2,3-cd]pyrene (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Pyrene (mg/kg)
MAINLAND SEEPS - Organic Surface Soil																										
MCBG-15-1	23-Sep-2015	0.0 - 0.1m	0.01	0.04	0.02	0.08	12	160	5200	3400	0.005	0.005	0.004	0.01	0.012	0.011	0.025	0.01	0.012	0.005	0.01	0.012	0.011	0.012	0.034	0.014
MEBG-10-3	21-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	98	300	100	0.005	0.005	0.004	0.01	0.005	0.032	0.031	0.005	0.14	0.012	0.005	0.005	0.0064	0.016	0.29	0.018
MEBG-15-3	24-Sep-2015	0.0 - 0.1m	0.011	0.044	0.022	0.088	12	27	510	180	0.01	0.01	0.008	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MEBG-15-4	24-Sep-2015	0.0 - 0.2m	0.011	0.042	0.021	0.084	19	69	1500	860	0.01	0.01	0.008	0.01	0.01	0.012	0.01	0.01	0.016	0.01	0.011	0.01	0.01	0.012	0.051	0.019
MAINLAND SEEPS - Mineral Surface Soil																										
MCBG-15-1	23-Sep-2015	0.1 - 0.3m	0.005	0.02	0.01	0.04	12	170	5100	3800	0.02	0.012	0.0096	0.014	0.032	0.017	0.06	0.005	0.15	0.005	0.024	0.021	0.005	0.047	0.052	0.059
	23-Sep-2015	0.3 - 0.5m	0.005	0.02	0.01	0.04	12	240	4100	1900	0.005	0.005	0.004	0.005	0.005	0.005	0.0083	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0061	0.005
MWBG-10-03	05-Aug-2010	0.0 - 0.3m	0.005	0.02	0.01	0.04	12	19	97	57	0.005	0.005	0.004	0.005	0.005	0.015	0.018	0.005	0.025	0.005	0.0067	0.005	0.005	0.0096	0.033	0.013
	05-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	12	14	72	34	0.005	0.005	0.004	0.005	0.005	0.012	0.013	0.005	0.028	0.005	0.005	0.005	0.005	0.005	0.027	0.0081
MEBG-15-3	24-Sep-2015	0.1 - 0.5m	0.012	0.046	0.023	0.092	13	23	250	120	0.01	0.01	0.008	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MEBG-15-4	24-Sep-2015	0.2 - 0.5m	0.005	0.02	0.01	0.04	12	20	380	170	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0071	0.005	0.005
MWBG-15-2	24-Sep-2015	0.0 - 0.15m	0.005	0.02	0.01	0.04	12	17	110	50	0.005	0.005	0.004	0.005	0.005	0.0093	0.013	0.005	0.0066	0.005	0.005	0.005	0.005	0.01	0.024	0.0092
	24-Sep-2015	0.15 - 0.6m	0.005	0.02	0.01	0.04	12	19	660	730	0.005	0.005	0.004	0.005	0.015	0.012	0.031	0.005	0.005	0.0079	0.005	0.005	0.013	0.0057	0.021	0.01
MAINLAND SEEPS - Mineral Subsurface Soil																										
MWBG-10-03	05-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	12	54	21	0.005	0.005	0.004	0.005	0.005	0.0087	0.0094	0.005	0.02	0.005	0.005	0.005	0.005	0.005	0.017	0.0061
	05-Aug-2010	2.2 - 2.7m	0.005	0.02	0.01	0.04	12	22	85	28	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.016	0.005	0.005	0.005	0.005	0.005	0.014	0.005
	05-Aug-2010	4.0 - 4.5m	0.69	0.02	0.01	21	1400	3900	6500	2500	0.21	0.005	0.004	0.11	0.005	0.091	0.05	0.005	0.95	0.005	0.048	0.93	0.005	2.1	3.5	0.43
MEBG-15-3	24-Sep-2015	0.5 - 1.2m	0.012	0.02	0.01	0.04	12	10	50	50	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	24-Sep-2015	2.4 - 3.0m	2.9	0.097	0.47	1.2	180	17	100	50	0.005	0.005	0.004	0.005	0.005	0.012	0.018	0.005	0.006	0.005	0.0052	0.005	0.005	0.0084	0.017	0.0093
MEBG-15-4	24-Sep-2015	0.5 - 0.8m	0.005	0.02	0.01	0.04	67	490	500	50	0.035	0.026	0.004	0.005	0.005	0.0059	0.005	0.005	0.005	0.005	0.005	0.12	0.005	0.061	0.26	0.011
	24-Sep-2015	1.8 - 2.4m	2.2	0.044	4.3	14	43	21	110	50	0.005	0.005	0.004	0.005	0.005	0.011	0.017	0.005	0.005	0.005	0.0066	0.0075	0.005	0.054	0.025	0.012
MWBG-15-2	24-Sep-2015	2.4 - 3.0m	0.005	0.02	0.01	0.04	12	210	610	190	0.015	0.0097	0.004	0.013	0.005	0.016	0.016	0.005	0.045	0.0062	0.0088	0.024	0.005	0.02	0.19	0.019
MAINLAND SEEPS - Bedrock																										
MCBG-15-1	23-Sep-2015	4.2 - 4.8m	0.039	0.02	0.02	0.063	150	1100	2100	670	0.061	0.039	0.004	0.028	0.005	0.026	0.028	0.005	0.08	0.01	0.023	0.25	0.0066	0.073	0.79	0.078
MEBG-10-3	21-Aug-2010	0.3 - 0.6m	0.005	0.02	0.01	0.04	13	73	200	73																
	21-Aug-2010	0.6 - 1.0m	0.005	0.02	0.01	0.04	12	98	390	150																
	21-Aug-2010	2.5 - 3.0m	0.005	0.02	0.01	0.04	80	1200	2900	1100																

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Table 11
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Metals

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water) (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Chromium (VI) (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Toluene (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
MAINLAND - Organic Surface Soil																						
P98-35A	23-Aug-1998	0.0 - 0.15m																				
MCBG-10-02	14-Aug-2010	0.3 - 0.6m	1	6	200	0.4	0.4	0.4	14	0.15	7	15	7	0.05	2.4	20	0.5	0.3	0.02	1	23	53
MEBG-10-01	15-Aug-2010	0.3 - 0.6m	1	7	320	0.4	1.5	0.6	12	0.15	5	14	6	0.05	2	18	0.8	0.3	0.071	1	23	60
MEBG-12-1	16-Jul-2012	0.0 - 0.3m	2	2.6	200	0.8	2.2	0.26	6.7	0.15	3.1	10	4.9	0.1	2.5	11	1	0.6	0.076	2	16	30
MEBG-12-2	16-Jul-2012	0.2 - 0.5m	1	6.2	290	0.5	3	0.98	16	0.15	6.4	26	7	0.053	1.3	24	0.93	0.3	0.044	1.5	30	85
MWBG-10-01	01-Aug-2010	0.0 - 0.3m	1	6	430	0.9	1.3	0.3	32	0.15	12	21	14	0.05	2.2	39	1	0.3	0.02	1	45	81
MWBG-10-02	01-Aug-2010	0.0 - 0.3m	1	8	280	0.5	0.3	0.3	22	0.15	10	17	11	0.05	2.8	31	0.6	0.3	0.02	1	39	77
MWBG-12-1	03-Aug-2012	0.0 - 0.4m	1	7.1	390	0.59	0.6	0.75	20	0.15	7.5	16	8.5	0.05	1.2	25	0.53	0.3	0.02	1	37	100
S12-2D	18-Sep-2012	0.15 - 0.3m	0.34	2.53	427	0.4		0.652	8.7		3.89	10.2	4.73	0.05	0.7	11.9	1.04	0.05		4.53	18	16.1
S12-2E	18-Sep-2012	0.15 - 0.3m	0.43	5.06	448	0.4		1	9.6		5.3	15.5	6.22	0.05	0.99	17.6	0.81	0.056			22.1	41.8
S12-2F	18-Sep-2012	0.15 - 0.3m	0.45	3.9	515	0.43		1.03	7.3		4.68	10.8	4.36	0.05	0.94	13.3	0.76	0.05			19.7	21.6
S12-5D	19-Sep-2012	0.1 - 0.2m	0.22	5.64	171	0.4		0.432	86.4		5.31	7.71	4.63	0.05	0.69	12.2	0.6	0.052		0.412	11	32.2
MLS-13-8	25-Aug-2013	0.5 - 0.7m																	0.07			
MLS-14-4	28-Feb-2014	1.0m																	0.02			
MWBG-15-1	23-Sep-2015	0.0 - 0.1m	1	2.9	190	0.8	1.1	0.34	5.4	0.08	3.5	6.8	6.2	0.13	2.8	9.3	1	0.2	0.05	0.47	13	20
MCBG-15-2	23-Sep-2015	0.0 - 0.1m	1	2.2	110	0.8	0.4	0.77	3.9	0.08	2	7.3	8.2	0.13	2.5	7.7	1	0.2	0.068	0.4	20	24
MEBG-10-2	16-Aug-2010	0.0 - 0.3m	2	11	240	0.4	0.3	0.2	16	0.15	4	16	9	0.14	44	30	2.7	2.5	0.02	4	47	31
MAINLAND - Mineral Surface Soil																						
MC-BG-12-1	03-Aug-2012	0.1 - 0.5m	1	7.7	230	0.52	0.89	0.48	18	0.15	8.5	23	10	0.05	1.7	27	0.67	0.3	0.02	1.2	29	84
MLS-09-22	01-Aug-2009	0.0 - 0.4m	1	11	300	0.5	0.3	0.4	22	0.15	11	20	11	0.09	1.7	33	0.5	0.3		1	33	85
MWBG-12-2	17-Jul-2012	0.3 - 0.6m	1	19	150	0.83	0.32	0.1	37	0.15	18	34	13	0.05	0.4	56	0.5	0.3	0.02	1	50	140
S12-2D	18-Sep-2012	0.3 - 0.35m	0.4	7.36	287	0.47		0.444	14.3		7.11	15.2	9.29	0.05	1.56	20.8	0.5	0.1			31.3	82.4
S12-2E	18-Sep-2012	0.3 - 0.35m	0.48	8.38	213	0.4		0.507	11.9		6.78	17.4	8.15	0.05	1.97	24.2	0.5	0.109			26.6	79.5
S12-2F	18-Sep-2012	0.3 - 0.35m	0.43	5.1	241	0.47		0.366	13.3		6.24	15.2	8.39	0.05	1.23	21	0.5	0.1			29.5	74.6
S12-5D	19-Sep-2012	0.5 - 0.6m	0.38	7.28	345	0.7		0.837	16.2		8.32	16.9	9.42	0.05	1.76	27.2	0.7	0.111			32.1	109
S12-6D	19-Sep-2012	0.1 - 0.2m	0.37	6.91	322	0.59		0.416	17.4		7.73	10.6	9.23	0.05	1.07	20.7	0.52	0.107		0.578	35.4	97.7
	19-Sep-2012	0.3 - 0.4m	0.34	5.55	303	0.4		0.36	11		5	10.3	6.27	0.05	1.17	15.3	0.5	0.084		0.672	25.6	51.1
S12-6E	19-Sep-2012	0.1 - 0.2m	0.41	7.15	371	0.71		0.234	21.4		8.2	7.92	11	0.05	1.26	20.1	0.5	0.13		0.442	45.1	94.2
	19-Sep-2012	0.3 - 0.4m	0.1	1.02	231	0.4		0.15	11.2		6.13	11.3	6.08	0.05	0.27	18.9	0.5	0.05		0.417	18.4	51.9
S12-6F	19-Sep-2012	0.1 - 0.2m	0.1	4.17	396	0.87		0.434	21.7		9.25	18.4	10.1	0.05	0.4	28.3	0.5	0.07		0.581	42.1	114
	19-Sep-2012	0.3 - 0.4m	0.1	2.13	402	0.67		1.09	16.3		7.92	18.3	8.53	0.05	0.2	27.5	0.5	0.074		0.903	32.8	150
MCBG-15-2	23-Sep-2015	0.1 - 0.3m	0.5	4.4	370	0.52	0.97	0.84	13	0.08	4.5	15	7.4	0.081	0.75	18	0.89	0.1	0.04	1.9	26	39
MWBG-15-1	23-Sep-2015	0.1 - 0.3m	0.5	5.5	310	0.54	0.38	0.52	15	0.08	7.6	14	9	0.055	1.2	20	0.69	0.11	0.046	1	29	68
MWBG-10-01	01-Aug-2010	0.3 - 0.6m	1	10	360	0.6	1.2	0.5	28	0.15	13	24	14	0.05	2.8	38	0.9	0.3	0.02	1	44	100
MWBG-10-02	01-Aug-2010	0.3 - 0.6m	1	9	350	0.5	0.6	0.7	24	0.15	12	20	13	0.05	2.5	34	0.7	0.3	0.02	1	40	120
MLS-14-2	27-Feb-2014	1.0m																	0.02			

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Table 11
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Metals

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water) (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Chromium (VI) (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Toluene (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
MAINLAND - Mineral Subsurface Soil																						
CLAY PIT#1	08-Sep-2003																					
	08-Sep-2003			17.7	242	1.3		2	10.8	0.3	24.7	32.8	25.6	0.06	6.1	127	1.3	1			11.8	350
CLAY PIT#2	08-Sep-2003																					
	08-Sep-2003			16.6	230	1.4		1.3	9.9	0.3	18.5	36.9	25.5	0.07	6.8	105	2.7	1			11.3	277
A45X OVERBURDEN 1	15-Aug-2010		1	7	260	0.4	0.9	0.4	17	0.15	8	15	9	0.05	1.7	24	0.6	0.3	0.02	1	28	64
A45X OVERBURDEN 2	15-Aug-2010		1	7	220	0.4	0.5	0.3	16	0.15	7	14	7	0.05	1.4	21	0.5	0.3	0.02	1	24	55
WBIO 08-1-2	30-Jul-2008	0.76 - 1.5m	1	10	240	0.4	0.3	0.5	17	0.15	7	14	9	0.05	1.7	24	0.5	0.3			21	69
	30-Jul-2008	2.3 - 3.0m	1	12	330	0.4	0.3	0.6	26	0.15	11	23	12	0.05	2	36	0.7	0.3			28	110
WBIO 08-2	29-Jul-2008	0.76 - 1.5m	1	10	270	0.4	0.4	0.5	20	0.15	9	19	9	0.05	1.5	30	0.5	0.3			24	90
	29-Jul-2008	2.3 - 3.0m	1	10	260	0.4	0.3	0.5	31	0.15	9	19	10	0.05	1.9	32	0.6	0.3			25	89
WBIO 08-3	29-Jul-2008	0.76 - 1.5m	1	10	260	0.4	0.4	0.5	22	0.15	9	18	10	0.33	1.8	30	0.6	0.3			24	81
	29-Jul-2008	3.0 - 3.8m	1	18	310	0.4	0.4	0.6	23	0.15	11	22	13	0.06	1.9	34	0.7	0.3			30	110
MCBG-10-02	14-Aug-2010	0.6 - 1.0m	1	5	200	0.4	0.3	0.4	12	0.15	6	13	7	0.05	1.5	18	0.5	0.3	0.02	1	21	51
(Duplicate)	14-Aug-2010	0.6 - 1.0m																				
	14-Aug-2010	1.5 - 2.0m	1	8	270	0.4	1.5	0.5	19	0.15	9	19	10	0.05	1.8	27	0.8	0.3	0.02	1	29	78
MC-BG-12-1	03-Aug-2012	0.6 - 0.9m	1	14	290	0.56	3.7	0.64	19	0.15	12	26	11	0.05	2.9	37	1.2	0.3	0.02	2.3	30	110
	03-Aug-2012	1.0 - 1.5m	1	10	320	0.62	1.3	0.6	21	0.15	12	25	13	0.05	1.9	36	1.3	0.3	0.02	1.2	32	110
(Duplicate)	03-Aug-2012	1.0 - 1.5m	1	11	300	0.55	1.3	0.59	21	0.15	12	25	12	0.05	2.3	36	1.1	0.3	0.02	1.3	32	110
	03-Aug-2012	1.7 - 2.1m	1	12	320	0.51	1.1	0.49	21	0.15	11	25	12	0.05	2.3	35	0.58	0.3	0.02	1	31	100
MEBG-10-01	15-Aug-2010	0.3 - 0.6m	1	7	320	0.4	1.5	0.6	12	0.15	5	14	6	0.05	2	18	0.8	0.3	0.071	1	23	60
	15-Aug-2010	0.6 - 1.0m	1	6	240	0.4	0.7	0.6	15	0.15	7	16	8	0.05	1.7	21	0.6	0.3	0.02	1	24	62
	15-Aug-2010	2.5 - 3.0m	1	8	250	0.4	1.5	0.5	20	0.15	10	21	11	0.05	1.9	30	0.7	0.3	0.02	1	30	81
MEBG-10-2	16-Aug-2010	0.3 - 0.6m	2	5	250	0.8	0.3	0.3	12	0.18	4	10	7	0.1	11	18	1	0.8	0.02	2	31	31
	16-Aug-2010	0.6 - 1.0m	1	4	390	0.4	0.9	0.7	15	0.16	6	12	8	0.05	1.1	18	1.1	0.3	0.02	2	30	46
	16-Aug-2010	1.8 - 2.3m	1	5	170	0.4	0.1	0.2	11	0.15	6	10	6	0.05	1.4	16	0.5	0.3	0.18	1	20	44
	16-Aug-2010	2.5 - 3.0m	1	9	340	0.4	1.3	0.9	21	0.15	10	22	11	0.05	2.2	31	0.8	0.3	0.02	1	34	85
MEBG-12-1	16-Jul-2012	1.5 - 2.0m	1	49	110	0.6	0.55	0.1	36	0.15	13	39	9.9	0.083	0.45	50	0.5	0.3	0.02	1	66	120
	16-Jul-2012	3.0 - 3.4m	1	27	230	0.88	1.9	0.1	39	0.15	19	38	12	0.05	0.4	58	0.5	0.3	0.02	1	54	140
MEBG-12-2	16-Jul-2012	1.0 - 1.5m	1	12	360	0.69	0.91	0.49	27	0.15	12	32	12	0.05	1.9	40	0.61	0.3	0.02	1.1	44	110
	16-Jul-2012	2.0 - 2.5m	1	29	290	0.75	1.3	0.1	38	0.15	19	45	12	0.05	0.4	61	0.5	0.3	0.02	1	49	150
MWBG-10-01	01-Aug-2010	0.6 - 1.0m	1	12	350	0.6	1.2	0.5	29	0.15	14	31	15	0.06	2.7	42	0.8	0.3	0.02	1	47	120
MWBG-10-02	01-Aug-2010	0.6 - 1.0m	1	12	350	0.6	0.7	0.8	28	0.15	14	29	16	0.06	3.5	43	0.9	0.3	0.02	1	45	120
	01-Aug-2010	2.4 - 2.7m	1	11	330	0.5	0.8	0.5	28	0.15	13	25	12	0.06	2.3	39	0.6	0.3	0.02	1	41	100
MLS-09-22	01-Aug-2009	1.0 - 1.3m																	0.02			
MWBG-12-1	03-Aug-2012	0.4 - 0.8m	1	7.5	240	0.41	0.4	0.35	17	0.15	6.8	14	7.1	0.05	1.6	23	0.5	0.3	0.02	1	26	68
	03-Aug-2012	1.5 - 2.0m	1	7.6	250	0.43	0.4	0.37	14	0.15	7.2	14	7.8	0.05	1.5	22	0.5	0.3	0.02	1	26	65
(Duplicate)	03-Aug-2012	1.5 - 2.0m	1	8.2	290	0.4	0.5	0.37	14	0.15	7.4	16	8.2	0.05	1.7	24	0.5	0.3	0.02	1	26	74
MLS-13-2	23-Aug-2013	1.5 - 1.7m																	0.02			
	23-Aug-2013	2.0 - 2.2m																	0.02			
MLS-13-4	23-Aug-2013	1.2 - 1.5m																	0.02			

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Table 11
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Metals

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water) (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Chromium (VI) (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Toluene (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
MLS-13-8	25-Aug-2013	1.3 - 1.5m																	0.02			
	25-Aug-2013	2.8 - 3.0m																	0.02			
MLS-14-4	28-Feb-2014	2.0m																	0.02			
(Duplicate)	28-Feb-2014	2.0m																	0.02			
MLS-14-8	03-Mar-2014	1.0m																	0.02			
	03-Mar-2014	2.0m	1	18	660	0.64	0.98	0.22	25	0.15	15	32	15	0.069	1.8	46	0.51	0.3	0.02	1	34	130
MLS-14-9	02-Mar-2014	1.0m																	0.02			
	02-Mar-2014	2.0m																	0.02			
MCBG-15-2	23-Sep-2015	0.3 - 0.5m	0.51	6.9	240	0.4	0.21	0.33	13	0.08	6.9	18	7.1	0.052	1.7	20	0.5	0.1	0.02	0.67	23	65
	23-Sep-2015	2.4 - 3.0m	0.63	9.4	300	0.51	0.62	0.57	19	0.08	10	24	11	0.058	2.4	31	0.7	0.18	0.02	1	28	99
MWBG-15-1	23-Sep-2015	0.3 - 0.8m	0.62	9.9	280	0.56	0.75	0.42	18	0.08	11	22	12	0.056	2.2	32	0.74	0.18	0.02	0.82	29	93
	23-Sep-2015	1.8 - 2.4m	0.79	10	340	0.6	0.9	0.61	19	0.08	12	27	13	0.062	2.4	34	0.87	0.21	0.02	1.1	30	110
MLS-14-2	27-Feb-2014	2.0m	1	12	190	0.69	0.2	0.1	31	0.15	16	32	12	0.055	0.4	47	0.5	0.3	0.02	1	40	120
MCBG-16-4	09-Mar-16	0.7 - 1.1m	0.76	12	290	0.63	2.2	0.85	18	0.08	12	34	13	0.12	2.8	37	0.89	0.21		1.6	29	130
	09-Mar-16	2.4 - 3.0 m	0.74	11	250	0.66	0.84	0.78	20	0.08	11	28	13	0.11	2.2	36	0.85	0.19		1.1	30	120
	09-Mar-16	4.0 - 4.5 m	0.65	11	340	0.52	1.2	0.61	18	0.08	10	25	11	0.1	2.3	32	0.67	0.17		1.1	28	110
MEBG-16-5	10-Mar-16	0.6 - 1.2 m	0.5	6.7	310	0.62	1.3	0.56	17	0.08	10	19	10	0.05	1.5	31	0.51	0.18		0.69	21	110
	10-Mar-16	2.5 - 3.0 m	0.64	10	400	0.76	0.72	0.52	22	0.08	13	23	14	0.05	2.6	37	0.74	0.24		0.96	30	110
	10-Mar-16	4.0 - 4.5 m	0.57	11	530	1.1	0.49	0.41	29	0.08	17	27	19	0.05	3	49	0.76	0.34		1	32	120
MAINLAND - BEDROCK-Siltstone																						
MEBG-12-2	16-Jul-2012	3.5 - 4.0m	1	24	260	0.95	3.1	0.1	42	0.15	21	53	11	0.05	0.4	64	0.5	0.3	0.02	1	55	150
MWBG-10-01	01-Aug-2010	2.4 - 2.7m	1	9	120	0.6	0.8	0.1	41	0.15	22	26	15	0.12	0.4	60	0.5	0.3	0.02	1	64	120
MWBG-12-2	17-Jul-2012	2.0 - 2.5m	1	13	140	0.62	0.33	0.1	34	0.15	16	28	11	0.05	0.4	52	0.5	0.3	0.02	1	49	120
MLS-13-4	23-Aug-2013	2.0 - 2.2m																	0.02			
	23-Aug-2013	2.8 - 3.0m																	0.02			
MLS-14-4	28-Feb-2014	3.0m	1	10	500	0.87	0.87	0.12	31	0.15	17	38	14	0.057	0.81	51	0.5	0.3	0.02	1	40	130
MLS-14-8	03-Mar-2014	3.0m																	0.02			
MLS-14-9	03-Mar-2014	3.0m	1	23	270	0.75	2.4	0.1	36	0.15	19	35	13	0.05	0.45	59	0.5	0.3	0.02	1	44	140
(Duplicate)	03-Mar-2014	3.0m																	0.02			
P98-35A	23-Aug-1998	2.0 - 3.0m																	0.78			
MLS-14-2	27-Feb-2014	2.5m																	0.02			
MAINLAND - BEDROCK-Shale																						
S12 - QUARRY 1	23-Sep-2012		1.31	21.2	77.3	0.66	3.4	0.82	4.6		7.16	43.6	9.59	0.312	66.4	36.3	7.9	2.09			43.7	95.7
S12 - QUARRY 2	23-Sep-2012		2.04	7.19	370	0.48		0.05	53.6		0.73	9.2	6.04	0.128	29.8	26.9	5.2	0.877			129	16.4
S12 - QUARRY 3	23-Sep-2012		2.13	17.9	265	0.48		0.278	37.3		4.11	31.3	9.62	0.12	50.3	49.6	4.38	2.33			107	64.7
SHALE-1	06-Sep-1998			42.9		0.6	0.11	0.3	4.7	0.25	5.9	36.4	11	0.05	55.2	47	5.6	1.3			100	108

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Table 11
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Metals

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water) (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Chromium (VI) (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Toluene (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
BEAR/FRENCHY'S/GOOSE ISLANDS -Organic Surface Soil																						
BI 08-01	26-Jul-2008	0.0 - 0.3m	1	10	380	0.4	0.2	0.7	17	0.15	9	21	11	0.06	2.2	29	1	0.4	0.02		27	100
BIBG-15-1	30-Sep-2015	0.0 - 0.05m	1	5	190	0.8	0.3	0.47	9.6	0.08	5.6	14	6.7	0.1	1.2	16	1	0.2	0.02	0.57	16	60
	30-Sep-2015	0.05 - 0.4m	0.5	7.7	260	0.45	0.21	0.53	14	0.08	8.2	18	8.9	0.05	1.6	25	0.62	0.13	0.083	0.68	23	78
BIBG-15-2	30-Sep-2015	0.0 - 0.4m	0.53	8.3	260	0.43	0.43	0.61	14	0.08	8.5	19	8.9	0.05	1.8	25	0.61	0.15	0.02	0.87	23	92
BIBG-15-3	30-Sep-2015	0.0 - 0.2m	1	5.1	180	0.8	0.45	1	9.9	0.08	6.2	17	6.8	0.1	1.6	19	1	0.2	0.02	0.73	17	120
BEAR/FRENCHY'S/GOOSE ISLANDS - Mineral Surface Soil																						
BIBG-10-3	28-Aug-2010	0.0 - 0.3m	1	4	200	0.4	0.3	0.2	8	0.15	3	6	5	0.05	4.1	12	0.5	0.3	0.02	1	16	28
BIBG-10-2	29-Aug-2010	0.0 - 0.3m	1	6	210	0.4	0.3	0.4	12	0.15	6	13	7	0.05	2.8	21	0.6	0.3	0.02	1	21	83
FIBG-10-1	30-Aug-2010	0.0 - 0.3m	1	6	230	0.4	0.3	0.6	12	0.15	7	13	9	0.05	2.1	21	0.5	0.3	0.02	1	20	76
(Duplicate)	30-Aug-2010	0.0 - 0.3m	1	6	230	0.4	0.3	0.6	11	0.15	7	13	9	0.05	2.1	21	0.5	0.3		1	20	77
GIBG-10-1	31-Aug-2010	0.0 - 0.3m	1	8	360	0.4	0.2	0.6	30	0.15	8	17	12	0.07	2.4	32	0.6	0.3	0.02	1	25	85
GIBG-10-2	01-Sep-2010	0.0 - 0.3m	1	7	290	0.4	0.2	0.6	13	0.15	7	14	8	0.05	2.1	22	0.6	0.3	0.02	1	23	75
S12-8D	20-Sep-2012	0.1 - 0.2m	0.54	8.44	338	0.63		0.727	17.6		9.43	21.3	13.9	0.05	1.78		0.82	0.174		0.95	29.5	91.4
S12-9D	20-Sep-2012	0.2 - 0.3m	0.61	8.47	283	0.61		1.32	17.9		9.43	23	10.9	0.05	2.22		1.01	0.195		1.18	29.4	140
BIBG-15-1	30-Sep-2015	0.4 - 0.8m	0.54	7	230	0.4	0.31	0.57	12	0.08	7.1	17	7.4	0.05	1.8	21	0.58	0.11	0.095	0.84	20	77
BIBG-15-2	30-Sep-2015	0.4 - 0.8m	0.58	8.2	260	0.46	0.26	0.53	15	0.08	8.8	19	9.6	0.05	1.9	26	0.65	0.14	0.02	0.86	23	88
BIBG-15-3	30-Sep-2015	0.2 - 0.5m	0.58	7.8	300	0.48	0.31	0.52	15	0.08	8.8	20	9.1	0.05	2.1	26	0.7	0.17	0.02	0.88	26	89
GIBG-15-13	03-Oct-2015	0.6m	0.62	8.6	310	0.48	0.27	0.63	16	0.08	8.9	19	10	0.05	1.9	27	0.68	0.16	0.02	0.85	25	92
(Duplicate)	03-Oct-2015	0.6m																	0.02			
GIBG-15-14	03-Oct-2015	0.3m	0.51	7.9	230	0.41	0.27	0.51	14	0.08	8.4	18	8.5	0.05	1.9	25	0.54	0.14	0.02	0.93	21	84
GIBG-15-15	03-Oct-2015	1.0m	0.56	8.4	280	0.45	0.23	0.59	15	0.08	8.6	18	8.6	0.05	1.9	26	0.65	0.15	0.02	0.99	25	86
GIBG-15-16	03-Oct-2015	0.3m	0.67	9.4	350	0.51	0.22	0.6	17	0.08	9.8	19	11	0.078	2	28	0.69	0.15	0.046	0.96	26	95
BEAR/FRENCHY'S/GOOSE ISLANDS - Mineral Subsurface Soil																						
BI 08-01	26-Jul-2008	0.8 - 1.2m	1	8	260	0.4	0.2	0.5	13	0.15	8	17	9	0.06	1.7	23	0.8	0.3	0.02		21	78
	26-Jul-2008	2.0 - 2.4m																	0.02			
BIBG-10-3	28-Aug-2010	0.6 - 1.0m	2	9	280	0.8	0.3	0.6	14	0.15	8	20	10	0.1	14	27	1	1	0.02	2	36	73
	28-Aug-2010	1.8 - 2.1m	1	7	260	0.4	0.3	0.5	13	0.15	7	15	8	0.05	2	21	0.6	0.3	0.02	1	22	74
	28-Aug-2010	4.2 - 4.5m	1	5	180	0.4	0.1	0.3	9	0.15	6	9	5	0.05	1.6	16	0.5	0.3	0.02	1	19	51
BIBG-10-2	29-Aug-2010	0.3 - 0.6m	1	6	240	0.4	0.2	0.4	11	0.15	6	11	7	0.05	1.6	17	0.5	0.3	0.02	1	20	55
	29-Aug-2010	0.6 - 1.0m	1	6	200	0.4	0.1	0.4	11	0.15	6	11	7	0.05	1.9	18	0.5	0.3	0.02	1	21	58
	29-Aug-2010	2.5 - 3.0m	1	4	130	0.4	0.1	0.2	8	0.15	5	6	4	0.05	1.2	15	0.5	0.3	0.02	1	16	42
	29-Aug-2010	4.0 - 4.5m	1	7	230	0.4	0.4	0.7	10	0.15	7	16	8	0.05	1.7	21	0.7	0.3	0.02	1	21	66
BIBG-10-1	29-Aug-2010	1.2 - 1.5m	1	8	320	0.4	0.4	0.6	17	0.15	9	19	10	0.06	2.5	27	0.8	0.3	0.02	1	30	85
	29-Aug-2010	1.5 - 1.8m	1	7	270	0.4	0.3	0.5	14	0.15	8	16	9	0.05	1.9	23	0.7	0.3	0.02	1	25	78
	29-Aug-2010	4.0 - 4.3m	1	6	220	0.4	0.2	0.4	10	0.15	6	13	7	0.05	1.8	18	0.5	0.3	0.02	1	20	65
BIBG-12-1	22-Jul-2012	0.5 - 0.8m	1	9	340	0.52	0.41	0.58	16	0.15	9.2	21	11	0.05	2.2	29	0.74	0.3	0.02	1	28	89
	22-Jul-2012	2.7 - 3.0m	1	7.7	270	0.4	0.31	0.48	13	0.15	7.7	23	8.6	0.05	1.9	25	0.6	0.3	0.02	1	23	81
	22-Jul-2012	4.2 - 4.5m	1	6.3	170	0.4	0.1	0.34	11	0.15	6.8	18	6.3	0.05	1.7	21	0.5	0.3	0.02	1	20	66
	22-Jul-2012	6.0 - 6.5m	1	5.9	160	0.4	0.21	0.39	11	0.15	7.3	25	6.1	0.05	1.7	23	0.5	0.3	0.02	1	18	70
	22-Jul-2012	7.0 - 7.5m	1	5.4	120	0.4	0.1	0.19	11	0.15	6.6	22	4.9	0.05	1.5	20	0.5	0.3	0.02	1	18	56
BIBG-12-2	25-Jul-2012	1.0 - 1.5m	1	9	330	0.55	0.58	0.65	18	0.15	9.4	22	11	0.05	2.2	30	0.77	0.3	0.02	1	30	99
(Duplicate)	25-Jul-2012	1.0 - 1.5m	1	9.6	350	0.56	0.45	0.58	18	0.15	10	21	11	0.05	2.2	30	0.78	0.3	0.02	1	30	95

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Table 11
Soil and Bedrock Geochemical Statistical Source Data (1998-2019) - Metals

PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water) (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Chromium (VI) (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Toluene (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
	25-Jul-2012	3.5 - 4.0m	1	7.3	240	0.4	0.26	0.48	13	0.15	7.3	16	8	0.05	2	23	0.59	0.3	0.02	1	24	74
	25-Jul-2012	4.5 - 5.0m	1	7.4	250	0.4	0.26	0.43	14	0.15	7.3	16	8.2	0.05	1.9	23	0.56	0.3	0.02	1	23	76
FIBG-10-1	30-Aug-2010	0.3 - 0.6m	1	7	240	0.4	0.1	0.5	20	0.15	8	15	8	0.05	2.2	24	0.6	0.3	0.02	1	21	72
	30-Aug-2010	0.6 - 1.0m	1	8	290	0.4	0.2	0.7	13	0.15	8	17	9	0.05	2.1	24	0.6	0.3	0.02	1	23	79
	30-Aug-2010	2.3 - 2.8m	1	6	180	0.4	0.1	0.3	10	0.15	6	10	6	0.05	1.6	17	0.5	0.3	0.02	1	18	56
GIBG-10-1	31-Aug-2010	0.3 - 0.6m	1	8	400	0.4	0.2	0.5	16	0.15	8	16	12	0.07	2.2	24	0.6	0.3	0.02	1	25	78
	31-Aug-2010	0.6 - 1.0m	1	8	330	0.4	0.1	0.5	15	0.15	8	16	10	0.06	2.2	23	0.6	0.3	0.02	1	25	75
(Duplicate)	31-Aug-2010	0.6 - 1.0m	1	7	300	0.4	0.2	0.5	13	0.15	7	14	10	0.06	1.9	21	0.6	0.3		1	21	74
	31-Aug-2010	2.5 - 3.0m	1	7	280	0.4	0.1	0.5	14	0.15	7	15	9	0.06	2.1	22	0.6	0.3	0.02	1	24	120
GIBG-10-2	01-Sep-2010	0.3 - 0.6m	1	7	310	0.4	0.2	0.5	14	0.15	8	16	9	0.05	1.9	23	0.6	0.3	0.02	1	23	76
	01-Sep-2010	0.6 - 1.0m	1	8	310	0.4	0.2	0.6	14	0.15	8	16	9	0.05	2.1	23	0.7	0.3	0.02	1	24	78
	01-Sep-2010	1.8 - 2.3m	1	6	210	0.4	0.1	0.3	9	0.15	6	8	6	0.05	1.6	15	0.5	0.3	0.02	1	18	50
	01-Sep-2010	3.0 - 3.3m																	0.02			
S12-8D	20-Sep-2012	0.5 - 0.6m	0.64	9.28	408	0.6		0.901	14.9			22.1	11	0.058	2.26	28.9	0.82	0.2			31.1	110
BIBG-15-1	30-Sep-2015	1.8 - 2.4m	0.58	8.4	280	0.43	0.52	0.53	14	0.08	8.7	20	9.2	0.05	2	26	0.63	0.14	0.048	0.93	23	85
BIBG-15-2	30-Sep-2015	1.8 - 2.4m	0.5	6.3	210	0.4	0.18	0.39	12	0.08	6.7	14	6.9	0.05	1.6	20	0.5	0.1	0.02	0.83	19	64
BIBG-15-3	30-Sep-2015	0.5 - 1.0m	0.6	8.4	290	0.46	0.54	0.54	14	0.08	9	20	9.4	0.05	2	26	0.65	0.15	0.02	0.87	24	90
	30-Sep-2015	1.8 - 2.4m	0.6	8.6	290	0.44	0.32	0.5	15	0.08	8.8	20	9.1	0.05	2	26	0.62	0.14	0.02	0.87	24	86
GIBG-15-13	03-Oct-2015	0.6m	0.62	8.6	310	0.48	0.27	0.63	16	0.08	8.9	19	10	0.05	1.9	27	0.68	0.16	0.02	0.85	25	92
(Duplicate)	03-Oct-2015	0.6m																	0.02			
	03-Oct-2015	4.8m	0.5	5.8	140	0.4	0.1	0.31	7.8	0.08	5.5	8.7	5.8	0.05	1.5	15	0.5	0.1	0.02	0.66	15	48
GIBG-15-14	03-Oct-2015	1.8m	0.5	5.8	160	0.4	0.1	0.36	11	0.08	6.4	11	5.9	0.05	1.5	18	0.5	0.1	0.02	0.72	19	57
	03-Oct-2015	3.6m	0.5	5.3	140	0.4	0.13	0.3	9.6	0.08	6.5	8.8	5.3	0.05	1.2	17	0.5	0.1	0.02	0.73	17	53
GIBG-15-15	03-Oct-2015	3.5m	0.5	4.4	120	0.4	0.1	0.25	8.6	0.08	5.3	8.5	4.4	0.05	1.1	14	0.5	0.1	0.02	0.55	15	43
GIBG-15-16	03-Oct-2015	1.8m	0.5	6.7	190	0.4	0.28	0.43	11	0.08	7.1	14	7.1	0.05	1.4	21	0.5	0.11	0.02	0.73	20	71
	03-Oct-2015	3.2m	0.5	5.7	140	0.4	0.21	0.43	8.8	0.08	6.8	11	6	0.05	1.6	18	0.5	0.1	0.02	0.98	17	59
(Duplicate)	03-Oct-2015	3.2m																	0.02			
BIBG-16-12	03-Mar-16	1.0 - 1.3m	0.7	9.9	370	0.57	0.38	0.63	18	0.08	10	23	11	0.053	2.4	31	0.77	0.17		1.1	30	100
MAINLAND - SEEPS																						
MAINLAND SEEPS - Organic Surface Soil																						
MCBG-15-1	23-Sep-2015	0.0 - 0.1m	1	2.3	120	0.8	0.43	0.52	4.3	0.08	1.9	6.2	6.5	0.11	2	8.5	1	0.2	0.04	0.49	14	20
MEBG-10-3	21-Aug-2010	0.0 - 0.3m	1	11	170	0.4	0.8	0.1	33	0.15	16	24	9	0.05	0.4	49	0.5	0.3	0.02	1	46	110
MEBG-15-3	24-Sep-2015	0.0 - 0.1m	1	5.4	230	0.8	0.7	0.36	10	0.08	5.3	12	21	0.1	4.1	17	1	0.27	0.044	1.9	22	50
MEBG-15-4	24-Sep-2015	0.0 - 0.2m	1	6.8	520	0.8	3.5	1.5	9.2	0.08	5.6	22	19	0.1	14	23	1.1	0.6	0.042	3	26	130

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PROJECT No.: 417011-00096

Sampling Location	Date (dd-mmm-yyyy)	Sample Depth	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (Hot Water) (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Chromium (VI) (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)	Toluene (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
MAINLAND SEEPS - Mineral Surface Soil																						
MCBG-15-1	23-Sep-2015	0.1 - 0.3m	0.5	6.7	400	0.6	0.46	1.1	17	0.08	7.5	15	9.4	0.05	1.3	23	0.65	0.1	0.02	1.1	31	120
	23-Sep-2015	0.3 - 0.5m	0.5	13	430	0.85	0.7	0.33	26	0.08	11	17	13	0.05	1.4	31	0.74	0.1	0.02	1	46	100
MWBG-10-03	05-Aug-2010	0.0 - 0.3m	1	3	270	0.4	0.4	0.4	19	0.15	9	18	10	0.05	2	26	0.5	0.3	0.02	1	28	73
	05-Aug-2010	0.3 - 0.6m	1	7	310	0.4	0.3	0.4	17	0.15	8	14	9	0.05	2.1	24	0.5	0.3	0.02	1	25	61
MEBG-15-3	24-Sep-2015	0.1 - 0.5m	1	3.1	340	0.8	0.54	0.46	7.6	0.08	4.6	9.9	5	0.1	0.8	12	1	0.2	0.046	1.6	14	37
MEBG-15-4	24-Sep-2015	0.2 - 0.5m	0.55	5.9	350	0.55	0.64	0.53	18	0.08	7.6	18	14	0.05	1.7	24	0.75	0.1	0.02	1.6	34	75
MWBG-15-2	24-Sep-2015	0.0 - 0.15m	0.56	9	300	0.47	0.34	0.51	16	0.08	9.1	19	8.9	0.05	2.3	27	0.62	0.17	0.02	0.9	27	92
	24-Sep-2015	0.15 - 0.6m	0.5	9.1	220	0.4	0.1	0.27	17	0.08	6.9	14	7.8	0.05	2	23	0.5	0.13	0.02	0.7	24	68
MAINLAND SEEPS - Mineral Subsurface Soil																						
MWBG-10-03	05-Aug-2010	0.6 - 1.0m	1	8	310	0.4	0.2	0.4	20	0.15	8	15	10	0.05	2.4	27	0.5	0.3	0.02	1	26	62
(Duplicate)	05-Aug-2010	0.6 - 1.0m	1	8	320	0.4	0.3	0.4	16	0.15	8	15	10	0.05	2.4	25	0.5	0.3		1	26	65
	05-Aug-2010	2.2 - 2.7m	1	10	250	0.4	0.2	0.3	18	0.15	7	11	9	0.05	3	24	0.5	0.3	0.02	1	27	49
	05-Aug-2010	4.0 - 4.5m	1	8	320	0.4	0.6	0.5	14	0.15	8	16	10	0.05	1.7	24	0.6	0.3	0.02	1	25	71
MEBG-15-3	24-Sep-2015	0.5 - 1.2m	0.5	6.6	160	0.4	0.52	0.31	14	0.08	7.1	15	6.2	0.05	1.6	23	0.5	0.1	0.02	0.66	21	61
	24-Sep-2015	2.4 - 3.0m	0.73	10	380	0.61	0.1	0.59	20	0.08	12	26	12	0.05	2.6	34	0.8	0.16	0.097	1.1	32	110
MEBG-15-4	24-Sep-2015	0.5 - 0.8m	0.53	6.1	150	0.4	0.15	0.35	13	0.08	7.3	15	8.4	0.05	1.7	23	0.5	0.12	0.02	0.73	22	61
	24-Sep-2015	1.8 - 2.4m	0.82	13	330	0.68	2.3	1.2	21	0.08	12	31	13	0.05	1.9	36	1.1	0.2	0.044	1.4	36	130
MWBG-15-2	24-Sep-2015	2.4 - 3.0m	0.67	25	310	0.99	0.67	0.079	42	0.08	21	49	17	0.052	0.73	63	0.5	0.19	0.02	0.45	54	170
MAINLAND SEEPS - Bedrock																						
MCBG-15-1	23-Sep-2015	4.2 - 4.8m	0.5	21	140	0.65	0.93	0.064	33	0.08	19	25	11	0.051	0.4	56	0.5	0.1	0.02	0.39	41	140
MEBG-10-3	21-Aug-2010	0.3 - 0.6m	1	16	160	0.4	1.1	0.1	31	0.15	16	23	9	0.05	0.4	49	0.5	0.3	0.02	1	45	110
	21-Aug-2010	0.6 - 1.0m	1	14	200	0.4	1.2	0.1	32	0.15	17	24	9	0.05	0.4	50	0.5	0.3	0.02	1	46	110
	21-Aug-2010	2.5 - 3.0m	1	21	130	0.4	1.1	0.1	37	0.15	14	31	11	0.08	0.4	49	0.5	0.3	0.02	1	94	100

Table 12

Groundwater Geochemical Statistical Source Data (1997-2019) - Indicator Parameters

PROJECT No.: 417011-00096

Monitoring Station		Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
MAINLAND - Surficial Sediments																	
B38 93-2-4	08-Jul-1997	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	07-Sep-1997	761	199	0.5	15.5	1130	668	0.5	0.11	0.022	7.9	---	2.3	0.5	24.7	16.5	828
	09-Sep-1998	781	191	0.5	14.7	1160	649	0.5	0.16	0.005	7.7	0.003	1.6	0.5	11.3	17	726
	15-Sep-1999	845	207	0.5	11	1180	710	0.5	0.04	0.014	8.1	---	2	0.5	10.7	12.3	780
	18-Oct-1999	---	---	---	---	---	---	---	---	---	---	0.003	---	---	---	---	---
	17-Sep-2000	881	213	0.5	7.7	1210	716	0.5	0.1	0.008	6.9	0.006	3	1	8.5	19	796
(Duplicate)	17-Sep-2000	878	198	0.5	8	1230	689	0.5	0.08	0.012	6.9	0.005	2	1	8.58	19.1	796
	26-Aug-2001	951	236	0.5	6.8	1360	788	0.5	0.08	0.005	7.1	0.003	2	1	9.04	22.5	834
	20-Aug-2002	957	245	0.5	9.9	1310	821	0.5	0.06	0.005	7.6	---	2	1	8.51	18.6	872
	25-Aug-2003	912	228	0.5	7	1190	752	0.5	0.2	0.06	6.7	---	1.97	1	8.32	23	786
(Duplicate)	25-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	10-Sep-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BT3 97-2-5	07-Sep-1997	984	274	0.5	2.5	1940	1250	0.5	0.02	0.006	8	---	3	0.5	20.4	470	1580
	10-Sep-1998	675	168	0.5	3.3	1330	792	0.5	0.02	0.005	7.7	0.02 0.02	2.3	0.5	16.8	237	986
	16-Sep-1999	995	303	0.5	2.8	2030	1230	0.5	0.05	0.005	7.4	0.008 0.008	2.8	0.5	16.2	465	1640
	18-Sep-1999	1000	---	0.5	2.8	2030	---	0.5	0.04	0.005	7.2	---	---	0.5	---	501	1600
	19-Sep-2000	---	---	---	---	---	---	---	---	---	---	0.021	---	---	---	---	---
	20-Aug-2002	595	281	0.5	3	1780	1100	0.5	0.3	0.111	8	0.008	4	1	25.3	286	1340
	24-Aug-2003	983	247	0.5	2	1480	945	0.5	0.2	0.06	7	---	3.9	1	20.3	254	1070
MCBG-10-1-3	29-Sep-2010	810	210	0.5	2	1200	738	0.5	0.07	0.011	6.95	0.002	3.4	0.5	13	58	810
	19-Aug-2011	820	180	0.5	3	1300	650	0.5	0.18	0.025	7.5	0.002	2.8	0.5	35	100	830
	16-Aug-2012	860	190	0.5	3.5	1400	640	0.5	0.016	0.003	7.71	0.002	2.2	0.5	60	86	840
	20-Aug-2013	---	170	---	3	1300	---	---	0.14	0.0036	---	0.01	2.1	---	50	58	---
	30-Jul-2014	---	160	---	3.1	1300	---	---	0.24	0.01	---	0.0042	5.2	---	160	48	---
	07-Aug-2015	---	210	---	3.6	1400	---	---	0.35	0.01	---	0.002	2	---	62	38	---
	04-Aug-2016	1000	220	0.5	4	1500	790	0.5	0.016	0.012	7.32	0.01	1.9	0.5	56	30	890
	12-Aug-2017	850	190	0.5	2.4	1300	680	0.5	0.11	0.01	---	0.0076	1.3	0.5	29	33	780
	18-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	22-Jul-2018	730	160	1	2.8	1100	570	1	0.01	0.01	---	0.0048	1.1	1	17	24	640
	11-Jul-2019	690	140	1	2.4	1000	490	1	0.01	0.01	---	0.0091	0.69	1	11	27	530
MCBG-12-1-2	17-Aug-2012	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2012	960	360	0.5	2.9	2400	1400	0.5	0.052	0.003	7.35	0.0052	4.8	0.5	49	750	1900
	25-Aug-2013	810	310	0.5	2.2	2000	1100	0.5	0.018	0.0039	7.72	0.013	3.4	0.5	24	640	1600
	31-Jul-2014	710	240	0.5	2.6	1400	830	0.5	0.085	0.01	7.3	0.0071	4.6	0.5	16	330	1100
	08-Aug-2015	800	240	0.5	2.5	1500	840	0.5	0.022	0.01	7.01	0.002	3	0.5	22	200	1000
	05-Aug-2016	790	240	0.5	3	1600	860	0.5	0.01	0.012	7.27	0.0082	2.5	0.5	15	250	1200
	08-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2017	790	280	0.5	5.4	1600	980	0.5	0.01	0.034	---	0.0078	2.4	0.5	13	310	1300
	22-Jul-2018	330	130	1	4.8	730	500	1	0.1	0.10	---	0.012	1.2	1	4.8	140	640
	15-Jul-2019	460	240	1	2.4	1300	890	1	0.011	0.01	---	0.012	1.5	1	7.4	400	1100
MEBG-10-1-3	29-Sep-2010	590	180	0.5	5	1000	609	0.5	0.021	0.003	7.27	0.002	2.1	0.5	8.9	99	650
	18-Aug-2011	690	150	0.5	4	1100	510	0.5	0.003	0.003	7.58	0.003	2.2	0.5	53	93	720
	19-Aug-2012	690	160	0.5	3.8	1100	560	0.5	0.026	0.003	7.5	0.002	2	0.5	27	85	720
	25-Aug-2013	---	200	---	3.2	1200	---	---	0.035	0.003	---	0.0079	1.9	---	25	120	---
	30-Jul-2014	800	200	0.5	2.2	1300	670	0.5	0.081	0.01	7.52	0.0028	7.4	0.5	37	160	860
	06-Aug-2015	610	200	0.5	3	1200	680	0.5	0.026	0.015	7.32	0.002	1.6	0.5	22	190	810
	14-Sep-2015	670	200	0.5	2.4	1200	680	0.5	0.013	0.01	7.2	0.002	1.9	0.5	23	170	780
	03-Aug-2016	520	170	0.5	2.2	980	570	0.5	0.021	0.01	7.45	0.002	1.3	0.5	12	140	460
	02-Oct-2016	530	190	0.5	2.3	970	660	0.5	0.015	0.01	7.67	0.002	1.8	0.5	15	130	560
	04-Nov-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Aug-2017	770	230	0.5	2.4	1400	760	0.5	0.011	0.01	---	0.0039	1.5	0.5	40	180	890
	13-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Sep-2017	750	220	0.5	2.4	1300	770	0.5	0.091	0.01	---	0.0026	1.7	0.5	33	180	910
	15-Sep-2018	630	210	1	2.3	1300	710	1	0.058	0.01	---	---	1.6	1	18	240	880
	15-Jul-2019	290	97	1	2	630	330	1	0.024	0.01	---	---	0.66	1	7.1	110	310

Table 12

Groundwater Geochemical Statistical Source Data (1997-2019) - Indicator Parameters

PROJECT No.: 417011-00096

Monitoring Station		Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
MEBG-12-2-3	30-Jul-2014	970	210	0.5	3.5	1500	810	0.5	0.039	0.01	7.37	0.0069	3.1	0.5	76	170	1200
	09-Aug-2015	730	130	0.5	2.7	1400	520	0.5	0.17	0.013	7.17	0.0055	1.7	0.5	130	220	980
	05-Aug-2016	570	95	0.5	2.2	1100	400	0.5	0.052	0.01	7.45	0.006	1.6	0.5	97	130	640
	11-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2017	570	67	0.5	5.4	970	250	0.5	0.044	0.01	---	0.0078	1.5	0.5	130	73	690
	22-Jul-2018	570	59	5	15	100	210	5	0.079	0.023	---	0.0051	2	5	170	95	1200
	14-Jul-2019	---	---	---	8.4	740	---	---	0.07	0.01	---	---	---	---	---	19	---
MLS 09-6-2	19-Aug-2009	580	120	0.5	5	1100	590	0.5	0.046	0.003	8.08	0.003	6.1	0.5	14	210	730
	19-Aug-2011	440	81	0.5	9	850	380	0.5	0.091	0.003	7.92	---	4.2	0.5	28	98	460
MLS-13-9-3	08-Aug-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	09-Aug-2015	280	56	0.5	2.4	510	220	0.5	0.081	0.015	7.58	0.002	1.4	0.5	25	46	280
	03-Aug-2016	280	63	0.5	1	540	230	0.5	0.072	0.01	8	0.002	1.4	0.5	29	49	300
	11-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	16-Aug-2017	210	50	0.5	1.4	450	180	0.5	0.43	0.01	---	0.0055	0.85	0.5	34	66	290
	19-Jul-2018	120	110	1	2.2	220	160	1	0.14	0.01	---	---	2.5	1	18	18	180
MLS-14-3-3	30-Jul-2014	290	32	0.5	18	520	130	0.5	0.01	0.01	7.87	0.013	4.4	0.5	71	29	400
	08-Aug-2015	470	53	0.5	15	750	230	0.5	0.039	0.01	7.66	0.002	2.8	0.5	77	20	370
	03-Aug-2016	580	66	0.5	17	930	300	0.5	0.16	0.01	7.89	0.0037	3.6	0.5	91	35	560
MLS-14-4-3	30-Jul-2014	280	18	0.5	13	500	80	0.5	0.014	0.01	8.06	0.0038	2.2	0.5	88	27	390
	08-Aug-2015	490	30	0.5	19	820	150	0.5	0.012	0.01	7.79	0.002	3	0.5	140	27	500
	03-Aug-2016	520	23	0.5	24	850	120	0.5	0.12	0.01	8.11	0.0058	3.6	0.5	160	23	550
(Duplicate)	03-Aug-2016	520	23	0.5	26	890	120	0.5	0.087	0.01	8.09	0.0028	3.6	0.5	160	24	520
MLS-14-8-3	29-Jul-2014	230	55	0.5	2.8	480	230	0.5	0.017	0.01	7.94	0.0057	3.4	0.5	12	79	290
	04-Aug-2016	640	130	0.5	8.7	960	520	0.5	0.021	0.012	7.65	0.0078	5	0.5	15	30	560
MWBG-10-1-3	30-Sep-2010	680	120	0.5	15	1200	580	0.5	0.015	0.003	7.62	0.002	2.8	0.5	63	130	760
	18-Aug-2011	750	100	0.5	16	1400	500	0.5	0.003	0.003	7.76	0.002	2.6	0.5	120	150	860
	17-Aug-2012	1100	170	0.5	8.3	2000	680	0.5	0.003	0.003	7.26	0.002	5.5	0.5	180	260	1400
	21-Aug-2013	---	170	---	6.1	1900	---	---	0.061	0.003	---	0.013	2.8	---	180	140	---
	30-Jul-2014	---	190	---	5	1600	---	---	0.029	0.01	---	0.006	2.9	---	58	200	---
	08-Aug-2015	---	180	---	11	1800	---	---	0.023	0.01	---	0.002	3.5	---	180	81	---
	03-Aug-2016	1100	170	0.5	11	1700	670	0.5	0.11	0.01	7.24	0.011	2.8	0.5	150	130	1100
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Aug-2017	1100	190	0.5	5.9	1600	720	0.5	0.13	0.01	---	0.007	2.3	0.5	110	120	1000
	22-Jul-2018	1000	200	1	4.6	1500	690	1	0.015	0.01	---	0.0048	2.3	1	72	79	930
	11-Jul-2019	920	160	1	9	1400	610	1	0.018	0.01	---	0.0095	2	1	74	65	900
MWBG-12-1-3	17-Aug-2012	400	120	0.5	14	900	430	0.5	0.003	0.003	7.87	---	12	0.5	31	160	580
WBIO 08-1-2	19-Aug-2009	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2009	900	330	0.5	7	2600	1600	0.5	36	0.033	7.41	0.002	1.8	0.5	46	820	2200
	20-Aug-2010	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	18-Aug-2011	900	280	0.5	6	2300	1300	0.5	9.5	0.005	7.63	0.002	1.7	0.5	41	700	2000
	17-Aug-2012	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	06-Aug-2015	---	400	---	7.5	2800	---	---	26	0.017	---	0.014	2	---	68	980	---
	03-Aug-2016	---	390	---	9.2	2800	---	---	14	0.012	---	---	1.8	---	46	960	---
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		-768.00	-120.00	4.50	-1.30	-290.00	-199.00	4.50	35.61	0.09	-1.46	0.00	5.20	4.50	-59.50	279.00	-90.00

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Table 12

Groundwater Geochemical Statistical Source Data (1997-2019) - Indicator Parameters

PROJECT No.: 417011-00096

Monitoring Station		Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
BEAR, FRENCHY'S GOOSE ISLANDS - Surficial Sediments																	
BI 08-1-4	19-Aug-2008	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	21-Aug-2008	1100	450	0.5	9.7	2600	1500	0.5	0.025	0.009	7.3	0.005	2.7	0.5	40	760	2200
	18-Aug-2009	1200	520	0.5	9	3000	1800	0.5	0.093	0.01	7.32	0.003	2.8	0.5	88	1000	2400
(Duplicate)	18-Aug-2009	---	540	---	---	---	---	---	---	---	---	0.007	2.7	---	82	---	---
	23-Aug-2010	900	480	0.5	9	2400	1630	0.5	0.19	0.015	7.25	0.002	2.4	0.5	24	820	1900
(Duplicate)	23-Aug-2010	---	450	---	---	---	---	---	---	---	---	0.006	2.3	---	22	---	---
	21-Aug-2011	---	410	---	9	2300	---	---	0.096	0.018	---	0.002	2.3	---	28	800	---
(Duplicate)	21-Aug-2011	---	410	---	---	---	---	---	---	---	---	0.002	2.3	---	28	---	---
	15-Aug-2012	670	330	0.5	11	2300	1300	0.5	0.28	0.003	7.95	0.002	2.5	0.5	100	900	1900
(Duplicate)	15-Aug-2012	---	330	---	---	---	---	---	---	---	---	0.002	2.5	---	100	---	---
BI-13-6-2	03-Aug-2014	400	140	0.5	9.8	960	580	0.5	0.2	0.01	7.16	0.015	3.2	0.5	8.2	190	740
	09-Aug-2015	450	130	0.5	8.3	920	560	0.5	0.014	0.012	7.4	0.015	2.9	0.5	9.1	170	700
	10-Aug-2016	520	150	0.5	8.5	1100	640	0.5	0.052	0.01	7.74	0.01	3.1	0.5	7.8	190	830
	14-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Jul-2019	620	150	1	9.3	1200	690	1	0.03	0.01	---	0.0075	1.7	1	14	180	920
BI-14-8-3	04-Aug-2014	450	310	0.5	9.3	1200	1100	0.5	0.46	0.01	7.29	0.0067	4.2	0.5	19	310	880
	08-Aug-2015	700	430	0.5	7.5	1500	1600	0.5	0.084	0.01	7.24	0.002	3.5	0.5	25	310	1200
BIBG-10-1-4	29-Sep-2010	990	420	0.5	9	2300	1420	0.5	0.026	0.006	7.16	0.005	5.3	0.5	14	650	1900
	21-Aug-2011	800	340	0.5	5	2100	1200	0.5	0.11	0.013	7.38	0.003	3.3	0.5	23	620	1700
	15-Aug-2012	810	360	0.5	4.6	2100	1300	0.5	6.7	0.047	7.75	0.0049	3.1	0.5	12	610	1700
	19-Sep-2013	740	260	0.5	3	1600	890	0.5	0.023	0.011	6.88	0.012	2.3	0.5	6.8	340	1200
	03-Aug-2014	---	240	---	3.5	1400	---	---	0.044	0.01	---	0.048	2.2	---	5.8	370	---
	09-Aug-2015	---	250	---	12	1400	---	---	0.032	0.01	---	0.0058	2.2	---	6.6	380	---
	09-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	10-Aug-2016	630	320	0.5	25	1800	1100	0.5	0.011	0.01	7.34	0.0027	2.1	0.5	7.4	520	1300
	11-Aug-2017	540	230	0.5	18	1400	800	0.5	0.18	0.01	---	0.002	1.9	0.5	7.5	350	1000
	20-Sep-2018	550	220	1	23	1300	780	1	0.01	0.01	---	---	1.8	1	7.5	1	1000
	17-Jul-2019	480	220	1	23	1300	750	1	0.01	0.01	---	---	1.7	1	6.7	3.7	950
BIBG-10-2-4	29-Sep-2010	630	290	0.5	7	1400	906	0.5	0.73	0.013	7.24	0.002	3.6	0.5	8.4	300	1100
BIBG-12-1-7	19-Sep-2013	460	76	0.5	9.2	1200	280	0.5	2.3	0.016	8.08	0.013	2.5	0.5	170	240	810
	03-Aug-2014	710	310	0.5	11	2500	1100	0.5	23	0.01	7.96	0.0087	---	0.5	---	840	---
	09-Aug-2015	960	110	0.5	8.1	2600	450	0.5	2.6	0.17	7.4	0.0056	2	0.5	520	670	2100
	07-Aug-2016	910	180	0.5	7.5	2400	770	0.5	0.4	0.043	7.42	---	1.5	0.5	300	620	1700
BIBG-12-2-4	15-Aug-2012	690	170	0.5	18	1200	590	0.5	0.11	0.003	8.03	0.002	4.3	0.5	57	110	790
	23-Aug-2013	---	190	---	24	1200	---	---	0.0073	0.0061	---	0.0069	3.6	---	26	83	---
	04-Aug-2014	840	250	0.5	18	1300	800	0.5	0.033	0.01	7.42	0.0073	3.7	0.5	37	83	880
	09-Aug-2015	850	200	0.5	15	1300	740	0.5	0.01	0.01	7.11	0.0061	3.3	0.5	28	73	850
	09-Aug-2016	830	190	0.5	11	1300	690	0.5	0.027	0.01	7.36	0.0044	3.7	0.5	21	55	800
	15-Aug-2017	720	180	0.5	8.8	1200	660	0.5	0.031	0.01	---	0.008	2.7	0.5	14	89	770
	18-Jul-2018	630	150	1	7.7	1100	540	1	0.023	0.01	---	0.0037	2.3	1	11	94	690
	12-Jul-2019	600	150	1	7.7	1000	580	1	0.012	0.01	---	0.0062	1.7	1	15	110	680
FIBG-10-1-4	29-Sep-2010	310	200	0.5	9	1000	621	0.5	0.015	0.004	7.19	0.003	3.2	0.5	9.6	310	720
(Duplicate)	29-Sep-2010	---	200	---	---	---	---	---	---	---	---	0.002	3	---	9.5	---	---
GIBG-10-1-5	21-Aug-2011	900	480	0.5	4	2900	1600	0.5	0.022	0.011	7.41	---	4.7	0.5	13	1200	2700
	15-Aug-2012	810	420	0.5	3.3	2600	1500	0.5	0.003	0.003	7.82	---	3.7	0.5	78	1100	2300
GIBG-10-2-3	28-Sep-2010	630	180	0.5	9	1100	577	0.5	0.007	0.003	7.54	0.002	4.5	0.5	10	77	630
(Duplicate)	28-Sep-2010	---	180	---	---	---	---	---	---	---	---	0.002	4.5	---	10	---	---
	21-Aug-2011	490	120	0.5	5	800	390	0.5	0.009	0.003	7.4	0.002	3.1	0.5	11	40	510
	15-Aug-2012	380	120	0.5	2.8	760	370	0.5	0.013	0.0058	7.92	0.002	2.5	0.5	22	110	480
(Duplicate)	15-Aug-2012	---	120	---	---	---	---	---	---	---	---	0.002	2.6	---	22	---	---
	25-Aug-2013	350	88	0.5	3.9	640	290	0.5	0.024	0.003	7.98	0.01	2.2	0.5	18	65	390
(Duplicate)	25-Aug-2013	350	88	0.5	3.9	640	290	0.5	0.024	0.003	7.99	0.01	2.2	0.5	17	65	400
	03-Aug-2014	390	120	0.5	5.9	730	390	0.5	0.038	0.01	7.76	0.0071	3.3	0.5	9.1	150	500
(Duplicate)	03-Aug-2014	290	120	0.5	6.1	720	390	0.5	0.084	0.01	7.75	0.0072	3.3	0.5	9.2	150	500
	10-Aug-2015	270	71	0.5	1.9	510	230	0.5	0.057	0.011	7.71	0.0034	2.5	0.5	18	58	330
(Duplicate)	10-Aug-2015	---	71	---	---	---	---	---	---	---	---	0.0035	2.4	---	17	---	---
	16-Sep-2015	440	170	0.5	3.1	1200	530	0.5	0.18	0.01	7.9	0.002	3.9	0.5	57	330	690
	07-Aug-2016	290	87	0.5	1	610	270	0.5	0.11	0.01	7.85	0.0032	2.6	0.5	30	77	430
(Duplicate)	07-Aug-2016	310	87	0.5	1	640	270	0.5	0.12	0.01	7.86	0.0031	2.6	0.5	30	84	360
	02-Oct-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	03-Oct-2016	470	120	0.5	2.3	840	390	0.5	0.016	0.01	7.76	0.002	3	0.5	34	98	570
	04-Nov-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2017	370	130	0.5	2.4	810	430	0.5	0.13	0.01	---	0.0026	2.9	0.5	30	140	560
(Duplicate)	20-Aug-2017	410	130	0.5	2.3	840	430	0.5	0.11	0.01	---	0.0038	2.9	0.5	29	130	560
	12-Sep-2017	630	190	0.5	2.9	1200	630	0.5	0.1	0.01	---	0.0027	3.7	0.5	43	180	740
	20-Sep-2018	460	140	1	6.9	870	450	1	0.1	0.01	---	---	2.8	1	30	130	580
	16-Jul-2019	390	93	1	9.9	690	310	1	0.19	0.01	---	---	1.7	1	17	61	450
(Duplicate)	16-Jul-2019	380	93	1	9.9	690	310	1	0.19	0.01	---	---	1.7	1	17	61	460

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Table 12

Groundwater Geochemical Statistical Source Data (1997-2019) - Indicator Parameters

PROJECT No.: 417011-00096

Monitoring Station		Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
SHALLOW BEDROCK - Inferred to Represent Natural Saline Water and Hydrocarbon Seepage																	
NWR 98-18-15	09-Sep-1998	1240	62.9	0.5	330	2660	327	0.5	0.02	0.005	8	0.016	6.7	0.5	582	7.1	1740
	15-Sep-1999	1310	35.6	23.1	230	2640	168	0.5	0.02	0.005	8.5	0.014	4.3	19.3	596	3.7	1740
	17-Sep-2000	1330	34.8	0.5	290	2820	163	0.5	0.06	0.005	8	0.016	4	1	560	11.2	1700
(Duplicate)	17-Sep-2000	1340	31.5	0.5	280	2810	150	0.5	0.02	0.005	7.8	0.016	4	1	496	7.6	1650
	27-Aug-2001	1510	36.4	0.5	230	2760	167	0.5	0.02	0.005	8.2	0.001	4	1	525	5.2	1720
	22-Aug-2002	1570	38.3	21.6	216	2860	172	0.5	0.02	0.005	8.4	0.003	4	18	637	12.4	1850
(Duplicate)	22-Aug-2002	1570	34.6	0.5	206	2830	149	0.5	0.02	0.005	8.2	0.007	5	1	711	8.7	1810
	26-Aug-2003	1400	51.9	0.5	346	2800	246	0.5	0.2	0.06	7	0.007	6.8	1	570	4	1820
(Duplicate)	26-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NWR 99-16-17	15-Sep-1999	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Sep-2000	1380	13.2	39.6	280	3000	47.5	0.5	0.04	0.006	8.5	0.025	5	33	675	24.7	1960
	27-Aug-2001	1540	13.9	26.4	257	3030	50.3	0.5	0.02	0.007	8.4	0.004	4	22	749	18	1730
	21-Aug-2002	1570	15.8	0.5	240	2970	62.8	0.5	0.02	0.005	8.4	0.01	5	1	771	10.6	1930
	26-Aug-2003	1680	13.2	0.5	318	2680	48.8	0.5	0.2	0.06	7.5	---	4.17	1	770	7	1440
RB 02-3-2	22-Aug-2002	1190	15.8	30	212	2420	55.1	0.5	0.02	0.005	8.5	0.007	6	25	592	2.2	1560
(Duplicate)	22-Aug-2002	1280	15.1	0.5	220	2490	52.4	0.5	0.02	0.005	8.6	0.004	6	1	589	2.5	1580
	26-Aug-2003	1370	13.7	0.5	163	2400	47.9	0.5	0.2	0.06	7.6	---	3.88	1	537	13	1580
(Duplicate)	26-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	23-Aug-2004	1370	17.8	0.5	147	2530	60.9	0.5	0.2	0.06	7.9	---	4.68	1	589	44	1590
(Duplicate)	23-Aug-2004	---	17.7	---	---	---	60.1	---	---	---	---	---	4.66	---	580	---	---
	25-Aug-2005	1330	19.8	8	164	2470	71	1	0.2	0.06	8.3	0.019	3.6	7	619	8	---
(Duplicate)	25-Aug-2005	---	16.8	---	---	---	---	---	---	---	---	0.021	3.9	---	509	---	---
	20-Aug-2006	1510	24.8	1	158	2690	86	1	0.2	0.06	7.9	0.01	3.6	1	730	185	1830
(Duplicate)	20-Aug-2006	---	24.7	---	---	---	---	---	---	---	---	0.011	3.7	---	733	---	---
NWR 09-1-20	25-Oct-2011	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2012	1100	64	0.5	140	1900	270	0.5	0.003	0.0034	7.73	0.007	5.4	0.5	360	1	1100
	25-Aug-2013	1200	34	0.5	130	2100	140	0.5	0.003	0.003	8.08	0.01	3.9	0.5	410	1.3	1300
	08-May-2014	1100	81	0.5	82	1800	350	0.5	0.01	0.01	7.42	---	---	0.5	---	3.1	1200
	01-Aug-2014	1100	88	0.5	100	1800	390	0.5	0.01	0.01	7.33	0.018	4.9	0.5	310	3.9	1200
	31-May-2015	1200	59	0.5	120	2100	250	0.5	0.01	0.011	7.84	0.0032	4.2	0.5	430	44	2600
	05-Jul-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
(Duplicate)	05-Jul-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	08-Aug-2015	1300	69	0.5	180	2400	300	0.5	0.01	0.01	7.66	0.0075	5.5	0.5	470	5.3	1600
	25-Nov-2015	1300	45	0.5	170	2200	190	0.5	0.01	0.01	7.81	0.0043	4.3	0.5	750	5	1300
(Duplicate)	25-Nov-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Mar-2016	1100	84	0.5	63	1700	360	0.5	0.01	0.01	7.56	0.0032	4.6	0.5	260	5.1	960
	05-Aug-2016	---	83	---	82	1700	---	---	0.01	0.01	---	---	4.8	---	240	9.7	---
	02-Nov-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	03-Nov-2016	1200	76	0.5	100	1900	340	0.5	0.05	0.05	7.67	0.0035	4.6	0.5	340	5.4	2000
	13-Aug-2017	---	52	---	290	3100	---	---	0.01	0.01	---	---	4.8	---	710	3.2	---
	22-Jul-2018	---	50	---	320	3300	---	---	0.01	0.01	---	---	4.8	---	680	1	---
	15-Jul-2019	---	53	---	270	2900	---	---	0.05	0.05	---	---	4.7	---	600	3	---
NWR 09-3-20	13-Sep-2009	1200	13	0.5	140	2200	44	0.5	0.003	0.003	7.66	0.004	2.5	0.5	470	64	1500
	20-Aug-2010	960	26	9.8	120	2000	109	0.5	0.003	0.003	8.35	0.004	3.6	8.2	410	18	1200
	18-Aug-2011	1100	57	0.5	120	1900	240	0.5	0.003	0.003	7.93	0.004	4.2	0.5	350	32	1200
	19-Aug-2012	960	58	0.5	95	1700	240	0.5	0.003	0.003	7.77	0.0044	4.4	0.5	290	8.2	1000
	21-Aug-2013	---	38	---	140	2200	---	---	0.01	0.003	---	0.019	3.1	---	440	15	---
	11-Oct-2013	970	83	0.5	85	1600	350	0.5	0.014	0.003	7.62	---	4.2	0.5	230	9.1	990
	08-May-2014	1000	45	0.5	110	1900	170	0.5	0.01	0.01	8.1	---	---	0.5	---	6.1	1200
	01-Aug-2014	---	48	---	110	1800	---	---	0.01	0.01	---	0.012	3.5	---	450	13	---
	31-May-2015	1400	29	0.5	200	2600	110	0.5	0.01	0.01	7.87	0.011	3.6	0.5	680	1	1700
	04-Jul-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
(Duplicate)	04-Jul-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	09-Aug-2015	---	32	---	190	2500	---	---	0.01	0.01	---	0.009	3.3	---	580	5.2	---
	25-Nov-2015	1300	30	0.5	170	2200	120	0.5	0.01	0.01	7.72	0.004	3.1	0.5	610	4	1400
	12-Mar-2016	1100	50	0.5	130	1900	190	0.5	0.01	0.01	7.62	0.0041	3.5	0.5	430	2.4	1400
	05-Aug-2016	---	53	---	130	1900	---	---	0.01	0.01	---	---	3.7	---	360	2.1	---
	13-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	15-Aug-2017	---	48	---	110	1900	---	---	0.01	0.01	---	---	3.5	---	400	1	---
	20-Jul-2018	---	47	---	170	2200	---	---	0.01	0.01	---	---	3.7	---	390	1	---
	15-Jul-2019	---	57	---	120	2000	---	---	0.01	0.01	---	---	4.1	---	390	1	---
NWR 09-4-17	13-Sep-2009	1100	28	0.5	86	2000	110	0.5	0.074	0.26	8.03	0.013	6.3	0.5	440	100	1300
	20-Aug-2010	1100	33	0.5	130	2100	137	0.5	0.02	0.006	8.22	0.003	5	0.5	430	30	1200
	18-Aug-2011	1200	28	0.5	140	2100	110	0.5	0.006	0.003	8.06	0.003	4.4	0.5	410	37	1300
	20-Aug-2012	1200	37	0.5	120	2100	150	0.5	0.083	0.019	8.13	0.0052	4.8	0.5	440	47	1100
	25-Aug-2013	---	34	---	110	2100	---	---	0.029	0.0095	---	0.0026	4.3	---	410	40	---
	08-May-2014	1200	40	0.5	110	2000	160	0.5	0.01	0.01	7.62	---	---	0.5	---	35	1300
	01-Aug-2014	---	50	---	100	2000	---	---	0.016	0.01	---	0.0074	4.8	---	420	40	---
	01-Jun-2015	1200	44	0.5	100	2000	170	0.5	0.01	0.01	7.86	0.0053	4.2	0.5	460	50	1300
	04-Jul-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
(Duplicate)	04-Jul-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	08-Aug-2015	---	45	---	100	2000	---	---	0.01	0.01	---	0.002	4.7	---	450	32	---
	25-Nov-2015	1200	41	0.5	110	2000	160	0.5	0.01	0.01	7.63	0.002	3.9	0.5	420	29	1300
	12-Mar-2016	1200	44	0.5	110	2000	180	0.5	0.01	0.01	7.77	0.0041	4	0.5	410	31	1300
	05-Aug-2016	---	43	---	100	2000	---	---	0.01	0.01	---	---	4	---	400	28	---
	13-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	02-Nov-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	03-Nov-2016	1200	42	0.5	100	2000	170	0.5	0.01	0.01	7.84	0.004	4.1	0.5	440	26	1200
	13-Aug-2017	---	42	---	110	2000	---	---	0.01	0.01	---	---	4.1	---	450	18	---
	22-Jul-2018	---	45	---	110	2000	---	---	0.01	0.01	---	---	4.1	---	410	11	---
	15-Jul-2019	---	42	---	110	2000	---	---	0.01	0.01	---	---	4.1	---	420	6.5	---

Table 12

Groundwater Geochemical Statistical Source Data (1997-2019) - Indicator Parameters

PROJECT No.: 417011-00096

Monitoring Station		Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
BT3 99-21-12	16-Sep-1999	1080	132	0.5	720	2910	514	0.5	0.02	0.005	8	---	6.3	0.5	296	27.8	2420
	18-Sep-2000	1010	137	0.5	570	3410	520	0.5	0.02	0.005	7.3	0.02	6	1	283	29	1890
	27-Aug-2001	1040	153	0.5	175	2010	602	0.5	0.02	0.005	7.6	0.004	7	1	213	43.4	1260
	20-Aug-2002	962	219	0.5	766	3780	792	0.5	0.02	0.005	7.9	0.011	8	1	358	36.6	2380
	25-Aug-2003	956	292	0.5	1340	4810	1020	0.5	0.2	0.06	6.8	---	14.1	1	562	18	3130
	22-Aug-2004	---	474	---	1500	5880	1580	---	0.2	0.06	---	---	16.8	---	848	22	---
	25-Aug-2005	---	171	---	76.9	1720	---	---	0.2	0.06	---	0.021	7.3	---	104	40.1	---
(Duplicate)	25-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	22-Aug-2006	---	155	---	216	1820	---	---	0.2	0.06	---	0.008	7.5	---	243	81	---
	22-Aug-2007	---	166	---	689	3320	---	---	0.2	0.06	---	0.007	6.8	---	347	52	---
	19-Aug-2008	---	150	---	480	2900	---	---	0.24	0.022	---	0.014	6	---	150	58	---
	17-Aug-2009	990	230	0.5	490	2900	---	0.5	0.19	0.019	7.29	0.005	7.6	0.5	220	120	---
	21-Aug-2010	920	210	0.5	770	3900	785	0.5	0.68	0.058	7.58	0.002	7.8	0.5	280	50	2200
	20-Aug-2011	---	150	---	140	1800	---	---	3.2	0.22	---	0.002	6.4	---	170	85	---
	20-Aug-2012	---	110	---	140	1600	---	---	2.4	0.018	---	0.003	4.6	---	220	160	---
	23-Aug-2013	---	140	---	270	2100	---	---	4	0.052	---	0.011	6.4	---	250	72	---
	31-Jul-2014	---	170	---	200	1900	---	---	1.9	0.073	---	0.0064	4.4	---	150	83	---
	08-Aug-2015	---	130	---	77	1100	---	---	0.25	0.014	---	---	2.1	---	65	61	---
	05-Aug-2016	---	160	---	160	1600	---	---	1.1	0.042	---	---	3.2	---	64	140	---
	13-Aug-2017	---	170	---	330	2400	---	---	0.75	0.016	---	---	5.8	---	200	87	---
	16-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Jul-2018	---	170	---	84	1300	---	---	0.37	0.012	---	---	4.2	---	130	130	---
	13-Jul-2019	---	160	---	170	1700	---	---	0.33	0.018	---	---	4	---	76	89	---
SURFICIAL SEDIMENTS - Inferred to Represent Natural Saline Water and Hydrocarbon seepage																	
NWR 03-38-3	26-Aug-2003	1220	89.7	0.5	291	2180	301	0.5	0.2	0.06	7	---	6.13	1	431	14	1500
(Duplicate)	26-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	23-Aug-2004	987	116	0.5	150	2000	368	0.5	0.2	0.06	7.5	---	5.88	1	372	31	1200
	25-Aug-2005	879	173	1	104	1740	540	1	0.2	0.06	7.8	0.023	4.4	1	212	93.5	---
(Duplicate)	25-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2006	1150	153	1	174	2010	490	1	0.2	0.06	7.8	0.012	4.7	1	322	49	1330
RB-13-2-2.4	06-Jun-2001	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	11-Oct-2013	1200	110	0.5	150	2100	390	0.5	0.003	0.0066	7.72	---	4.4	0.5	340	39	1300
	14-Sep-2014	1100	160	0.5	130	2000	520	0.5	0.01	0.01	7.36	0.018	5	0.5	260	47	1300
	31-May-2015	580	150	0.5	37	1400	510	0.5	0.01	0.01	7.41	0.0037	3	0.5	130	270	960
	18-Oct-2015	1100	160	0.5	60	1800	550	0.5	0.01	0.01	7.13	0.01	4.1	0.5	230	71	1100
	15-Aug-2016	1300	120	0.5	89	2200	420	0.5	0.01	0.01	7.71	0.014	4.7	0.5	280	17	1200
	01-Oct-2016	---	---	---	---	1900	---	---	---	---	7.4	0.012	---	---	---	---	---
	14-Sep-2017	640	110	0.5	170	1700	360	0.5	0.01	0.01	---	---	5.2	0.5	260	140	860
RB-13-4-3	11-Oct-2013	95	12	200	280	2000	37	0.5	0.015	0.015	10.1	---	5.4	160	420	120	1500
	14-Sep-2014	250	8.7	2.3	120	790	37	0.5	0.01	0.01	8.4	0.0088	4.7	1.9	310	27	580
	18-Oct-2015	1100	15	82	230	2600	61	0.5	0.01	0.01	8.76	0.019	8.6	51	680	18	1700
(Duplicate)	18-Oct-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	01-Oct-2016	---	---	---	---	2800	---	---	---	---	8.13	0.0069	---	---	---	---	---
	14-Sep-2017	1000	26	0.5	180	2000	110	0.5	0.01	0.01	---	---	7	0.5	440	24	1100
RB-13-5-2.4	11-Oct-2013	400	220	0.5	160	2000	770	0.5	0.055	0.013	7.77	---	5.2	0.5	130	590	1400
	14-Sep-2014	590	390	0.5	180	2800	1300	0.5	0.01	0.01	7.65	0.0042	7.5	0.5	150	990	2300
	18-Oct-2015	490	350	0.5	190	2700	1200	0.5	0.01	0.01	7.15	0.007	5.1	0.5	210	1000	2000
	15-Aug-2016	330	200	0.5	73	1400	640	0.5	0.053	0.01	7.66	0.0046	3.6	0.5	76	400	990
	01-Oct-2016	---	---	---	---	1400	---	---	---	---	7.49	0.0031	---	---	---	---	---
RB-13-8-1.5	11-Oct-2013	440	100	0.5	160	1600	330	0.5	0.36	0.0085	7.92	---	3.9	0.5	200	220	950
	13-Sep-2014	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	19-Oct-2015	710	110	0.5	170	1700	350	0.5	0.17	0.01	7.68	0.015	4.4	0.5	270	120	870
	15-Aug-2016	500	85	0.5	200	1700	300	0.5	0.01	0.01	7.83	0.019	4.8	0.5	270	180	980
	01-Oct-2016	---	---	---	---	1600	---	---	---	---	7.96	0.004	---	---	---	---	---

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Table 12
Groundwater Geochemical Statistical Source Data (1997-2019) - Indicator Parameters

PROJECT No.: 417011-00096

Monitoring Station		Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (CO3) (mg/L)	Chloride (mg/L)	Electrical Conductivity (uS/cm)	Hardness (as CaCO3) (mg/L)	Hydroxide (mg/L)	Nitrate (as N) (mg/L)	Nitrite (as N) (mg/L)	pH (pH units)	Phenols (mg/L)	Potassium (mg/L)	PP Alkalinity (as CaCO3) (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	Total Dissolved Solids (mg/L)
SURFICIAL SEDIMENTS - Inferred to Represent Natural Gas Seepage without Saline Water																	
MEBG-15-4-3	05-Aug-2016	---	---	---	---	---	---	---	---	---	---	0.002	---	---	---	---	---
	12-Aug-2017	390	89	0.5	7.7	610	310	0.5	0.01	0.011	---	0.016	1.3	0.5	5.8	1.7	260
	21-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	16-Jul-2018	600	140	1	13	930	480	1	0.1	0.1	---	0.013	1.8	1	8.7	1	540
	13-Jul-2019	520	130	1	9	810	430	1	0.01	0.01	---	0.02	1.8	1	7.7	1.2	520
MLS-14-2-3	29-Jul-2014	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	30-Jul-2014	480	110	0.5	3.9	830	480	0.5	0.01	0.01	7.22	0.064	3.7	0.5	8.1	85	640
	08-Aug-2015	310	120	0.5	3.6	880	500	0.5	0.01	0.025	7.41	0.028	4.4	0.5	16	210	620
	03-Aug-2016	710	170	0.5	6.7	1300	680	0.5	0.016	0.01	7.46	0.027	5.3	0.5	38	180	870
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	16-Aug-2017	950	190	0.5	2	1300	720	0.5	0.01	0.01	---	0.035	4.4	0.5	7.3	27	810
	19-Jul-2018		140		1.6	970											
	18-Jul-2019		110		1.6	770											
B38 02-33-3	20-Aug-2002	755	152	0.5	9.8	881	502	0.5	0.02	0.005	7.7	0.002	2	1	8.82	17.5	540
	24-Aug-2003	589	144	0.5	6	831	478	0.5	0.2	0.06	7	---	1.33	1	6.12	11	496
	22-Aug-2004	750	196	0.5	6	1110	638	0.5	0.2	0.06	7.2	---	2.41	1	7.07	14	664
	24-Aug-2005	782	215	1	9	1100	700	1	0.2	0.06	7.3	0.016	1.8	1	6.22	19.9	---
(Duplicate)	24-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	21-Aug-2006	517	138	1	6	763	460	1	0.2	0.06	7.7	0.005	1.5	1	6.22	19	470
	19-Aug-2007	800	233	1	5	1210	740	1	0.2	0.06	7.2	0.016	2.1	1	8.6	65	776
	19-Aug-2008	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Aug-2009	810	330	0.5	5	1600	---	0.5	0.005	0.003	7.05	0.008	1.8	0.5	6.2	330	1200
	22-Aug-2010	770	220	0.5	6	1300	740	0.5	0.007	0.003	7.65	0.009	1.9	0.5	7	95	820
	17-Aug-2011	---	180	---	7	1100	---	---	0.021	0.003	---	0.004	1.9	---	11	36	---
	19-Aug-2012	---	220	---	7.6	1300	---	---	0.0037	0.003	---	0.0029	1.9	---	13	30	---
	01-Aug-2014	---	230	---	---	---	---	---	---	---	---	---	10	---	18	---	---
	10-Aug-2015	---	250	---	---	---	---	---	---	---	---	---	0.89	---	14	---	---
	03-Aug-2016	---	260	---	---	---	---	---	---	---	---	---	1.3	---	15	---	---
B38 02-34-3	20-Aug-2002	769	137	0.5	10.7	1260	564	0.5	0.02	0.006	7.9	0.03	6	1	60.4	61.7	804
	24-Aug-2003	851	172	0.5	7	1360	665	0.5	0.2	0.06	6.8	---	5.43	1	71.7	167	894
	22-Aug-2004	844	134	0.5	8	1290	636	0.5	0.2	0.06	7.3	---	6.51	1	37.2	29	754
	24-Aug-2005	795	144	1	13.3	1220	700	1	0.2	0.06	7.5	0.072	4.8	1	16.8	25.6	---
(Duplicate)	24-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	21-Aug-2006	879	149	1	10	1220	670	1	0.2	0.06	7.4	0.049	5.2	1	28.7	25	772
	19-Aug-2007	818	118	1	10	1160	600	1	0.2	0.06	7	0.009	5	1	10.1	6	672
	17-Aug-2009	810	190	0.5	10	1400	750	0.5	0.003	0.003	7.04	0.011	4.4	0.5	32	160	920
	22-Aug-2010	820	180	0.5	11	1300	736	0.5	0.003	0.003	7.69	0.014	4.7	0.5	24	67	820
	17-Aug-2011	---	140	---	11	1200	---	---	0.042	0.004	---	0.006	4.6	---	15	11	---
	19-Aug-2012	---	170	---	10	1300	---	---	0.003	0.003	---	0.015	5.2	---	14	96	---
	26-Aug-2013	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	01-Aug-2014	---	260	---	---	---	---	---	---	---	---	---	7.4	---	11	---	---
	10-Aug-2015	---	280	---	---	---	---	---	---	---	---	---	2	---	9.9	---	---
	03-Aug-2016	---	220	---	---	---	---	---	---	---	---	---	3.3	---	10	---	---

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Table 13
Groundwater Geochemical Statistical Source Data (1997-2019) - Dissolved Metals

PROJECT No.: 417011-00096

Monitoring Station		Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Uranium (mg/L)	Zinc (mg/L)
MAINLAND - Surficial Sediments																			
B38 93-2-4	08-Jul-1997																		
B38 93-2-4	07-Sep-1997	0.08	0.0005	0.88	0.076	0.002	0.004	0.003	0.053	0.001	0.796	0.00005	0.004	0.014	0.0005	0.01	0.02	---	0.012
	09-Sep-1998	0.02	0.07	0.593	0.055	0.002	0.002	0.001	0.017	0.02	0.468	---	0.004	0.009	0.03	0.01	0.02	---	0.002
	15-Sep-1999	0.02	0.002	0.656	0.062	0.0002	0.004	0.001	0.588	0.002	0.661	0.00005	0.004	0.013	0.002	0.0001	0.02	---	0.003
	18-Oct-1999	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Sep-2000	0.02	0.001	0.503	0.051	0.0002	0.005	0.005	0.009	0.001	0.149	0.00005	0.005	0.008	0.001	0.0001	0.03	---	0.008
(Duplicate)	17-Sep-2000	0.02	0.001	0.478	0.047	0.0001	0.005	0.005	0.02	0.002	0.156	0.00005	0.005	0.008	0.002	0.0001	0.03	---	0.006
	26-Aug-2001	0.02	0.05	0.555	0.059	0.002	0.005	0.005	0.006	0.03	0.364	---	0.005	0.008	0.03	0.01	0.03	---	0.008
	20-Aug-2002	0.018	0.001	0.505	0.048	0.00021	0.001	0.0047	0.055	0.0005	0.234	0.00005	0.005	0.008	0.001	0.0001	0.0001	0.00692	0.042
	25-Aug-2003	---	0.005	0.521	0.05	0.002	0.007	0.009	0.044	0.1	0.154	0.00005	---	---	0.001	---	---	1	0.011
(Duplicate)	25-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	10-Sep-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BT3 97-2-5	07-Sep-1997	0.04	0.0019	0.093	0.095	0.002	0.002	0.004	0.657	0.001	1.61	0.00007	0.004	0.017	0.0012	0.01	0.02	---	0.002
	10-Sep-1998	0.05	0.04	0.29	0.092	0.002	0.002	0.001	0.29	0.02	0.96	---	0.004	0.01	0.03	0.01	0.02	---	0.002
	16-Sep-1999	0.02	0.006	0.115	0.129	0.0001	0.002	0.001	8.91	0.001	3.33	0.00005	0.004	0.019	0.002	0.0001	0.02	---	0.003
	18-Sep-1999	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	19-Sep-2000	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2002	0.008	0.003	0.269	0.134	0.00046	0.001	0.0056	0.865	0.0011	3.66	0.00094	0.005	0.031	0.001	0.0001	0.0001	0.0152	0.042
	24-Aug-2003	---	0.005	0.121	0.164	0.002	0.007	0.009	0.135	0.1	2.332	0.00005	---	---	0.001	---	---	1	0.005
MCBG-10-1-3	29-Sep-2010	0.003	0.001	0.27	0.34	0.00012	0.001	0.0031	0.06	0.0002	1.5	---	0.0014	0.0095	0.0003	0.0001	0.0002	0.015	0.008
	19-Aug-2011	0.01	0.002	0.21	0.21	0.00023	0.01	0.006	0.06	0.002	0.81	---	0.002	0.011	0.002	0.001	0.002	0.016	0.03
	16-Aug-2012	0.004	0.00047	0.17	0.13	0.00019	0.001	0.0037	0.06	0.0002	0.087	---	0.0024	0.0069	0.00023	0.0001	0.0002	0.018	0.0076
	20-Aug-2013	0.007	0.0005	0.17	0.11	0.00023	0.001	0.0027	0.06	0.0002	0.75	---	0.0018	0.0098	0.0004	0.0001	0.0002	0.016	0.0079
	30-Jul-2014	0.013	0.00059	0.093	0.17	0.00017	0.001	0.0037	0.16	0.0002	0.86	---	0.002	0.01	0.00042	0.0001	0.0002	0.0082	0.017
	07-Aug-2015	0.008	0.00052	0.29	0.11	0.0002	0.001	0.0063	0.06	0.00038	0.2	---	0.0019	0.011	0.00039	0.0001	0.0002	0.012	0.01
	04-Aug-2016	0.02	0.00074	0.37	0.098	0.00029	0.001	0.0043	0.66	0.0002	1	---	0.002	0.014	0.00033	0.0001	0.0002	0.0093	0.0082
	12-Aug-2017	0.016	0.0006	0.21	0.084	0.00015	0.001	0.0083	0.094	0.0002	0.13	---	0.0016	0.013	0.00041	0.0001	0.0002	0.011	0.007
	18-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	22-Jul-2018	0.21	0.0012	0.21	0.063	0.00027	0.001	0.0085	1.5	0.00082	0.53		0.0012	0.014	0.00036	0.0001	0.0002	0.0083	0.018
	15-Jul-2019	0.021	0.00075	0.16	0.051	0.00013	0.001	0.0037	1.2	0.0002	0.83		0.0013	0.012	0.0002	0.001	0.0002	0.006	0.0095
MCBG-12-1-2	17-Aug-2012	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MCBG-12-1-2	20-Aug-2012	0.01	0.0061	0.075	0.34	0.00047	0.001	0.0077	1.9	0.0002	1.4	---	0.0024	0.033	0.00072	0.0001	0.0002	0.022	0.026
	25-Aug-2013	0.027	0.0016	0.06	0.31	0.00032	0.001	0.0067	0.23	0.0002	1.5	---	0.0011	0.021	0.00058	0.0001	0.0002	0.041	0.0084
	31-Jul-2014	0.033	0.0012	0.081	0.3	0.00026	0.001	0.013	0.11	0.0002	0.97	---	0.0013	0.021	0.00044	0.00012	0.0002	0.032	0.014
	08-Aug-2015	0.018	0.00093	0.099	0.24	0.00019	0.001	0.0049	0.19	0.0002	1.2	---	0.0012	0.012	0.00052	0.0001	0.0002	0.024	0.0077
	05-Aug-2016	0.02	0.0013	0.083	0.26	0.00029	0.001	0.0053	0.2	0.0002	0.97	---	0.0012	0.016	0.00036	0.0001	0.0002	0.03	0.008
	08-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2017	0.021	0.0013	0.088	0.24	0.00031	0.001	0.0059	0.33	0.0002	1	---	0.00099	0.015	0.00047	0.0001	0.0002	0.031	0.013
	22-Jul-2018	0.48	0.0018	0.12	0.06	0.00032	0.0014	0.01	1.3	0.0035	0.98	---	0.0012	0.017	0.00035	0.0001	0.0002	0.01	0.021
	15-Jul-2019	0.025	0.001	0.073	0.14	0.00027	0.001	0.0073	0.15	0.0002	1.5	---	0.0012	0.018	0.00038	0.0001	0.0002	0.018	0.0063
MEBG-10-1-3	29-Sep-2010	0.001	0.0008	0.4	0.05	0.00003	0.001	0.0019	0.1	0.0002	2.9	---	0.0005	0.0063	0.0004	0.0001	0.0002	0.0047	0.005
	18-Aug-2011	0.01	0.002	0.39	0.04	0.00009	0.01	0.002	0.12	0.002	3.1	---	0.002	0.006	0.002	0.001	0.002	0.005	0.03
	19-Aug-2012	0.001	0.00076	0.41	0.045	0.00014	0.001	0.0023	0.16	0.0002	3	---	0.00068	0.0071	0.00025	0.0001	0.0002	0.0049	0.0068
	25-Aug-2013	0.0048	0.0016	0.45	0.042	0.00011	0.001	0.00073	3.3	0.0002	2	---	0.0012	0.0064	0.00034	0.0001	0.0002	0.0083	0.0073
	30-Jul-2014	0.0043	0.00066	0.42	0.029	0.000094	0.001	0.0074	1.9	0.0002	1.3	---	0.0015	0.0058	0.00023	0.00045	0.0002	0.009	0.01
	06-Aug-2015	0.013	0.00062	0.44	0.03	0.000085	0.001	0.0017	1.5	0.00081	1.1	---	0.0012	0.0039	0.00084	0.0001	0.0002	0.0062	0.015
	14-Sep-2015	0.003	0.0012	0.43	0.039	0.000035	0.001	0.00074	4.2	0.0002	1.7	---	0.0011	0.0062	0.0002	0.0001	0.0002	0.0052	0.0076
	03-Aug-2016	0.0041	0.0019	0.35	0.025	0.00002	0.001	0.00062	5.8	0.0002	2.1	---	0.0011	0.0049	0.0002	0.0001	0.0002	0.0039	0.009
	02-Oct-2016	0.0051	0.0031	0.44	0.038	0.00002	0.001	0.00053	9.9	0.0002	2.6	0.0000021	0.0015	0.0059	0.00023	0.0001	0.0002	0.0046	0.0067
	04-Nov-2016	---	---	---	---	---	---	---	---	---	---	0.0000031	---	---	---	---	---	---	---
	12-Aug-2017	0.0044	0.00096	0.39	0.022	0.000032	0.001	0.00078	2.8	0.0002	0.67	0.000002	0.0027	0.0052	0.00039	0.0001	0.0002	0.011	0.004
	13-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Sep-2017	0.0067	0.0014	0.4	0.025	0.000034	0.001	0.00057	3.6	0.0002	1.2	0.000002	0.0022	0.0057	0.00026	0.0001	0.0002	0.009	0.0038
	15-Sep-2018	0.003	0.00085	0.31	0.029	0.00005	0.001	0.00069	3.2	0.0002	1.4	0.000002	0.0013	0.0053	0.00022	0.0001	0.0002	0.0057	0.0046
	15-Jul-2019	0.003	0.0002	0.14	0.02	0.000051	0.001	0.0007	0.27	0.0002	0.97	0.000002	0.00079	0.0024	0.0002	0.0001	0.0002	0.0023	0.0048
MEBG-12-2-3	30-Jul-2014	0.073	0.002	0.078	0.053	0.00034	0.01	0.0086	5.3	0.002	2.2	---	0.002	0.04	0.002	0.001	0.002	0.017	0.03
	09-Aug-2015	0.036	0.00055	0.065	0.068	0.00019	0.001	0.02	0.31	0.0002	1.1	---	0.0011	0.028	0.00044	0.0001	0.0002	0.012	0.016
	05-Aug-2016	0.014	0.0013	0.099	0.07	0.000068	0.001	0.0017	0.1	0.0002	1.1	---	0.0013	0.018	0.00022	0.0001	0.0002	0.0081	0.0088
	11-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	20-Aug-2017	0.047	0.0012	0.084	0.051	0.00019	0.001	0.011	0.2	0.00036	0.85	---	0.0033	0.024	0.00034	0.0001	0.0002	0.0066	0.015
	22-Jul-2018	1.4	0.0068	0.25	0.039	0.0014	0.0013	0.018	9	0.048	0.67	---	0.00057	0.045	0.00023	0.0001	0.0002	0.0088	0.15

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Table 13
Groundwater Geochemical Statistical Source Data (1997-2019) - Dissolved Metals

PROJECT No.: 417011-00096

Monitoring Station		Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Uranium (mg/L)	Zinc (mg/L)
MLS 09-6-2	19-Aug-2009	0.001	0.0007	0.11	0.11	0.000069	0.001	0.003	0.06	0.0002	0.27	---	0.0004	0.004	0.0002	0.0001	0.0002	0.002	0.008
	19-Aug-2011	---	---	---	---	---	---	---	0.06	---	0.004	---	---	---	---	---	---	---	---
MLS-13-9-3	08-Aug-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MLS-13-9-3	09-Aug-2015	0.003	0.00027	0.043	0.021	0.000051	0.001	0.0036	0.06	0.0002	0.46	---	0.0025	0.0091	0.0002	0.0001	0.0002	0.0023	0.0098
	03-Aug-2016	0.0053	0.00024	0.05	0.024	0.00002	0.001	0.0014	0.06	0.0002	0.032	---	0.0028	0.006	0.0002	0.0001	0.0002	0.0027	0.0059
	11-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	16-Aug-2017	0.0086	0.0004	0.048	0.02	0.00002	0.001	0.0046	0.06	0.0002	0.0074	---	0.0017	0.0026	0.0002	0.0001	0.0002	0.0023	0.0037
	18-Jul-2018	3.7	0.002	0.46	0.02	0.00053	0.0065	0.024	11	0.012	0.24	---	0.00025	0.023	0.0002	0.0001	0.0002	0.0024	0.09
MLS-14-3-3	30-Jul-2014	0.021	0.00074	0.072	0.098	0.000024	0.001	0.0013	0.22	0.0002	0.25	---	0.0013	0.0044	0.00041	0.0001	0.0002	0.0017	0.003
	08-Aug-2015	0.003	0.0016	0.12	0.12	0.00002	0.001	0.0002	0.7	0.0002	0.86	---	0.00072	0.0027	0.00037	0.0001	0.0002	0.0015	0.0066
	03-Aug-2016	0.0039	0.00044	0.15	0.17	0.000034	0.001	0.001	0.06	0.0002	0.6	---	0.00045	0.002	0.0002	0.0001	0.0002	0.0016	0.0064
MLS-14-4-3	30-Jul-2014	0.012	0.0004	0.086	0.079	0.00002	0.001	0.0037	0.06	0.0002	0.0074	---	0.0019	0.001	0.00042	0.0001	0.0002	0.0024	0.003
	08-Aug-2015	0.003	0.00045	0.14	0.17	0.00002	0.001	0.0002	0.06	0.0002	0.81	---	0.0017	0.0052	0.00034	0.0001	0.0002	0.0022	0.003
	03-Aug-2016	0.0053	0.00058	0.15	0.21	0.00002	0.001	0.00053	0.06	0.0002	0.3	---	0.00074	0.0017	0.0002	0.0001	0.0002	0.0019	0.0036
(Duplicate)	03-Aug-2016	0.0038	0.0005	0.14	0.2	0.00002	0.001	0.00062	0.06	0.0002	0.28	---	0.00073	0.0018	0.0002	0.0001	0.0002	0.0019	0.0055
MLS-14-8-3	29-Jul-2014	0.0055	0.00083	0.086	0.11	0.000063	0.001	0.002	0.21	0.0002	0.0076	---	0.0011	0.0022	0.0002	0.0001	0.0002	0.0016	0.0039
	04-Aug-2016	0.0051	0.0044	0.25	0.2	0.000058	0.001	0.00064	0.06	0.00023	0.85	---	0.00082	0.0055	0.0002	0.0001	0.0002	0.0028	0.0066
MWBG-10-1-3	30-Sep-2010	0.001	0.0008	0.09	0.24	0.00003	0.005	0.0017	0.46	0.0002	0.73	---	0.0002	0.0089	0.0005	0.0001	0.0002	0.005	0.003
	18-Aug-2011	0.003	0.0013	0.08	0.25	0.000038	0.001	0.0012	1.5	0.0002	0.68	---	0.001	0.0048	0.0005	0.0001	0.0002	0.0057	0.012
	17-Aug-2012	0.0044	0.00086	0.082	0.25	0.00019	0.001	0.0045	0.06	0.0002	1.5	---	0.0028	0.01	0.0012	0.0001	0.0002	0.015	0.015
	21-Aug-2013	0.011	0.0018	0.11	0.16	0.00014	0.001	0.0022	2.9	0.0002	1.4	---	0.0016	0.013	0.00031	0.0001	0.0002	0.0088	0.012
	30-Jul-2014	0.0076	0.00039	0.19	0.11	0.000087	0.001	0.0042	0.06	0.0002	0.00883	---	0.0017	0.0073	0.00034	0.0001	0.0002	0.015	0.011
	08-Aug-2015	0.0077	0.00073	0.14	0.23	0.00017	0.001	0.003	0.77	0.0002	1.6	---	0.0018	0.0096	0.00045	0.0001	0.0002	0.0085	0.016
	03-Aug-2016	0.0052	0.00049	0.099	0.24	0.0002	0.001	0.005	0.06	0.0002	0.72	---	0.001	0.0075	0.00026	0.0001	0.0002	0.0077	0.014
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Aug-2017	0.0047	0.00038	0.11	0.18	0.00023	0.001	0.0048	0.072	0.0002	0.67	---	0.0013	0.011	0.00031	0.0001	0.0002	0.007	0.013
	22-Jul-2018	0.0072	0.00053	0.11	0.1	0.00018	0.001	0.0042	0.37	0.00024	0.67	---	0.0015	0.0097	0.00024	0.0001	0.0002	0.0087	0.019
	11-Jul-2019	0.013	0.0024	0.1	0.091	0.000027	0.001	0.00096	3.8	0.0002	1.6	---	0.00083	0.011	0.0002	0.0001	0.0002	0.005	0.021
MWBG-12-1-3	17-Aug-2012	---	---	---	---	---	---	---	0.06	---	0.094	---	---	---	---	---	---	---	---
WBIO 08-1-2	19-Aug-2009	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
WBIO 08-1-2	20-Aug-2009	0.004	0.0009	0.15	0.08	0.00042	0.001	0.016	0.08	0.0002	3.2	---	0.0013	0.018	0.0029	0.0001	0.0002	0.038	0.016
	20-Aug-2010	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	18-Aug-2011	---	---	---	---	---	---	---	0.1	---	1	---	---	---	---	---	---	---	---
	17-Aug-2012	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	06-Aug-2015	0.0071	0.00067	0.056	0.14	0.00012	0.001	0.012	0.06	0.0011	0.045	---	0.0018	0.0064	0.00075	0.0001	0.0002	0.04	0.016
	03-Aug-2016	0.0085	0.00073	0.042	0.12	0.00013	0.001	0.011	0.06	0.0002	0.029	---	0.0015	0.0071	0.00057	0.0001	0.0002	0.037	0.018
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BEAR, FRENCHY'S AND GOOSE ISLANDS - Surficial Sediments																			
BI 08-1-4	19-Aug-2008	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BI 08-1-4	21-Aug-2008	0.001	0.001	0.08	0.02	0.00041	0.001	0.014	0.2	0.0002	7.8	---	0.0023	0.039	0.001	0.0001	0.0002	0.02	0.03
	18-Aug-2009	0.006	0.0009	0.03	0.02	0.00026	0.001	0.0093	3.6	0.0002	1.2	---	0.0014	0.02	0.0009	0.0001	0.0002	0.016	0.019
(Duplicate)	18-Aug-2009	0.005	0.0009	0.03	0.02	0.00028	0.001	0.0086	3	0.0002	1.2	---	0.0013	0.021	0.0009	0.0001	0.0002	0.016	0.017
	23-Aug-2010	0.009	0.0015	0.03	0.02	0.00024	0.001	0.012	0.22	0.0002	1.3	---	0.0008	0.023	0.0006	0.0001	0.0002	0.013	0.009
(Duplicate)	23-Aug-2010	0.01	0.0015	0.03	0.02	0.00023	0.001	0.011	0.33	0.0002	1.1	---	0.0008	0.02	0.0006	0.0001	0.0002	0.013	0.01
	21-Aug-2011	0.01	0.002	0.07	0.02	0.00016	0.01	0.002	64	0.002	1.3	---	0.002	0.014	0.002	0.001	0.002	0.004	0.03
(Duplicate)	21-Aug-2011	0.01	0.002	0.06	0.02	0.00015	0.01	0.002	60	0.002	1.4	---	0.002	0.014	0.002	0.001	0.002	0.004	0.03
	15-Aug-2012	0.0065	0.00067	0.038	0.02	0.000098	0.001	0.0054	0.15	0.0002	0.1	---	0.0069	0.0081	0.00037	0.0001	0.0002	0.023	0.0046
(Duplicate)	15-Aug-2012	0.0045	0.0006	0.038	0.02	0.000078	0.001	0.0058	0.14	0.0002	0.1	---	0.0067	0.0096	0.00035	0.0001	0.0002	0.023	0.0074
BI-13-6-2	03-Aug-2014	0.018	0.0019	0.096	0.02	0.00012	0.001	0.0046	2.2	0.0002	0.58	---	0.0036	0.0092	0.00047	0.0001	0.0002	0.0034	0.011
	09-Aug-2015	0.029	0.0038	0.069	0.02	0.00011	0.001	0.0034	2.2	0.00041	0.97	---	0.0039	0.011	0.00066	0.0001	0.0002	0.0028	0.0061
	10-Aug-2016	0.032	0.0024	0.069	0.02	0.00015	0.001	0.0036	1.5	0.00035	1.1	---	0.0034	0.012	0.00078	0.0001	0.0002	0.0032	0.0065
	14-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Jul-2019	0.015	0.0014	0.047	0.02	0.00011	0.001	0.0043	0.2	0.0002	0.38	---	0.0042	0.0079	0.00027	0.0001	0.0002	0.0036	0.0059
BI-14-8-3	04-Aug-2014	0.0097	0.0021	0.039	0.02	0.00015	0.001	0.0049	8.8	0.00024	3.2	---	0.0018	0.011	0.00057	0.0001	0.0002	0.0077	0.0057
	08-Aug-2015	0.008	0.0036	0.052	0.02	0.000026	0.001	0.0002	21	0.0002	4.9	---	0.0013	0.017	0.00064	0.0001	0.0002	0.014	0.014
BIBG-10-1-4	29-Sep-2010	0.001	0.0007	0.06	0.03	0.00021	0.001	0.0044	0.32	0.0002	10	---	0.0013	0.024	0.0004	0.0001	0.0002	0.02	0.019
	21-Aug-2011	0.005	0.0003	0.04	0.04	0.00051	0.001	0.0055	0.07	0.0002	2.5	---	0.0022	0.015	0.0004	0.0001	0.0002	0.012	0.03
	15-Aug-2012	0.0074	0.00044	0.035	0.035	0.00029	0.001	0.0044	0.06	0.0002	0.048	---	0.0023	0.0078	0.00028	0.0001	0.0002	0.0054	0.012
	19-Sep-2013	0.007	0.0003	0.042	0.031	0.00066	0.001	0.0038	0.46	0.0002	1.2	---	0.011	0.0091	0.00026	0.0001	0.0002	0.0047	0.015
	03-Aug-2014	0.008	0.00041	0.044	0.021	0.00044	0.001	0.0027	0.23	0.0002	1.3	---	0.025	0.0062	0.00049	0.0001	0.0002	0.0062	0.013
	09-Aug-2015	0.0055	0.00084	0.044	0.02	0.000044	0.001	0.0026	0.24	0.0002	5.5	---	0.041	0.01	0.00088	0.0001	0.0002	0.0059	0.0089
	09-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	10-Aug-2016	0.0093	0.0005	0.046	0.02	0.000091	0.001	0.0014	0.23	0.0002	3.3	---	0.03	0.0077	0.00026	0.0001	0.0002	0.0082	0.014
	11-Aug-2017	0.0074	0.00025	0.037	0.02	0.00023	0.001	0.0029	0.072	0.0002	0.14	---	0.014	0.004	0.0011	0.0001	0.0002	0.0052	0.013
	17-Jul-2018	0.048	0.00026	0.043	0.02	0.00021	0.001	0.003	0.12	0.00025	0.31	0.0000032	0.023	0.0056	0.00032	0.0001	0.0002	0.0069	0.015
	20-sep-2018	0.0087	0.00038	0.044	0.02	0.000028	0.001	0.00093	0.3	0.0002	2	0.000002	0.032	0.0077	0.0006	0.0001	0.0002	0.0099	0.012
	17-Jul-2019	0.0076	0.00052	0.038	0.02	0.000038	0.001	0.0015	0.13	0.0002	0.73	0.000002	0.026	0.0053	0.0002	0.0001	0.0002	0.0052	0.015

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Table 13
Groundwater Geochemical Statistical Source Data (1997-2019) - Dissolved Metals

PROJECT No.: 417011-00096

Monitoring Station		Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Uranium (mg/L)	Zinc (mg/L)
BIBG-10-2-4	29-Sep-2010	0.002	0.002	0.13	0.02	0.00005	0.001	0.0007	3.1	0.0002	4	---	0.0008	0.013	0.0003	0.0001	0.0002	0.0099	0.016
BIBG-12-1-7	19-Sep-2013	0.0091	0.00085	0.061	0.042	0.000059	0.001	0.0047	0.061	0.0002	0.2	---	0.0048	0.0096	0.00075	0.0001	0.0002	0.024	0.021
	03-Aug-2014	---	---	---	---	---	---	---	0.069	---	---	---	---	---	---	---	---	---	---
	09-Aug-2015	0.0059	0.0023	0.013	0.091	0.00017	0.001	0.005	0.06	0.0017	0.09	---	0.025	0.007	0.00064	0.0001	0.0002	0.082	0.014
	07-Aug-2016	0.0032	0.0015	0.013	0.074	0.00018	0.001	0.0036	0.06	0.00088	0.11	---	0.021	0.0074	0.00042	0.0001	0.0002	0.055	0.011
BIBG-12-2-4	15-Aug-2012	0.039	0.00086	0.13	0.026	0.00016	0.001	0.0056	0.06	0.0002	0.44	---	0.0014	0.014	0.00048	0.0001	0.0002	0.0071	0.0062
	23-Aug-2013	0.015	0.00066	0.099	0.027	0.00019	0.001	0.0039	0.06	0.0002	0.64	---	0.00061	0.011	0.0002	0.0001	0.0002	0.0035	0.008
	04-Aug-2014	0.019	0.00056	0.11	0.031	0.00023	0.001	0.0052	0.06	0.0002	0.25	---	0.00064	0.0081	0.00028	0.0001	0.0002	0.0049	0.011
	09-Aug-2015	0.034	0.0011	0.13	0.02	0.000094	0.001	0.0033	0.61	0.0002	1.1	---	0.0011	0.011	0.00029	0.0001	0.0002	0.0049	0.013
	09-Aug-2016	0.019	0.00074	0.12	0.026	0.00035	0.001	0.0036	0.079	0.0002	0.81	---	0.0011	0.0098	0.00026	0.0001	0.0002	0.0052	0.011
	15-Aug-2017	0.017	0.00054	0.1	0.02	0.00039	0.001	0.0053	0.06	0.0002	0.31	---	0.001	0.0085	0.00031	0.0001	0.0002	0.0051	0.0087
	18-Jul-2018	0.0089	0.001	0.1	0.02	0.00045	0.001	0.0016	0.27	0.0002	0.81	---	0.0012	0.0087	0.00023	0.0001	0.0002	0.0034	0.011
	12-Jul-2019	0.012	0.00075	0.098	0.02	0.00012	0.001	0.002	0.14	0.0002	0.91	---	0.0013	0.0076	0.0002	0.0001	0.0002	0.0034	0.0075
FIBG-10-1-4	29-Sep-2010	0.002	0.0008	0.05	0.02	0.0001	0.001	0.001	0.06	0.0002	1.8	---	0.0004	0.0067	0.0002	0.0001	0.0002	0.0023	0.005
(Duplicate)	29-Sep-2010	0.002	0.0006	0.05	0.02	0.00009	0.001	0.0007	0.06	0.0002	1.7	---	0.0005	0.0054	0.0002	0.0001	0.0002	0.0022	0.003
GIBG-10-1-5	21-Aug-2011	---	---	---	---	---	---	---	0.15	---	6.8	---	---	---	---	---	---	---	---
	15-Aug-2012	0.01	0.0017	0.22	0.049	0.00016	0.001	0.0017	3	0.0002	4	---	0.0021	0.022	0.0002	0.0001	0.0002	0.037	0.034
GIBG-10-2-3	28-Sep-2010	0.002	0.0019	0.18	0.03	0.00016	0.001	0.0006	2.5	0.0002	2.8	---	0.0014	0.0098	0.0002	0.0001	0.0002	0.0023	0.011
(Duplicate)	28-Sep-2010	0.001	0.0018	0.18	0.03	0.00009	0.001	0.0003	2.5	0.0002	2.8	---	0.0015	0.008	0.0002	0.0001	0.0002	0.0023	0.009
	21-Aug-2011	0.007	0.0021	0.23	0.03	0.00015	0.001	0.0017	0.91	0.0002	5.2	---	0.0008	0.017	0.0002	0.0001	0.0002	0.002	0.024
	15-Aug-2012	0.0059	0.0014	0.19	0.024	0.00012	0.001	0.0015	1	0.0002	2.9	---	0.0018	0.0083	0.0002	0.0001	0.0002	0.0024	0.0077
(Duplicate)	15-Aug-2012	0.0064	0.0015	0.19	0.024	0.00013	0.001	0.0017	1.1	0.0002	2.9	---	0.0018	0.0086	0.0002	0.0001	0.0002	0.0024	0.0096
	25-Aug-2013	0.013	0.0016	0.15	0.021	0.00013	0.001	0.0011	1	0.0002	2	---	0.0016	0.0086	0.00026	0.0001	0.0002	0.0019	0.0062
(Duplicate)	25-Aug-2013	0.011	0.0015	0.16	0.024	0.00013	0.001	0.00076	0.9	0.0002	2	---	0.0016	0.0083	0.00021	0.0001	0.0002	0.0019	0.0046
	03-Aug-2014	0.0081	0.0023	0.14	0.027	0.000062	0.001	0.00084	2.7	0.0002	2.4	---	0.0028	0.0086	0.0002	0.0001	0.0002	0.0027	0.0069
(Duplicate)	03-Aug-2014	0.0094	0.0024	0.14	0.02	0.00008	0.001	0.0018	3	0.0002	2.4	---	0.0028	0.0096	0.0002	0.0001	0.0002	0.0027	0.01
	10-Aug-2015	0.0053	0.00082	0.11	0.02	0.000089	0.001	0.00086	0.23	0.0002	1.6	---	0.0033	0.0053	0.0002	0.0001	0.0002	0.002	0.0048
(Duplicate)	10-Aug-2015	0.0053	0.0011	0.11	0.02	0.000078	0.001	0.00077	0.23	0.0002	1.6	---	0.0034	0.0055	0.0002	0.0001	0.0002	0.002	0.003
	16-Sep-2015	0.0057	0.0016	0.23	0.023	0.000062	0.001	0.0018	0.82	0.0002	1.5	---	0.0035	0.007	0.00032	0.0001	0.0002	0.0086	0.011
	07-Aug-2016	0.005	0.0012	0.16	0.02	0.00014	0.001	0.0011	0.15	0.0002	1.7	---	0.0023	0.0046	0.0002	0.0001	0.0002	0.0028	0.0063
(Duplicate)	07-Aug-2016	0.0065	0.0011	0.17	0.02	0.00012	0.001	0.00094	0.15	0.0002	1.7	---	0.0023	0.0044	0.0002	0.0001	0.0002	0.0027	0.0051
	02-Oct-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	03-Oct-2016	0.0052	0.0019	0.23	0.02	0.00016	0.001	0.0014	1.5	0.0002	2.1	0.000002	0.0026	0.0079	0.0002	0.0001	0.0002	0.0036	0.011
	04-Nov-2016	---	---	---	---	---	---	---	---	---	---	0.000003	---	---	---	---	---	---	---
	20-Aug-2017	0.0059	0.00065	0.2	0.036	0.00017	0.001	0.0014	0.43	0.0002	1.7	0.000002	0.0014	0.0066	0.00033	0.0001	0.0002	0.0056	0.0094
(Duplicate)	20-Aug-2017	0.0055	0.0006	0.2	0.03	0.00016	0.001	0.0018	0.44	0.0002	1.7	0.000002	0.0013	0.0068	0.0002	0.0001	0.0002	0.0054	0.0097
	12-Sep-2017	0.0042	0.00026	0.2	0.036	0.00073	0.001	0.0032	0.06	0.0002	0.83	0.000002	0.0014	0.011	0.0002	0.0001	0.0002	0.0093	0.024
	14-Jul-2018	0.0053	0.00038	0.16	0.024	0.00018	0.001	0.0016	0.16	0.0002	0.66	0.000002	0.00063	0.0053	0.0002	0.0001	0.0002	0.003	0.008
(Duplicate)	14-Jul-2018	0.0052	0.00032	0.16	0.022	0.00017	0.001	0.0016	0.15	0.0002	0.65	0.000002	0.0007	0.0055	0.0002	0.0001	0.0002	0.003	0.0082
	20-Sep-2018	0.0049	0.0002	0.16	0.031	0.000053	0.001	0.0025	0.06	0.0002	0.052	0.000002	0.00065	0.0024	0.0002	0.0001	0.0002	0.0028	0.0081
	16-Jul-2019	0.0058	0.00042	0.11	0.02	0.00018	0.001	0.0029	0.06	0.0002	0.46	0.000002	0.0011	0.004	0.0002	0.0001	0.0002	0.0016	0.0083
(Duplicate)	16-Jul-2019	0.0054	0.00034	0.11	0.02	0.00017	0.001	0.0011	0.06	0.0002	0.47	0.000002	0.001	0.0039	0.0002	0.0001	0.0002	0.0016	0.0068
SHALLOW BEDROCK- Inferred to Represent Natural Saline Water and Hydrocarbon Seepage																			
NWR 98-18-15	09-Sep-1998	0.12	0.007	7.51	1.28	0.0001	0.003	0.003	0.101	0.001	0.417	0.00005	0.004	0.008	0.001	0.0001	0.02	---	0.002
	15-Sep-1999	0.02	0.004	4.31	1.24	0.0001	0.002	0.001	0.197	0.001	0.229	0.00005	0.009	0.008	0.001	0.0001	0.02	---	0.002
	17-Sep-2000	0.02	0.003	4.34	1.25	0.0001	0.005	0.005	0.005	0.001	0.193	0.00005	0.005	0.008	0.003	0.0001	0.03	---	0.005
(Duplicate)	17-Sep-2000	0.02	0.003	3.98	1.26	0.0001	0.005	0.005	0.005	0.001	0.174	0.00005	0.005	0.008	0.002	0.0001	0.03	---	0.005
	27-Aug-2001	0.14	0.05	4.24	1.23	0.002	0.005	0.005	0.322	0.03	0.18	---	0.005	0.008	0.03	0.01	0.03	---	0.005
	22-Aug-2002	0.034	0.001	4.52	1.36	0.0001	0.001	0.0101	0.717	0.0005	0.197	0.00021	0.005	0.008	0.002	0.0001	0.0001	0.0001	0.008
(Duplicate)	22-Aug-2002	0.284	0.002	4.24	1.37	0.0001	0.001	0.0115	1.42	0.0005	0.201	0.00058	0.005	0.008	0.001	0.0001	0.0001	0.0001	0.006
	26-Aug-2003	0.012	0.0052	6.147	1.335	0.002	0.007	0.021	0.344	0.0002	0.32	0.00005	0.0002	0.044	0.0015	0.0001	0.0002	0.099	0.005
(Duplicate)	26-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NWR 99-16-17	15-Sep-1999	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NWR 99-16-17	17-Sep-2000	0.05	0.012	0.531	1.17	0.0001	0.005	0.005	0.047	0.001	0.291	0.00005	0.008	0.01	0.004	0.0001	0.03	---	0.009
	27-Aug-2001	0.1	0.05	0.811	1.23	0.002	0.005	0.005	0.147	0.03	0.272	---	0.005	0.008	0.03	0.01	0.03	---	0.005
	21-Aug-2002	5.35	0.015	1.4	1.34	0.0001	0.006	0.0185	12.4	0.0062	0.255	0.00005	0.005	0.018	0.002	0.0001	0.0001	0.00266	0.212
	26-Aug-2003	---	0.018	1.66	1.339	0.002	0.007	0.009	0.115	0.1	0.235	0.00005	---	---	0.002	---	---	1	0.012
RB 02-3-2	22-Aug-2002	0.047	0.004	0.893	1.07	0.0001	0.001	0.0108	0.093	0.0005	0.275	0.00005	0.005	0.008	0.001	0.0001	0.0001	0.00105	0.015
(Duplicate)	22-Aug-2002	0.009	0.004	0.859	1.05	0.0001	0.001	0.0097	0.019	0.0007	0.273	0.00005	0.005	0.008	0.001	0.0001	0.0001	0.00099	0.018
	26-Aug-2003	---	0.005	1.277	1.103	0.002	0.007	0.009	0.032	0.1	0.134	0.00005	---	---	0.001	---	---	1	0.005
(Duplicate)	26-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	23-Aug-2004	0.01	0.053	1.34	1.287	0.000034	0.005	0.015	0.044	0.002	0.075	0.00005	0.005	0.008	0.002	0.0002	0.0016	0.002	0.005
(Duplicate)	23-Aug-2004	0.01	0.066	1.307	1.249	0.000034	0.005	0.013	0.026	0.002	0.072	0.00005	0.005	0.008	0.002	0.0002	0.0016	0.002	0.005
	25-Aug-2005	0.005	0.0486	1.12	1.17	0.00001	0.007	0.004	0.508	0.001	0.141	0.00005	0.006	0.024	0.001	0.0001	0.0008	0.001	0.007
(Duplicate)	25-Aug-2005	0.005	0.0496	1.19	1.11	0.00001	0.007	0.003	0.813	0.001	0.143	0.00005	0.006	0.008	0.002	0.0001	0.0008	0.001	0.015
	20-Aug-2006	0.005	0.015	0.388	1.32	0.00001	0.007	0.002	0.112	0.001	0.097	0.00005	0.006	0.008	0.001	0.0001	0.0008	0.001	0.005
(Duplicate)	20-Aug-2006	---	0.018	0.383	1.31	0.00001	0.007	0.002	0.133	0.001	0.096	0.00005	0.006	0.008	0.003	0.0001	---	0.001	0.005

Advisian
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Table 13
Groundwater Geochemical Statistical Source Data (1997-2019) - Dissolved Metals

PROJECT No.: 417011-00096

Monitoring Station		Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Uranium (mg/L)	Zinc (mg/L)
NWR 09-1-20	20-Aug-2012	0.0036	0.013	6.3	0.6	0.000011	0.001	0.0009	1.6	0.0002	0.3	---	0.0011	0.0031	0.0029	0.0001	0.0002	0.00029	0.0071
	25-Aug-2013	0.0043	0.0075	4.5	0.61	0.000025	0.001	0.00031	2.4	0.0002	0.27	---	0.00091	0.0015	0.0007	0.0001	0.0002	0.00019	0.003
	08-May-2014	---	---	---	---	---	---	---	---	---	0.32	---	---	---	---	---	---	---	---
	01-Aug-2014	0.0066	0.0038	9.3	0.54	0.00002	0.001	0.001	1.7	0.0002	0.3	---	0.0002	0.00059	0.0042	0.0001	0.0002	0.0001	0.0049
	31-May-2015	0.0055	0.0034	3.8	0.75	0.00002	0.001	0.0012	0.42	0.0002	0.15	---	0.0002	0.0014	0.0017	0.0001	0.0002	0.0001	0.003
	05-Jul-2015	---	---	---	---	---	---	---	---	0.00025	---	---	---	---	---	---	---	---	---
(Duplicate)	05-Jul-2015	---	---	---	---	---	---	---	---	0.00022	---	---	---	---	---	---	---	---	---
	08-Aug-2015	0.003	0.0033	6.7	0.67	0.00002	0.001	0.00061	0.34	0.0002	0.22	---	0.0002	0.0016	0.005	0.0001	0.0002	0.0001	0.0054
	25-Nov-2015	0.0073	0.0051	6.2	1	0.00002	0.001	0.0012	0.84	0.0002	0.18	---	0.0002	0.0011	0.0019	0.0001	0.0002	0.0001	0.0074
(Duplicate)	25-Nov-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Mar-2016	0.0051	0.002	7.2	0.6	0.00002	0.001	0.00058	0.24	0.0002	0.24	---	0.0002	0.0017	0.0005	0.0001	0.0002	0.0001	0.012
	05-Aug-2016	0.006	0.0035	8.5	0.58	0.00002	0.0025	0.0012	0.82	0.0002	0.24	---	0.0002	0.0029	0.001	0.0001	0.0002	0.0001	0.0074
	02-Nov-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	03-Nov-2016	0.005	0.0022	9.2	0.66	0.00002	0.001	0.0002	1.2	0.0002	0.24	---	0.0002	0.0005	0.0034	0.0001	0.0002	0.0011	0.003
	13-Aug-2017	0.0078	0.0039	7.5	0.75	0.00002	0.001	0.00055	1.1	0.0002	0.2	---	0.0002	0.00069	0.00026	0.0001	0.0002	0.0001	0.008
	22-Jul-2018	0.011	0.0028	7.2	0.87	0.00002	0.001	0.00059	1.2	0.0002	0.19	---	0.0002	0.00055	0.00061	0.0001	0.0002	0.0001	0.0044
	15-Jul-2019	0.0042	0.0024	7.1	0.84	0.00002	0.001	0.0016	1.2	0.0002	0.19	---	0.0002	0.00083	0.00039	0.0001	0.0002	0.0001	0.0039
NWR 09-3-20	13-Sep-2009	0.002	0.018	0.24	0.69	0.0001	0.001	0.0031	0.06	0.0003	0.15	---	0.031	0.0069	0.0009	0.0001	0.0002	0.0054	0.01
	20-Aug-2010	0.002	0.016	0.97	0.82	0.000012	0.001	0.0011	0.06	0.0003	0.21	---	0.0035	0.0088	0.0003	0.0001	0.0002	0.0004	0.012
	18-Aug-2011	0.003	0.012	3.3	0.65	0.000006	0.001	0.001	0.1	0.0002	0.24	---	0.0034	0.0031	0.0006	0.0001	0.0002	0.0004	0.013
	19-Aug-2012	0.0032	0.0096	2.9	0.58	0.000025	0.001	0.00036	0.073	0.0002	0.25	---	0.0058	0.0032	0.00046	0.0001	0.0002	0.00035	0.0078
	21-Aug-2013	0.0039	0.011	1.3	0.86	0.000028	0.001	0.00036	1.7	0.0002	0.27	---	0.0042	0.0029	0.00033	0.0001	0.0002	0.00051	0.0063
	11-Oct-2013	---	---	---	---	---	---	---	0.12	---	0.26	---	---	---	---	---	---	---	---
	08-May-2014	---	---	---	---	---	---	---	---	---	0.27	---	---	---	---	---	---	---	---
	01-Aug-2014	0.0053	0.0072	2.1	0.85	0.00002	0.001	0.00087	1.5	0.00023	0.25	---	0.0047	0.0023	0.00078	0.0001	0.0002	0.00059	0.0089
	31-May-2015	0.003	0.0057	1.7	1	0.00002	0.001	0.00081	2	0.0002	0.22	---	0.0039	0.0018	0.00026	0.0001	0.0002	0.00044	0.003
	04-Jul-2015	---	---	---	---	---	---	---	---	0.0002	---	---	---	---	---	---	---	---	---
(Duplicate)	04-Jul-2015	---	---	---	---	---	---	---	---	0.0002	---	---	---	---	---	---	---	---	---
	09-Aug-2015	0.0034	0.0054	2.3	0.98	0.00002	0.001	0.0023	2.2	0.0002	0.24	---	0.0032	0.0013	0.00023	0.0001	0.0002	0.00036	0.007
	25-Nov-2015	0.0033	0.0056	1.8	1	0.00002	0.001	0.00063	3.1	0.0002	0.24	---	0.003	0.0025	0.0007	0.0001	0.0002	0.00037	0.0087
	12-Mar-2016	0.0042	0.0056	2.3	0.9	0.00002	0.001	0.0002	2.4	0.0002	0.28	---	0.0012	0.0013	0.0013	0.0001	0.0002	0.00032	0.0064
	05-Aug-2016	0.0039	0.0054	2.7	0.82	0.000056	0.001	0.00072	2.2	0.0017	0.31	---	0.0009	0.0013	0.0004	0.0001	0.0002	0.00026	0.0039
	13-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	15-Aug-2017	0.004	0.005	2.7	0.84	0.00002	0.001	0.0013	2.4	0.0002	0.3	---	0.00088	0.0013	0.00029	0.0001	0.0002	0.00027	0.0053
	20-Jul-2018	0.003	0.0047	3	0.81	0.00002	0.001	0.00043	2.9	0.0002	0.3	---	0.00068	0.00079	0.00058	0.0001	0.0002	0.00022	0.0048
	15-Jul-2019	0.0047	0.0038	3.7	0.88	0.00002	0.001	0.00063	3.3	0.0002	0.33	---	0.00058	0.0013	0.00042	0.0001	0.0002	0.00019	0.0071
NWR 09-4-17	13-Sep-2009	0.001	0.022	1.6	0.65	0.00005	0.001	0.0019	0.06	0.0002	0.21	---	0.022	0.013	0.002	0.0001	0.0002	0.0062	0.003
	20-Aug-2010	0.002	0.013	1.1	0.95	0.000009	0.001	0.0013	0.06	0.0002	0.4	---	0.013	0.012	0.0006	0.0001	0.0002	0.0021	0.009
	18-Aug-2011	---	---	---	---	---	---	---	0.06	---	0.057	---	---	---	---	---	---	---	---
	20-Aug-2012	0.0019	0.0074	0.78	0.89	0.000011	0.001	0.00053	0.22	0.0002	0.25	---	0.0031	0.0074	0.00041	0.0001	0.0002	0.0015	0.0045
	25-Aug-2013	0.0047	0.013	1.1	0.83	0.000025	0.001	0.0002	0.14	0.0002	0.21	---	0.002	0.005	0.00043	0.0001	0.0002	0.0012	0.003
	08-May-2014	---	---	---	---	---	---	---	---	---	0.27	---	---	---	---	---	---	---	---
	01-Aug-2014	0.0041	0.01	0.58	0.92	0.000038	0.001	0.0012	1	0.074	0.22	---	0.0028	0.025	0.00035	0.0001	0.0002	0.0014	0.029
	01-Jun-2015	0.003	0.01	0.49	0.88	0.000038	0.001	0.0012	1.4	0.0014	0.23	---	0.0026	0.029	0.00021	0.0001	0.0002	0.0017	0.0062
	04-Jul-2015	---	---	---	---	---	---	---	---	0.0018	---	---	---	---	---	---	---	---	---
(Duplicate)	04-Jul-2015	---	---	---	---	---	---	---	---	0.0014	---	---	---	---	---	---	---	---	---
	08-Aug-2015	0.003	0.0094	0.55	0.98	0.00002	0.001	0.0002	1.3	0.0018	0.26	---	0.0012	0.012	0.00056	0.0001	0.0002	0.0011	0.0048
	25-Nov-2015	0.003	0.0092	0.57	0.94	0.00002	0.001	0.00043	2.4	0.00072	0.27	---	0.00037	0.0068	0.00072	0.0001	0.0002	0.0009	0.0063
	12-Mar-2016	0.0037	0.0088	0.53	1	0.000024	0.001	0.0002	1.6	0.00086	0.26	---	0.00064	0.01	0.00082	0.0001	0.0002	0.00096	0.0083
	05-Aug-2016	0.0034	0.015	0.72	0.95	0.00002	0.001	0.00036	1.8	0.00025	0.29	---	0.0005	0.02	0.00028	0.0001	0.0002	0.00093	0.011
	13-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	02-Nov-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	03-Nov-2016	0.0038	0.0025	0.68	0.97	0.000038	0.001	0.0026	0.23	0.0029	0.28	---	0.001	0.015	0.00021	0.0001	0.0002	0.066	0.13
	13-Aug-2017	0.003	0.02	1	0.95	0.000031	0.001	0.0003	2.4	0.00049	0.29	---	0.00061	0.0088	0.0003	0.0001	0.0002	0.00078	0.0047
	22-Jul-2018	0.003	0.025	1.2	0.93	0.00002	0.001	0.00026	2.5	0.0006	0.3	---	0.0004	0.006	0.00036	0.0001	0.0002	0.00075	0.0031
(Duplicate)	22-Jul-2018	0.003	0.025	1.3	0.92	0.00002	0.001	0.0002	2.6	0.00061	0.31	---	0.00039	0.0063	0.00038	0.0001	0.0002	0.00074	0.003
	15-Jul-2019	0.003	0.021	1.3	0.95	0.00002	0.001	0.00049	2.1	0.00027	0.28	---	0.00039	0.0056	0.00027	0.0001	0.0002	0.00063	0.0041
BT3 99-21-12	16-Sep-1999	0.02	0.002	5.46	0.774	0.0001	0.002	0.001	0.515	0.001	0.487	0.00005	0.004	0.008	0.001	0.0001	0.02	---	0.002
	18-Sep-2000	0.02	0.002	4.54	0.76	0.0001	0.005	0.005	0.055	0.001	0.429	0.00005	0.005	0.008	0.001	0.0001	0.03	---	0.005
	27-Aug-2001	0.95	0.05	3.05	0.682	0.002	0.005	0.005	4.23	0.03	0.518	---	0.005	0.008	0.03	0.01	0.03	---	0.005
	20-Aug-2002	0.847	0.003	5.69	0.712	0.0001	0.002	0.0031	5.33	0.001	0.593	0.00005	0.005	0.008	0.001	0.0001	0.0001	0.00025	0.017
	25-Aug-2003	---	0.005	9.582	0.854	0.002	0.007	0.009	3.48	0.1	0.64	0.00005	---	---	0.001	---	---	1	0.005
	22-Aug-2004	0.025	0.025	23.69	0.992	0.000085	0.005	0.019	8.571	0.005	0.937	0.00005	0.005	0.008	0.005	0.0005	0.004	0.005	0.005
	25-Aug-2005	0.008	0.005	3.22	0.58	0.00001	0.007	0.002	1.62	0.001	0.642	0.00005	0.006	0.008	0.001	0.0001	0.0008	0.001	0.121
(Duplicate)	25-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	22-Aug-2006	0.005	0.005	2.37	0.58	0.00001	0.007	0.002	0.216	0.001	0.335	0.00005	0.006	0.043	0.001	0.0001	0.0008	0.001	0.005
	22-Aug-2007	0.002	0.008	3.16	0.61	0.00001	0.005	0.0017	1.86	0.0002	0.324	---	0.0016	0.0065	0.002	0.0001	0.0002	0.0006	0.011
	19-Aug-2008	0.006	0.002	1.3	0.5	0.00001	0.001	0.0067	0.18	0.0002	0.14	---	0.0017	0.023	0.001	0.0001	0.0002	0.0012	0.087
	17-Aug-2009	0.002	0.0022	1	0.53	0.000005	0.001	0.0025	0.79	0.0002	0.44	---	0.0014	0.017	0.0004	0.0001	0.0002	0.0006	0.006
	21-Aug-2010	0.005	0.0015	2.6	0.54	0.00003	0.001	0.0026	0.88	0.0002	0.36	---	0.0012	0.013	0.0004	0.0001	0.0002	0.0014	0.008
	20-Aug-2011	0.004	0.0019	1.2	0.44	0.00003	0.001	0.0013	0.52	0.0002	0.18	---	0.0006	0.018	0.0005	0.0001	0.0002	0.0025	0.017
	20-Aug-2012	0.0025	0.0014	1.6	0.28	0.000018	0.001	0.0023	0.51	0.0002	0.16	---	0.0018	0.0091	0.001	0.0001	0.0002	0.0061	0.0058
	23-Aug-2013	0.0059	0.0016	2.4	0.54	0.000025	0.001	0.0015	1.2	0.0002	0.3	---	0.0016	0.0099	0.0016	0.0001	0.0002	0.0023	0.0055
	31-Jul-2014	0.0048	0.0013	1.6	0.33	0.00002	0.001	0.0019	0.33	0.0002	0.26	---	0.0016	0.018	0.00044	0.0001	0.0002	0.0069	0.007
	08-Aug-2015	0.003	0.0017	0.42	0.11	0.00002	0.001	0.001	0.24	0.0002	0.15	---	0.007	0.012	0.0016	0.0001	0.0002	0.0036	0.012
	05-Aug-2016	0.0053	0.0011	0.26	0.087	0.000031	0.001	0.0014	0.06	0.0002	0.32	---	0.0044	0.014	0.00037	0.0001	0.0002	0.0069	0.016
	13-Aug-2017	0.072	0.0033	1.1	0.41	0.00002	0.001	0.0013	1.5	0.00026	0.79	---	0.0037	0.0067	0.00022	0.0001	0.0002	0.0048	0.0043
	16-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	12-Jul-2018	0.81	0.005	0.7	0.26	0.000027	0.0017	0.0017	5.4	0.0021	1.2	---	0.0024	0.011	0.00048	0.0001	0.0002	0.0023	0.02
	13-Jul-2019	0.0086	0.0029	0.82	0.21	0.00002	0.001	0.0028	0.34	0.0002	1.3	---	0.0035	0.0074	0.00021	0.0001	0.0002	0.003	0.0051

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Table 13
Groundwater Geochemical Statistical Source Data (1997-2019) - Dissolved Metals

PROJECT No.: 417011-00096

Monitoring Station		Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Uranium (mg/L)	Zinc (mg/L)
SURFICIAL SEDIMENTS - Inferred to Represent Natural Saline Water and Hydrocarbon seepage																			
NWR 03-38-3	26-Aug-2003	---	0.01	2.011	0.943	0.002	0.007	0.009	5.244	0.1	0.96	0.00005	---	---	0.001	---	---	1	0.005
(Duplicate)	26-Aug-2003	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	23-Aug-2004	0.01	0.01	0.506	0.786	0.000049	0.005	0.011	0.099	0.003	1.064	0.00005	0.005	0.011	0.002	0.0002	0.0016	0.003	0.005
	25-Aug-2005	0.005	0.005	0.262	0.55	0.00019	0.007	0.006	1.17	0.003	2.33	0.00005	0.006	0.017	0.001	0.0001	0.0008	0.003	0.016
(Duplicate)	25-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	29-Aug-2006	0.005	0.005	0.568	0.59	0.00001	0.007	0.014	2.15	0.001	1.61	0.00005	0.006	0.012	0.001	0.0001	0.0008	0.004	0.009
RB-13-2-2.4	06-Jun-2001	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
RB-13-2-2.4	11-Oct-2013	---	---	---	---	---	---	---	3.8	---	0.35	---	---	---	---	---	---	---	---
	14-Sep-2014	0.0068	0.028	0.27	0.53	0.00002	0.001	0.0018	28	0.00087	0.5	---	0.011	0.018	0.00047	0.0001	0.0002	0.0058	0.0068
	31-May-2015	0.0049	0.0026	0.047	0.16	0.00002	0.001	0.0014	1.6	0.0002	1	---	0.014	0.013	0.00029	0.0001	0.0002	0.018	0.0075
	18-Oct-2015	0.0088	0.022	0.6	0.4	0.00002	0.001	0.00033	25	0.00028	0.61	---	0.01	0.016	0.00042	0.0001	0.0002	0.012	0.0087
	15-Aug-2016	0.01	0.035	0.98	0.59	0.00003	0.001	0.00031	22	0.00036	0.46	---	0.0033	0.02	0.0011	0.0001	0.0002	0.0025	0.015
	01-Oct-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	14-Sep-2017	---	---	---	---	---	---	---	9.4	---	2.8	---	---	---	---	---	---	---	---
RB-13-4-3	11-Oct-2013	---	---	---	---	---	---	---	0.47	---	0.027	---	---	---	---	---	---	---	---
	14-Sep-2014	0.032	0.0033	0.32	0.71	0.00002	0.001	0.001	0.06	0.0002	0.0087	---	0.02	0.0036	0.00034	0.0001	0.0002	0.00026	0.0077
	18-Oct-2015	0.036	0.017	0.38	1.4	0.00002	0.001	0.00033	0.093	0.0002	0.022	---	0.02	0.005	0.00049	0.0001	0.0002	0.0019	0.0052
(Duplicate)	18-Oct-2015	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	01-Oct-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	14-Sep-2017	---	---	---	---	---	---	---	0.56	---	0.13	---	---	---	---	---	---	---	---
RB-13-5-2.4	11-Oct-2013	---	---	---	---	---	---	---	0.06	---	2.8	---	---	---	---	---	---	---	---
	14-Sep-2014	---	---	---	---	---	---	---	0.06	---	2.8	---	---	---	---	---	---	---	---
	18-Oct-2015	0.0047	0.0008	0.028	0.083	0.001	0.001	0.00068	1.6	0.0002	2.4	---	0.0024	0.024	0.00027	0.0001	0.0002	0.0065	1.7
	15-Aug-2016	0.0056	0.00083	0.068	0.053	0.0002	0.001	0.0015	0.06	0.0002	0.3	---	0.0025	0.013	0.00056	0.0001	0.0002	0.004	1.2
	01-Oct-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
RB-13-8-1.5	11-Oct-2013	---	---	---	---	---	---	---	0.06	---	0.24	---	---	---	---	---	---	---	---
	13-Sep-2014	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	19-Oct-2015	0.12	0.00059	0.04	0.049	0.00038	0.001	0.0027	0.42	0.00043	0.75	---	0.0031	0.0094	0.00029	0.0001	0.0002	0.0047	0.59
	15-Aug-2016	---	---	---	---	---	---	---	0.06	---	2	---	---	---	---	---	---	---	---
	01-Oct-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SURFICIAL SEDIMENTS - Inferred to Represent Natural Gas Seepage without Saline Water																			
MEBG-15-4-3	05-Aug-2016	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MEBG-15-4-3	12-Aug-2017	0.0035	0.0021	0.64	0.02	0.000025	0.001	0.0013	2	0.0012	5.9	---	0.0012	0.014	0.00041	0.0001	0.0002	0.0018	0.013
	21-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	16-Jul-2018	0.16	0.01	1.8	0.026	0.00009	0.001	0.0025	64	0.0024	6.2	---	0.0017	0.016	0.00083	0.0001	0.0002	0.00098	0.018
	13-Jul-2019	0.01	0.011	2.7	0.02	0.00002	0.001	0.0017	54	0.0014	1.7	---	0.0015	0.02	0.00047	0.0001	0.0002	0.00047	0.017
MLS-14-2-3	29-Jul-2014	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MLS-14-2-3	30-Jul-2014	0.0084	0.0015	0.11	0.045	0.00013	0.001	0.0016	1.6	0.0002	1.8	---	0.00037	0.0054	0.00062	0.0001	0.0002	0.00095	0.0067
	08-Aug-2015	0.003	0.0021	0.051	0.07	0.00002	0.001	0.0002	0.86	0.0002	1.2	---	0.00047	0.004	0.0023	0.0001	0.0002	0.0013	0.003
	03-Aug-2016	0.016	0.019	0.3	0.12	0.00002	0.001	0.00038	8.9	0.00032	4.5	---	0.0011	0.02	0.00032	0.0001	0.0002	0.00086	0.0075
	12-Aug-2017	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	16-Aug-2017	0.019	0.0098	0.48	0.032	0.00002	0.001	0.00062	19	0.0002	6.4	---	0.00051	0.011	0.00021	0.0001	0.0002	0.0004	0.0073
	19-Jul-2018	0.029	0.017	0.11	0.28	0.00002	0.001	0.00067	10	0.0002	4	---	0.00027	0.01	0.00021	0.0001	0.0002	0.00096	0.0086
	18-Jul-2019	0.019	0.009	0.15	0.26	0.00002	0.001	0.00054	5.7	0.0002	2.6	---	0.00046	0.0058	0.0002	0.0001	0.0002	0.00047	0.0071
B38 02-33-3	20-Aug-2002	0.006	0.001	0.466	0.025	0.00005	0.001	0.0018	0.023	0.0005	0.428	0.00005	0.005	0.008	0.001	0.0001	0.0001	0.00477	0.018
	24-Aug-2003	---	0.005	0.47	0.05	0.002	0.007	0.009	0.028	0.1	0.149	0.00005	---	---	0.001	---	---	1	0.005
	22-Aug-2004	0.005	0.005	0.846	0.032	0.000148	0.005	0.002	0.005	0.001	1.157	0.00005	0.005	0.008	0.002	0.0001	0.0008	0.007	0.005
	24-Aug-2005	0.005	0.005	0.685	0.05	0.00018	0.007	0.005	0.071	0.001	0.296	0.00005	0.006	0.012	0.002	0.0001	0.0008	0.008	0.005
(Duplicate)	24-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	21-Aug-2006	0.005	0.005	0.436	0.05	0.00041	0.007	0.003	0.076	0.001	0.094	0.00005	0.006	0.008	0.002	0.0001	0.0008	0.003	0.005
	19-Aug-2007	0.136	0.002	0.37	0.02	0.00016	0.003	0.0051	2.13	0.0003	1.38	---	0.0008	0.0085	0.003	0.0001	0.0002	0.0073	0.023
	19-Aug-2008	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	17-Aug-2009	0.005	0.0005	0.14	0.03	0.0006	0.001	0.0073	0.08	0.0002	2.4	---	0.0004	0.018	0.0009	0.0001	0.0002	0.0075	0.018
	22-Aug-2010	0.001	0.0009	0.3	0.03	0.000042	0.001	0.0024	0.06	0.0002	1.6	---	0.0003	0.0098	0.0011	0.0001	0.0002	0.0067	0.007
	17-Aug-2011	0.011	0.0043	0.39	0.03	0.000022	0.001	0.0013	12	0.0002	1.4	---	0.0003	0.009	0.0012	0.0001	0.0002	0.0045	0.007
	19-Aug-2012	0.011	0.0031	0.56	0.033	0.000035	0.001	0.0027	11	0.0002	1.9	---	0.00071	0.011	0.00031	0.0001	0.0002	0.0083	0.0047
	01-Aug-2014	0.016	0.0023	0.6	0.033	0.00002	0.001	0.00092	6.8	0.0002	1.3	---	0.00099	0.0075	0.00048	0.00021	0.0002	0.012	0.0081
	10-Aug-2015	0.029	0.002	0.55	0.02	0.00002	0.001	0.00095	3.7	0.0002	2.4	---	0.0019	0.012	0.00038	0.0001	0.0002	0.011	0.003
	03-Aug-2016	0.024	0.0029	0.72	0.02	0.000023	0.001	0.00073	7.2	0.00042	1.8	---	0.0011	0.009	0.00035	0.0001	0.0002	0.0078	0.01
B38 02-34-3	20-Aug-2002	0.008	0.009	1.09	0.069	0.00001	0.001	0.0035	0.186	0.0006	0.686	0.00005	0.005	0.014	0.001	0.0001	0.0001	0.00392	0.037
	24-Aug-2003	---	0.005	1.024	0.073	0.002	0.007	0.009	0.616	0.1	0.728	0.00005	---	---	0.001	---	---	1	0.009
	22-Aug-2004	0.006	0.009	1.298	0.087	0.000017	0.005	0.002	0.73	0.001	0.44	0.00005	0.005	0.019	0.002	0.0001	0.0008	0.004	0.005
	24-Aug-2005	0.009	0.0213	1.1	0.08	0.00002	0.007	0.004	0.352	0.001	0.313	0.00005	0.006	0.03	0.002	0.0001	0.0008	0.001	0.005
(Duplicate)	24-Aug-2005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	21-Aug-2006	0.005	0.012	1.35	0.08	0.0001	0.007	0.002	5.44	0.001	0.588	0.00005	0.006	0.017	0.001	0.0001	0.0008	0.002	0.005
	19-Aug-2007	0.001	0.002	1.41	0.09	0.00004	0.001	0.0004	6.75	0.0002	0.31	---	0.0002	0.0005	0.001	0.0001	0.0002	0.0001	0.012
	17-Aug-2009	0.004	0.0034	0.39	0.07	0.000008	0.001	0.0027	8.4	0.0002	0.62	---	0.0007	0.014	0.0006	0.0001	0.0002	0.0014	0.013
	22-Aug-2010	0.005	0.0029	0.33	0.08	0.000047	0.001	0.0019	3.3	0.0002	1	---	0.001	0.016	0.0005	0.0001	0.0002	0.0024	0.012
	17-Aug-2011	0.01	0.0046	0.6	0.07	0.000014	0.001	0.0005	5.9	0.0002	0.56	---	0.0005	0.01	0.0008	0.0001	0.0002	0.002	0.009
	19-Aug-2012	0.013	0.0062	0.58	0.092	0.000025	0.0014	0.0015	11	0.0002	0.73	---	0.00079	0.0093	0.0005	0.0001	0.0002	0.0009	0.003
	26-Aug-2013	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	01-Aug-2014	0.0092	0.0047	0.27	0.088	0.000021	0.001	0.00072	16	0.0002	0.82	---	0.0015	0.0088	0.00045	0.0001	0.0002	0.0036	0.0082
	10-Aug-2015	0.0071	0.0034	0.088	0.02	0.00002	0.001	0.00039	7.7	0.0002	1.9	---	0.00042	0.011	0.00094	0.0001	0.0002	0.0026	0.003
	03-Aug-2016	0.01	0.0014	0.082	0.043	0.0001	0.001	0.0012	1.7	0.0003	0.73	---	0.002	0.0091	0.00032	0.0001	0.0002	0.0085	0.02

Table 14
Groundwater Geochemical Statistical Source Data (1997-2019) - Petroleum Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Benzene (mg/L)	Ethylbenzene (mg/L)	PHC F1 (C6-C10) - BTEX (mg/L)	PHC F2 (C10-C16) (mg/L)	Toluene (mg/L)	Xylenes-Total (mg/L)
MAINLAND - Surficial Sediments							
B38 93-2-4	17-Sep-2000	0.0005	0.0005	---	---	0.0005	0.0005
(Duplicate)	17-Sep-2000	0.0005	0.0005	---	---	0.0005	0.0005
	26-Aug-2001	0.0005	0.0005	---	---	0.0005	0.001
	20-Aug-2002	0.0005	0.0005	---	---	0.0005	0.0005
	25-Aug-2003	0.0005	0.0005	---	---	0.0005	0.001
(Duplicate)	25-Aug-2003	---	---	---	---	---	---
	10-Sep-2016	---	---	---	---	---	---
BT3 97-2-5	07-Sep-1997	---	---	---	---	---	---
	10-Sep-1998	---	---	---	---	---	---
	16-Sep-1999	---	---	---	---	---	---
	18-Sep-1999	---	---	---	---	---	---
BT3 97-2-5	19-Sep-2000	0.005	0.005	---	---	0.005	0.005
	20-Aug-2002	0.0005	0.0005	---	---	0.0005	0.0005
	24-Aug-2003	0.0005	0.0005	0.1	---	0.0005	0.001
MCBG-10-1-3	29-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	19-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	16-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	20-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	30-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	07-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	04-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	12-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Aug-2017	---	---	---	---	---	---
	22-Jul-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	15-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
MCBG-12-1-2	17-Aug-2012	---	---	---	---	---	---
MCBG-12-1-2	20-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	25-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	31-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	08-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	05-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	08-Aug-2017	---	---	---	---	---	---
	12-Aug-2017	---	---	---	---	---	---
	20-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	22-Jul-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	15-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
MEBG-10-1-3	29-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	19-Aug-2012	0.0004	0.0004	0.19	0.1	0.0004	0.0008
	25-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	30-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	06-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	14-Sep-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	02-Oct-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	04-Nov-2016	---	---	---	---	---	---
	12-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	13-Aug-2017	---	---	---	---	---	---
	12-Sep-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	15-Sep-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	15-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
MEBG-12-2-3	30-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	05-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	11-Aug-2017	---	---	---	---	---	---
	20-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	22-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	14-Jul-2019	0.0004	0.0004	0.1	---	0.0004	0.00089
MLS 09-6-2	19-Aug-2009	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	19-Aug-2011	0.0004	0.0004	0.1	---	0.0004	0.0008
MLS-13-9-3	08-Aug-2015	---	---	---	---	---	---
MLS-13-9-3	09-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	11-Aug-2017	---	---	---	---	---	---
	16-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Jul-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
MLS-14-3-3	30-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	08-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008

Table 14
Groundwater Geochemical Statistical Source Data (1997-2019) - Petroleum Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Benzene (mg/L)	Ethylbenzene (mg/L)	PHC F1 (C6-C10) - BTEX (mg/L)	PHC F2 (C10-C16) (mg/L)	Toluene (mg/L)	Xylenes-Total (mg/L)
MLS-14-4-3	30-Jul-2014	0.0004	0.0004	0.1	0.1	---	0.0008
	08-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	03-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
MLS-14-8-3	29-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	04-Aug-2016	0.0004	0.0004	0.1	0.15	0.0004	0.0008
MWBG-10-1-3	30-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	17-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	21-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	30-Jul-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	08-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	12-Aug-2017	---	---	---	---	---	---
	17-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	22-Jul-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	11-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
MWBG-12-1-3	17-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
WBIO 08-1-2	19-Aug-2009	---	---	---	---	---	---
WBIO 08-1-2	20-Aug-2009	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	20-Aug-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	17-Aug-2012	0.0004	0.0004	0.1	0.2	0.0004	0.0008
	06-Aug-2015	---	---	---	---	---	---
	03-Aug-2016	---	---	---	---	---	---
	12-Aug-2017	---	---	---	---	---	---
BEAR, FRENCHY'S AND GOOSE ISLANDS - Surficial Sediments							
BI 08-1-4	19-Aug-2008	---	---	---	---	---	---
BI 08-1-4	21-Aug-2008	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Aug-2009	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	18-Aug-2009	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	23-Aug-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	23-Aug-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	21-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	21-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
BI-13-6-2	03-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	10-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	14-Aug-2017	---	---	---	---	---	---
	17-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
BI-14-8-3	04-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	08-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
BIBG-10-1-4	29-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	21-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	19-Sep-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2016	---	---	---	---	---	---
	10-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	11-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	20-Sep-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	17-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
BIBG-10-2-4	29-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008

Table 14
Groundwater Geochemical Statistical Source Data (1997-2019) - Petroleum Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Benzene (mg/L)	Ethylbenzene (mg/L)	PHC F1 (C6-C10) - BTEX (mg/L)	PHC F2 (C10-C16) (mg/L)	Toluene (mg/L)	Xylenes-Total (mg/L)
BIBG-12-1-7	19-Sep-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	07-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
BIBG-12-2-4	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	23-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	04-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	09-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	15-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Jul-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	12-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
FIBG-10-1-4	29-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	29-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
GIBG-10-1-5	21-Aug-2011	0.0004	0.0004	0.1	---	0.0004	0.0008
	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
GIBG-10-2-3	28-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	28-Sep-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	21-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	15-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	25-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	25-Aug-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	03-Aug-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	10-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	10-Aug-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	16-Sep-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	07-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	07-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	02-Oct-2016	---	---	---	---	---	---
	03-Oct-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	04-Nov-2016	---	---	---	---	---	---
	20-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
(Duplicate)	20-Aug-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	12-Sep-2017	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	20-Sep-2018	0.0004	0.0004	0.1	0.1	0.0004	0.00089
	16-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
(Duplicate)	16-Jul-2019	0.0004	0.0004	0.1	0.1	0.0004	0.00089
SHALLOW BEDROCK - Inferred to Represent Natural Saline Water and Hydrocarbon Seepage							
NWR 98-18-15	09-Sep-1998	0.033	0.0025	---	---	0.0025	0.021
	15-Sep-1999	0.01	0.01	---	---	0.01	0.01
	17-Sep-2000	0.0045	0.0005	---	---	0.0005	0.0028
(Duplicate)	17-Sep-2000	0.005	0.0005	---	---	0.0005	0.0031
	27-Aug-2001	0.05	0.05	---	---	0.05	0.1
	22-Aug-2002	0.0005	0.0005	---	---	0.0005	0.0005
(Duplicate)	22-Aug-2002	0.0006	0.0005	---	---	0.0005	0.0005
	26-Aug-2003	0.0007	0.0005	---	---	0.0005	0.0039
(Duplicate)	26-Aug-2003	---	---	---	---	---	---
NWR 99-16-17	15-Sep-1999	---	---	---	---	---	---
NWR 99-16-17	17-Sep-2000	0.0009	0.0005	---	---	0.0005	0.0007
	27-Aug-2001	0.0007	0.0005	---	---	0.0005	0.001
	21-Aug-2002	0.0009	0.0005	---	---	0.0005	0.0007
	26-Aug-2003	0.0128	0.0005	---	---	0.0005	0.001
RB 02-3-2	22-Aug-2002	0.0008	0.0005	---	---	0.0005	0.0019
(Duplicate)	22-Aug-2002	0.0007	0.0005	---	---	0.0005	0.0019
	26-Aug-2003	0.0008	0.0005	---	---	0.0005	0.001
(Duplicate)	26-Aug-2003	0.0007	0.0005	---	---	0.0005	0.0006
	23-Aug-2004	0.0007	0.0005	0.9	1	0.0005	0.0005
(Duplicate)	23-Aug-2004	0.0006	0.0005	1.2	8	0.0005	0.001
	25-Aug-2005	0.0005	0.0005	0.13	2.2	0.0005	0.0015
(Duplicate)	25-Aug-2005	0.0005	0.0005	0.12	5	0.0005	0.0015
	20-Aug-2006	0.0005	0.0005	0.1	0.6	0.0005	0.001
(Duplicate)	20-Aug-2006	0.0005	0.0005	0.1	1	0.0005	0.001
NWR 09-1-20	25-Oct-2011	0.0055	0.0004	0.57	45	0.0004	0.0025
	20-Aug-2012	0.023	0.0004	0.88	1.4	0.0004	0.0008
	25-Aug-2013	0.024	0.0004	0.58	11	0.0004	0.0008
	08-May-2014	0.098	0.0004	0.21	2.6	0.0004	0.0037
	01-Aug-2014	0.073	0.0004	0.41	27	0.0004	0.0028
	31-May-2015	0.059	0.0004	0.33	7.6	0.0004	0.0028
	05-Jul-2015	0.065	0.0004	0.17	4.9	0.0004	0.0026
(Duplicate)	05-Jul-2015	0.063	0.0004	0.1	5.1	0.0004	0.0027
	08-Aug-2015	0.035	0.0004	0.34	5.3	0.0004	0.0018
	25-Nov-2015	0.038	0.0004	0.16	20	0.0004	0.0024
(Duplicate)	25-Nov-2015	0.041	0.0004	0.1	0.53	0.0004	0.0024
	12-Mar-2016	0.039	0.0004	0.54	5.6	0.0004	0.0014
	05-Aug-2016	0.004	0.004	3.9	130	0.004	0.008
	02-Nov-2016	---	---	---	---	---	---
	03-Nov-2016	0.17	0.0004	0.1	47	0.0004	0.0071
	13-Aug-2017	0.0076	0.0004	0.34	1.2	0.0004	0.0008

Table 14
Groundwater Geochemical Statistical Source Data (1997-2019) - Petroleum Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Benzene (mg/L)	Ethylbenzene (mg/L)	PHC F1 (C6-C10) - BTEX (mg/L)	PHC F2 (C10-C16) (mg/L)	Toluene (mg/L)	Xylenes-Total (mg/L)
NWR 09-3-20	13-Sep-2009	0.0076	0.0006	0.22	0.2	0.0033	0.01
	20-Aug-2010	0.0067	0.0004	0.3	0.3	0.0007	0.0008
	18-Aug-2011	0.048	0.0004	0.18	0.3	0.0014	0.0021
	19-Aug-2012	0.033	0.0004	0.1	0.13	0.0004	0.0008
	21-Aug-2013	0.0095	0.0004	0.1	0.27	0.00079	0.0008
	11-Oct-2013	0.0004	0.0004	0.1	0.15	0.0004	0.0008
	08-May-2014	0.0032	0.0004	0.1	0.1	0.0004	0.0008
	01-Aug-2014	0.0026	0.0004	0.1	0.26	0.0004	0.0008
	31-May-2015	0.0065	0.0004	0.1	0.12	0.0004	0.0008
	04-Jul-2015	0.0011	0.0004	0.1	0.22	0.0004	0.0008
(Duplicate)	04-Jul-2015	0.00077	0.0004	0.1	0.18	0.0004	0.0008
	09-Aug-2015	0.0025	0.0004	0.1	0.18	0.0004	0.0008
	25-Nov-2015	0.0028	0.0004	0.1	0.1	0.0004	0.0008
	12-Mar-2016	0.0019	0.0004	0.1	0.11	0.0004	0.0008
	05-Aug-2016	---	---	---	---	---	---
	13-Aug-2016	---	---	---	---	---	---
	15-Aug-2017	---	---	---	---	---	---
NWR 09-4-17	13-Sep-2009	0.014	0.0004	**0.53**	5.4	0.0019	0.013
	20-Aug-2010	0.001	0.0004	0.1	1.8	0.0004	0.0008
	18-Aug-2011	0.0004	0.0004	0.1	---	0.0004	0.0008
	20-Aug-2012	0.0035	0.0004	0.1	0.1	0.0004	0.0008
	25-Aug-2013	0.017	0.0004	0.1	0.27	0.0004	0.0012
	08-May-2014	0.003	0.0004	0.1	0.1	0.0004	0.0008
	01-Aug-2014	0.0004	0.0004	0.1	0.2	0.0004	0.0008
	01-Jun-2015	0.0013	0.0004	0.1	0.22	0.0004	0.0022
	04-Jul-2015	0.0013	0.0004	0.1	0.23	0.0004	0.0017
(Duplicate)	04-Jul-2015	0.0014	0.0004	0.1	0.26	0.0004	0.0018
	08-Aug-2015	0.002	0.0004	0.1	0.21	0.0004	0.0008
	25-Nov-2015	0.0041	0.0004	0.1	0.1	0.0004	0.0008
	12-Mar-2016	0.0028	0.0004	0.1	0.2	0.0004	0.0008
	05-Aug-2016	---	---	---	---	---	---
	13-Aug-2016	---	---	---	---	---	---
	02-Nov-2016	---	---	---	---	---	---
	03-Nov-2016	0.0041	0.0004	0.1	0.15	0.0004	0.0008
	13-Aug-2017	---	---	---	---	---	---
BT3 99-21-12	16-Sep-1999	0.005	0.005	---	---	0.005	0.005
	18-Sep-2000	0.0005	0.0005	---	---	0.0005	0.0005
	27-Aug-2001	0.0005	0.0005	---	---	0.0005	0.0005
	20-Aug-2002	0.0005	0.0005	---	---	0.0005	0.0005
	25-Aug-2003	0.0008	0.0005	0.1	---	0.0005	0.001
	22-Aug-2004	0.0005	0.0005	0.1	0.1	0.0005	0.0005
	25-Aug-2005	0.0006	0.0005	0.1	0.1	0.0005	0.0015
(Duplicate)	25-Aug-2005	---	---	---	---	---	---
	22-Aug-2006	0.0005	0.0005	0.1	0.1	0.0005	0.001
	22-Aug-2007	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	19-Aug-2008	0.0004	0.0004	0.1	0.2	0.0004	0.0008
	17-Aug-2009	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	21-Aug-2010	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	20-Aug-2011	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	20-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	23-Aug-2013	0.0014	0.0004	0.1	0.1	0.0004	0.0008
	31-Jul-2014	0.002	0.0004	0.1	0.1	0.0004	0.0008
	08-Aug-2015	---	---	---	---	---	---
	05-Aug-2016	---	---	---	---	---	---
	13-Aug-2017	---	---	---	---	---	---
	16-Aug-2017	---	---	---	---	---	---
SURFICIAL SEDIMENTS - Inferred to Represent Natural Saline Water and Hydrocarbon seepage							
NWR 03-38-3	26-Aug-2003	0.0027	0.0005	---	0.1	0.0005	0.0131
(Duplicate)	26-Aug-2003	---	---	---	---	---	---
	23-Aug-2004	0.0005	0.0005	**0.1**	0.3	0.0005	0.001
	25-Aug-2005	0.0005	0.0005	0.1	0.3	0.0005	0.0015
(Duplicate)	25-Aug-2005	---	---	---	---	---	---
	20-Aug-2006	0.0005	0.0005	0.1	0.2	0.0005	0.001
RB-13-2-2.4	06-Jun-2001	---	---	---	---	---	---
RB-13-2-2.4	11-Oct-2013	0.005	0.0004	0.6	1.3	0.0004	0.0084
	14-Sep-2014	0.00062	0.0004	0.1	0.78	0.0004	0.0008
	31-May-2015	0.0004	0.0004	0.1	0.18	0.0004	0.0008
	18-Oct-2015	0.00092	0.0004	0.1	3	0.0004	0.0008
	15-Aug-2016	0.0004	0.0004	0.1	0.72	0.0004	0.0008
	01-Oct-2016	0.0004	0.0004	0.1	0.68	0.0004	0.0008
	14-Sep-2017	0.0082	0.0032	0.1	0.19	0.0004	0.0033

Table 14
Groundwater Geochemical Statistical Source Data (1997-2019) - Petroleum Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Benzene (mg/L)	Ethylbenzene (mg/L)	PHC F1 (C6-C10) - BTEX (mg/L)	PHC F2 (C10-C16) (mg/L)	Toluene (mg/L)	Xylenes-Total (mg/L)
RB-13-4-3	11-Oct-2013	0.098	0.0023	0.27	0.97	0.0014	0.08
	14-Sep-2014	0.034	0.00054	0.1	0.42	0.0004	0.015
	18-Oct-2015	0.075	0.0013	0.11	1.7	0.0004	0.0056
(Duplicate)	18-Oct-2015	0.074	0.0013	0.13	---	0.0004	0.0058
	01-Oct-2016	0.1	0.002	0.1	0.36	0.0004	0.0017
	14-Sep-2017	0.047	0.00059	**0.1**	0.35	0.0004	0.0008
RB-13-5-2.4	11-Oct-2013	0.013	0.00098	0.1	0.1	0.001	0.0032
	14-Sep-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	18-Oct-2015	0.015	0.0004	0.1	0.1	0.0004	0.0017
	15-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	01-Oct-2016	0.0053	0.0004	0.1	0.1	0.0004	0.0008
RB-13-8-1.5	11-Oct-2013	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	13-Sep-2014	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	19-Oct-2015	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	15-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	01-Oct-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
SURFICIAL SEDIMENTS - Inferred to Represent Natural Gas Seepage without Saline Water							
MEBG-15-4-3	05-Aug-2016	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	12-Aug-2017	0.00058	0.0004	0.82	0.6	0.0004	0.00097
	21-Aug-2017	---	---	---	---	---	---
	22-Jul-2018	0.11	0.17	2.2	0.64	0.00048	0.42
	14-Jul-2019	0.14	0.31	2.2	0.74	0.00068	0.45
MLS-14-2-3	29-Jul-2014	---	---	---	---	---	---
MLS-14-2-3	30-Jul-2014	0.0004	0.0004	0.1	0.1	0.00061	0.0008
	08-Aug-2015	0.0004	0.0004	0.1	0.26	0.00047	0.0008
	03-Aug-2016	0.0004	0.0004	0.1	0.29	0.00087	0.0008
	12-Aug-2017	---	---	---	---	---	---
	16-Aug-2017	0.0004	0.0004	0.1	0.19	0.024	0.0008
	19-Jul-2018	0.0004	0.0004	0.1	0.1	0.00064	0.00089
	18-Jul-2019	0.0004	0.0004	0.1	0.1	0.0016	0.00089
B38 02-33-3	20-Aug-2002	0.0005	0.0005	---	---	0.0005	0.001
	24-Aug-2003	0.0005	0.0005	0.1	---	0.0005	0.001
	22-Aug-2004	0.0005	0.0005	0.1	0.1	0.0005	0.001
	24-Aug-2005	0.0005	0.0005	0.1	0.1	0.0005	0.0015
(Duplicate)	24-Aug-2005	---	---	---	---	---	---
	21-Aug-2006	0.0005	0.0005	0.1	0.1	0.0005	0.001
	19-Aug-2007	0.0004	0.0004	0.1	0.8	0.0004	0.0008
	19-Aug-2008	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	17-Aug-2009	0.0004	0.0004	0.12	1	0.0004	0.0008
	22-Aug-2010	0.0009	0.0004	0.1	0.1	0.0004	0.0008
	17-Aug-2011	0.0033	0.0004	0.1	0.1	0.0004	0.0008
	19-Aug-2012	0.0004	0.0004	0.1	0.1	0.0004	0.0008
	01-Aug-2014	---	---	---	---	---	---
	10-Aug-2015	---	---	---	---	---	---
	03-Aug-2016	---	---	---	---	---	---
B38 02-34-3	20-Aug-2002	0.95	0.025	---	---	0.025	0.37
	24-Aug-2003	0.543	0.0089	0.3	---	0.0073	0.0939
	22-Aug-2004	1.25	0.005	0.1	2.3	0.005	0.275
	24-Aug-2005	0.987	0.005	0.17	0.9	0.005	0.162
(Duplicate)	24-Aug-2005	---	---	---	---	---	---
	21-Aug-2006	0.575	0.005	0.217	0.7	0.005	0.033
	19-Aug-2007	0.365	0.0004	0.23	2.8	0.0004	0.0177
	17-Aug-2009	0.74	0.0004	0.12	1.4	0.0004	0.065
	22-Aug-2010	0.23	0.0004	0.1	0.4	0.0004	0.0008
	17-Aug-2011	0.36	0.0004	0.1	0.5	0.0004	0.038
	19-Aug-2012	0.7	0.00042	0.1	0.52	0.0004	0.0085
	26-Aug-2013	0.094	0.0004	0.1	0.2	0.0004	0.0008
	01-Aug-2014	0.25	0.0004	0.1	0.2	0.0004	0.0008
	10-Aug-2015	0.034	0.0004	0.1	0.1	0.0004	0.0008
	03-Aug-2016	---	---	---	---	---	---

Table 15
Groundwater Geochemical Statistical Source Data (1997-2019) - Polycyclic Aromatic Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Acenaphthene (mg/L)	Acridine (mg/L)	Anthracene (mg/L)	Benzo(a)anthracene (mg/L)	Benzo(a)pyrene (mg/L)	Fluoranthene (mg/L)	Fluorene (mg/L)	Naphthalene (mg/L)	Phenanthrene (mg/L)	Pyrene (mg/L)	Quinoline (mg/L)
MAINLAND - Surficial Sediments												
MCBG-10-1-3	30-Jul-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	07-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	04-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	12-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	22-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	11-Jul-2019	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
MCBG-12-1-2	31-Jul-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	08-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	05-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	20-Aug-2017	0.0001	0.00005	0.000032	0.000068	0.0000075	0.00039	0.00005	0.0001	0.00036	0.00028	0.0002
	22-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	15-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
MEBG-10-1-3	30-Jul-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	06-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	03-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	12-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.000042	0.00005	0.0001	0.00008	0.000037	0.0002
	16-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.000027	0.00005	0.0001	0.00005	0.000024	0.0002
	15-Sep-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	15-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
MEBG-12-2-3	30-Jul-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	09-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.000051	0.00002 ---	
	05-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	20-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	22-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
MWBG-10-1-3	30-Jul-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	08-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	03-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	17-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	22-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	11-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
WBIO 08-1-2	06-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	03-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
BEAR, FRENCHY'S AND GOOSE ISLANDS - Surficial Sediments												
BIBG-10-1-4	03-Aug-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	09-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	10-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	11-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	17-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	20-Sep-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	17-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
BIBG-12-1-7	03-Aug-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	09-Aug-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	07-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	

Table 15
Groundwater Geochemical Statistical Source Data (1997-2019) - Polycyclic Aromatic Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Acenaphthene (mg/L)	Acridine (mg/L)	Anthracene (mg/L)	Benzo[a]anthracene (mg/L)	Benzo[a]pyrene (mg/L)	Fluoranthene (mg/L)	Fluorene (mg/L)	Naphthalene (mg/L)	Phenanthrene (mg/L)	Pyrene (mg/L)	Quinoline (mg/L)
BIBG-12-2-4	04-Aug-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	09-Aug-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	09-Aug-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	15-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	18-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	12-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
GIBG-10-2-3	03-Aug-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
(Duplicate)	03-Aug-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	10-Aug-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
(Duplicate)	10-Aug-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.00013	0.000058	0.00002	---
	07-Aug-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.000068	0.00002	---
(Duplicate)	07-Aug-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	03-Oct-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	20-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.000053	0.00002	0.0002
(Duplicate)	20-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	14-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
(Duplicate)	14-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	20-Sep-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	16-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
(Duplicate)	16-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.000063	0.00002	0.0002
SHALLOW BEDROCK - Inferred to Represent Natural Saline Water and Hydrocarbon Seepage												
NWR 09-1-20	08-May-2014	0.00013	---	0.00001	0.000019	0.0000075	0.000026	0.00048	0.0025	0.0011	0.00011	---
	01-Aug-2014	0.00033	---	0.00001	0.000074	0.00002	0.000058	0.0012	0.0038	0.0032	0.0003	---
	31-May-2015	0.00096	---	0.00001	0.000094	0.000077	0.000069	0.0017	0.0066	0.0039	0.00018	---
	05-Jul-2015	---	---	---	---	---	---	---	---	---	---	---
(Duplicate)	05-Jul-2015	---	---	---	---	---	---	---	---	---	---	---
	08-Aug-2015	0.0001	---	0.00001	0.000031	0.000037	0.00003	0.00005	0.0043	0.0012	0.00007	---
	25-Nov-2015	0.00061	---	0.00001	0.00011	0.000029	0.000089	0.0022	0.0058	0.0047	0.00049	---
(Duplicate)	25-Nov-2015	---	---	---	---	---	---	---	---	---	---	---
	12-Mar-2016	0.00021	---	0.00001	0.000055	0.0000075	0.00001	0.00068	0.0034	0.0012	0.00015	---
	05-Aug-2016	0.00016	---	0.00001	0.000028	0.0000075	0.000021	0.00062	0.0037	0.0012	0.00011	---
	02-Nov-2016	---	---	---	---	---	---	---	---	---	---	---
	03-Nov-2016	0.00027	---	0.000034	0.000023	0.00002	0.000027	0.00046	0.0019	0.00073	0.00016	---
	13-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00022	0.002	0.00034	0.00002	0.0002
	22-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00026	0.0015	0.0004	0.00002	0.0002
	15-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00016	0.00023	0.00028	0.00002	0.0002
NWR 09-3-20	11-Oct-2013	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00014	0.00035	0.00005	0.00002	---
	08-May-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00007	0.0001	0.00012	0.00002	---
	01-Aug-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000078	0.00019	0.000086	0.00002	---
	31-May-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000059	0.00028	0.000083	0.00002	---
	09-Aug-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000073	0.00019	0.00015	0.000024	---
	25-Nov-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000056	0.0001	0.000086	0.00002	---
	12-Mar-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000065	0.00015	0.00011	0.00002	---
	05-Aug-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000058	0.0001	0.00012	0.00002	---
	15-Aug-2017	0.0001	0.00005	0.000012	0.0000085	0.0000075	0.000047	0.000064	0.00038	0.00015	0.000038	0.0002
	20-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.000015	0.000056	0.00017	0.00011	0.00002	0.0002
	15-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.000031	0.00005	0.00035	0.00011	0.000036	0.0002
NWR 09-4-17	08-May-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	01-Jun-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.000071	0.00057	0.000092	0.00002	---
	25-Nov-2015	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	12-Mar-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.00013	0.00005	0.00002	---
	03-Nov-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.000057	0.00002	---
BT3 99-21-12	31-Jul-2014	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00021	0.00002	---
	08-Aug-2015	0.00011	---	0.000011	0.000009	0.0000079	0.000011	0.000053	0.00011	0.000053	0.000021	---
	05-Aug-2016	0.0001	---	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	---
	13-Aug-2017	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00019	0.00002	0.0002
	12-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002
	13-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002	0.0002

Table 15
Groundwater Geochemical Statistical Source Data (1997-2019) - Polycyclic Aromatic Hydrocarbons

PROJECT No.: 417011-00096

Monitoring Station		Acenaphthene (mg/L)	Acridine (mg/L)	Anthracene (mg/L)	Benzo[a]anthracene (mg/L)	Benzo[a]pyrene (mg/L)	Fluoranthene (mg/L)	Fluorene (mg/L)	Naphthalene (mg/L)	Phenanthrene (mg/L)	Pyrene (mg/L)	Quinoline (mg/L)
SURFICIAL SEDIMENTS - Inferred to Represent Natural Saline Water and Hydrocarbon seepage												
RB-13-2-2.4	11-Oct-2013	0.00015 ---		0.00001	0.0000085	0.0000075	0.00001	0.00058	0.0038	0.00038	0.00002 ---	
	14-Sep-2014	0.00021 ---		0.000076	0.000016	0.0000075	0.000063	0.0011	0.0021	0.0011	0.0002 ---	
	31-May-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.00026	0.00005	0.00002 ---	
	18-Oct-2015	0.0004 ---		0.00001	0.0000085	0.0000075	0.000056	0.0018	0.0012	0.0015	0.00021 ---	
	15-Aug-2016	0.0001 ---		0.000018	0.0000085	0.0000075	0.00001	0.00037	0.00033	0.0002	0.000049 ---	
	01-Oct-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00027	0.00015	0.00013	0.000039 ---	
RB-13-4-3	11-Oct-2013	0.00025 ---		0.00001	0.0000085	0.0000075	0.00001	0.00066	0.003	0.00089	0.000049 ---	
	14-Sep-2014	0.00014 ---		0.000012	0.0000085	0.0000075	0.00001	0.00043	0.0017	0.00064	0.000039 ---	
	18-Oct-2015	0.00062 ---		0.00001	0.0000085	0.0000075	0.000042	0.002	0.003	0.0037	0.00016 ---	
	01-Oct-2016	0.00015 ---		0.00001	0.0000085	0.0000075	0.00001	0.0004	0.0015	0.00037	0.00002 ---	
RB-13-5-2.4	11-Oct-2013	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.000076	0.00016	0.00005	0.00002 ---	
	14-Sep-2014	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	18-Oct-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	15-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.000013	0.00005	0.0001	0.00005	0.000059 ---	
	01-Oct-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
RB-13-8-1.5	11-Oct-2013	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	13-Sep-2014	---	---	---	---	---	---	---	---	---	---	
	19-Oct-2015	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.00015	0.00005	0.00002 ---	
	15-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.000024	0.00005	0.0001	0.00005	0.00011 ---	
	01-Oct-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00004 ---	
SURFICIAL SEDIMENTS - Inferred to Represent Natural Gas Seepage without Saline Water												
MEBG-15-4-3	05-Aug-2016	0.0001 ---		0.00001	0.0000085	0.0000075	0.00001	0.00005	0.0001	0.00005	0.00002 ---	
	12-Aug-2017	0.00016	0.00005	0.000051	0.00004	0.000013	0.00032	0.00016	0.0037	0.00044	0.00023	0.0002
B38 02-34-3	16-Jul-2018	0.0001	0.00005	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.016	0.00005	0.00002	0.0002
	13-Jul-2019	0.0001	0.00004	0.00001	0.0000085	0.0000075	0.00001	0.00005	0.014	0.00005	0.00002	0.0002

Appendix C. Well Logs

EXPLANATION OF BOREHOLE DESCRIPTIONS AND GRAPHICS

CLIENT Imperial Oil Resources Ltd. **PROJECT NAME** SNP 2025 Drilling Program

PROJECT NUMBER 417085-54419-24100 **PROJECT LOCATION** Norman Wells

Grain Size Ranges

Description	Diameter (mm)
Clay, Silt	<0.075
Fine Sand	0.075 - 0.425
Medium Sand	0.425 - 2
Coarse Sand	2 - 4.75
Fine Gravel	4.75 - 19
Coarse Gravel	19 - 75
Cobble	75 - 300
Boulder	>300

Cohesive Soil Consistency

Description	N-Value
Very Soft	<2
Soft	2 - 4
Firm	4 - 8
Stiff	8 - 15
Very Stiff	15 - 30
Hard	>30

Particle Size Distribution

Description	Volume %
Trace (e.g. Trace Clay)	0 - 10%
Some (e.g. Some Clay)	10 - 20%
Adjective (e.g. Sandy Silt)	20 - 35%
And (e.g. Sand and Silt)	Both are >35%
Noun (e.g. Sand)	>35%

Cohesionless Soil Compactness

Description	N-Value
Very Loose	<4
Loose	4 - 10
Compact	10 - 30
Dense	30 - 50
Very dense	>50

Abbreviations

PI	Plastic Index (%)
W	Moisture Content (%)
DD	Dry Density
NP	Non Plastic
-200	Percent Passing No. 200 Sieve
PP	Pocket Penetrometer
TV	Torvane
UC	Unconfined Compression
ppm	Parts Per Million (by volume)
LEL	Lower Explosive Limit
PID	Photoionization Detector
OVA	Organic Vapour Analyzer
RQD	Rock Quality Designation
▼	Water Level

LITHOLOGIC SYMBOLS

CLAY (CL)

CLAYEY SILT (CL-ML)

FILL

SAND (SP)

SHALE

SILT (ML)

SILTY CLAY (CL-CH)

SILTY SAND (SM)

WELL CONSTRUCTION SYMBOLS

BENTONITE CHIPS

SAND

SLOUGH/CUTTING

Well # GIT7-25-01
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 17-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	
		SILTY SAND (0.0-4.5 m) Very fine-grained, brown, dry, frozen (poor recovery, sloughing off auger).	
1		At 1.4 m:Fine-grained, decreased silt content to some, becomes moist, brown/grey mottling.	
2		At 2.0 m: Medium-grained,	
		At 2.5 m: Moisture content increase with depth to wet.	
3		At 2.8 m: Saturated.	
4		4.5 m End of Borehole	
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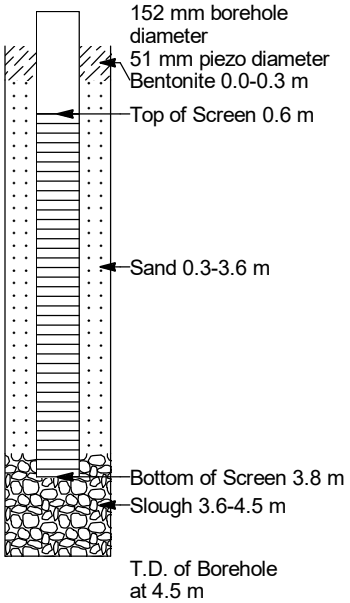

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Enterprise Project ID: 417085-54419

Well # GIT7-25-02
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 17-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter Bentonite 0.0-0.6 m
		SILTY SAND (0.0-0.4 m) Brown, frozen, loose.	
1		NO RECOVERY (0.4-2.4 m) At 0.4 m: Gravel layer and crush rock (fill, rounded to angular, <1 cm to 4 cm in diameter), some cobbles (up to 12 cm in diameter), sloughing off auger/spun up. Switched bit to get through.	Top of Screen 0.9 m
2			Sand 0.6-4.1 m
3		SAND (2.4-4.5 m) Fine to medium-grained, trace gravels (slough from above), some silt, brown, moist, loose.	
4		At 3.5 m: Fine-grained, siltier, some decaying , saturated. From 3.8-4.5 m: Coarser (medium-grained) sand, less silt, saturated.	Bottom of Screen 4.1 m Slough 4.1-4.5 m
		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
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Enterprise Project ID: 417085-54419

Well # GIT7-25-03
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 17-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter Bentonite 0.0-0.6 m
		`SHALE (FILL) (0.0-0.1 m) Grey/black, frozen, bitumen odour.	
		SILT (FILL) (0.1-0.3 m) Some clay, trace gravel (<1 cm in diameter), dark brown, moist.	
1		SAND (0.3-4.5 m) Fine- to medium-grained, some silt, brown, moist, uniform.	Top of Screen 0.9 m Sand 0.6-2.4 m
2		At 1.7 m: Medium-grained, trace silt, wet. At 2.0 m: Medium-grained, saturated.	Bottom of Screen 2.4 m
3			Slough 2.4-4.5 m
4			
		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
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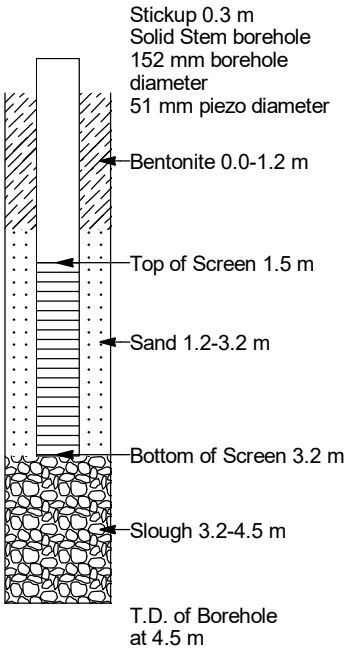
Enterprise Project ID: 417085-54419

Well # GIT7-25-04
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 17-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	
		SAND (0.0-4.5 m) Fine-grained, brown, frozen, loose, poor returns. From 0.3-1.5 m: Slow drilling, switched bit. At 1.0 m: Medium-grained, solid, brown, frozen. From 1.5-1.7 m: Silt lenses, grey, moist, wetness increased with depth, trace oxidation. At 2.5 m: Saturated.	
4.5		4.5 m End of Borehole	



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Enterprise Project ID: 417085-54419

worley
DELIVERING SUSTAINABLE CHANGE

Well # GIT8-25-01

Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 18-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter
		SILT (0.0-1.5 m) Brown, frozen, loose.	Bentonite 0.0-1.2 m
1			Top of Screen 1.5 m
2		SAND (1.5-4.5 m) Fine-grained, brown, moist, loose, uniform.	
3		At 2.5 m: Medium-grained.	Sand 1.2-4.5 m
4		At 3.8 m: Become wet.	Bottom of Screen 4.5 m
		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
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Enterprise Project ID: 417085-54419

Well # GIT8-25-02
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 18-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter
		SAND (0.0-1.4 m) Very fine- to fine-grained, some silt, brown, loose, frozen. At 0.5 m: Damp. At 1.0 m: Moist.	Bentonite 0.0-1.2 m
1			
2		SAND AND SILT (1.4-2.4 m) Interbedded, brown, moist, oxidation mottling throughout.	Top of Screen 1.5 m
		SILT (2.4-2.7 m) Grey to brown, wet.	
3		SAND (2.7-4.5 m) Medium-grained, damp, loose. At 3.3 m: Becomes saturated. At 3.4 m: Becomes fine-grained and silty, dark brown to end of borehole.	Sand 1.2-4.47 m
4			
		4.5 m End of Borehole	Slough 4.47-4.5 m Bottom of Screen 4.5 m T.D. of Borehole at 4.5 m
5			
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Enterprise Project ID: 417085-54419

Well # GIT8-25-03
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 18-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter
		SILT (0.0-1.4 m) Trace fine-grained sand, brown, loose, frozen.	Bentonite 0.0-1.2 m
1		SILTY SAND (1.4-2.0 m) Fine-grained, brown, damp, loose.	Top of Screen 1.5 m
2		SILT AND SAND (2.0-3.0 m) Interbedded, brown, moist, oxidation mottling.	Sand 1.2-4.47 m
3		SILT (3.0-3.2 m) Grey to brown, wet.	
		SAND (3.2-4.5 m) Medium-grained, no silt, moist to wet. From 4.2-4.5 m: Saturated.	Slough 4.47-4.5 m Bottom of Screen 4.5 m
4		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
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Enterprise Project ID: 417085-54419

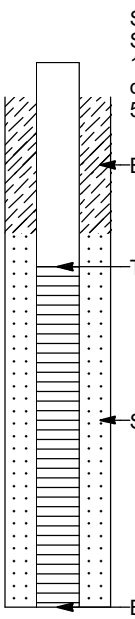
Well # GIT8-25-04
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 18-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description
0		Ground Surface
		SILT (0.0-1.3 m) Brown, frozen, loose.
1		SAND (1.3-2.0 m) Fine-grained, brown, frozen, loose. At 1.5 m: Moist. At 2.0 m: Wet.
2		SILT AND SAND (2.0-3.0 m) Interbedded, trace oxidation mottling.
3		SAND (3.0-4.5 m) Medium-grained, no silt, moist, clean.
4		From 4.1-4.4 m: Wet.
		4.5 m End of Borehole
5		
6		
7		
8		
9		

Well Data



Stickup 0.3 m
Solid Stem borehole
152 mm borehole diameter
51 mm piezo diameter
Bentonite 0.0-1.2 m
Top of Screen 1.5 m
Sand 1.2-4.5 m
Bottom of Screen 4.5 m
T.D. of Borehole at 4.5 m

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Enterprise Project ID: 417085-54419

Well # MLE-25-01
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 16-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter
0		SILTY CLAY (0.0-4.5 m) Trace gravels (rounded, 1-2 cm in diameter), brown, poor recovery.	Bentonite 0.0-0.6 m
1		At 0.7 m: Frozen.	Top of Screen 0.8 m
1		From 1.0-1.4 m: Grey mottling (depth approximately due to spin-up).	
1		From 1.4-1.5 m: Sample still on auger.	
2			Sand 0.6-3.8 m
2		From 2.3-3.0 m: Still frozen, some to common oxidation.	
3		From 3.0-4.5 m: Grey, poor recovery.	
4			Bottom of Screen 3.8 m
4			Bentonite 3.8-4.3 m
4			Slough 4.3-4.5 m
4		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
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Enterprise Project ID: 417085-54419

Well # MLE-25-02
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 16-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter
		SHALE (FILL) (0.0-2.0 m) Silty/clayey, frozen, hydrocarbon odour.	Bentonite 0.0-1.0 m
2		SILTY CLAY (2.0-4.5 m) Green to grey, saturated, soft, mottled, trace oxidation, no hydrocarbon odour	Top of Screen 2.5 m Sand 2.3-4.0 m
3		From 3.5-4.5 m: Some coarse-grained sand, fine gravel decreased moisture content with depth.	
4		From 4.0-4.5 m: Frozen.	Bottom of Screen 4.0 m Bentonite 4.0-4.3 m Slough 4.3-4.5 m
		4.5 m End of Borehole	T.D. of Borehole at 4.5 m

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Enterprise Project ID: 417085-54419

Well # MLW-25-01
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 15-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter Bentonite 0.0-0.6 m
		CLAYEY SILT (0.0-4.0 m) Brown, frozen (disco PF).	Top of Screen 0.7 m
1		At 1.5 m: Slow drilling, poor/no recovery.	
2		From 2.0-3.5 m: Grey to brown, frozen solid, common oxidation, some grey mottling, common fine gravels (<1 cm in diameter), some shale fragments, hard to drill, hard to set off auger, had to backspin out of hole.	Sand 0.6--4.0 m
3			
4		SHALE (4.0-4.5 m) Weathered bedrock, green to grey, dry to damp, ground to powder by auger, lots of spin-up, had to clean hole (cuttings backfilled to 4.0 m).	Bottom of Screen 3.8 m Slough 4.0-4.5 m
		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
5			
6			
7			
8			
9			

DRAFT

Created by: N. Durairaj | Date Created: 03-Apr-2025 | Reviewed By: | Page 1 of 1

Enterprise Project ID: 417085-54419

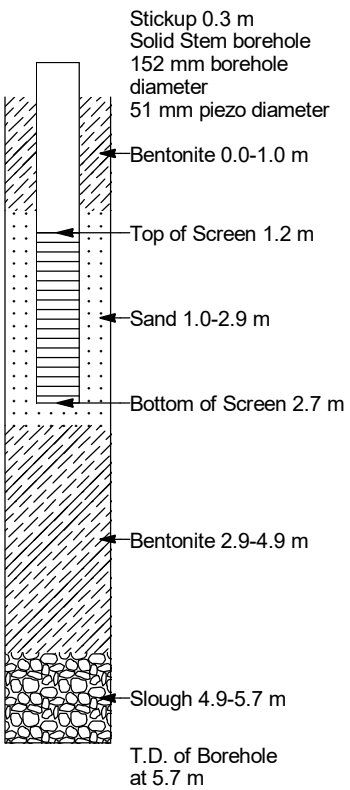
Well # MLW-25-02
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 15-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description
		Ground Surface
0		SILTY CLAY (0.0-3.0 m) Trace gravels (rounded, 0.7-1.5 cm in diameter), brown, moist, soft, trace oxidation mottling.
1		From 1.3-1.5 m: Increase in gravels to some.
2		At 2.0 m: Trace fine-grained sand begins.
		From 2.5-2.7 m: Trace coarse gravels (1-2 cm in diameter), oxidation mottling around clast,
3		CLAY (3.0-5.7 m) Light grey, dry to damp, loose, possible hydrocarbon, persists into PF, poor returns as powder. From 3.0-4.5 m: Poor recovery.
4		From 4.0-.4.5 m: No recovery.
5		At 5.5 m: Slow drilling (frost).
6		5.7 m End of Borehole
7		
8		
9		

Well Data



DRAFT

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Enterprise Project ID: 417085-54419

Well # MLW-25-03
Project Number: 417085-54419-24100

Project: SNP 2025 Drilling Program
Client: Imperial Oil Resources Ltd.
Drilled by: Midnight sun
Drilling Method: Solid Stem Auger
Drill Date: 15-Mar-2025
Logged by: L. Glatiots

Location: Norman Wells
Coordinate System: -
Northing: -
Easting: -
Elevation: -

Depth (m)	Symbol	Material Description	Well Data
0		Ground Surface	Stickup 0.3 m Solid Stem borehole 152 mm borehole diameter 51 mm piezo diameter Bentonite 0.0-0.6 m
		SILTY CLAY (0.0-4.5 m) Trace gravels (<1 cm in diameter), brown. Moist, soft.	Top of Screen 0.7 m
1		From 1.1-1.2 m: Woody debris. At 1.3 m: Colour change to grey. From 1.4-1.5 m: Frozen solid.	
2			Sand 0.6-4.0 m
3			
4			Bottom of Screen 3.8 m Slough 4.0-4.5 m
		4.5 m End of Borehole	T.D. of Borehole at 4.5 m
5			
6			
7			
8			
9			

DRAFT

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Enterprise Project ID: 417085-54419

WorleyParsons
resources & energy

Borehole # BI N42 09-2

PIEZOMETER # BI N42 09-1-3

PROJECT # C53760930

Project Name: 2009 Phase II
Client: Imperial Oil Resources
Drilled by: Encore
Drilling Method: Solid Stem Auger (Track Mounted)
Drill Date: 16 Aug 09
Logged by: KEAM

Location: Bear Island
Northing: 7238818.681
Easting: 599214.8256
Elevation: 51.3568 (toc)

Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	VOC % LEL (0 25 50 75 100) / ppm (0 250 500)	Well Data
0		Ground Surface				Stickup 1.0 m 52 mm ID Sch 40 PVC pipe Solid stem Borehole (156 mm diameter)
0		***SANDY SILT (0.0-0.9 m)*** Medium brown; moist; trace dark organics and orange mottling; some sand in inferred layers.	0.0-0.3 0.0-0.9		5	Bentonite chips 0.0-0.55 m
1		***SILTY SAND (0.9-2.0 m)*** Medium brown; soft; fine- to coarse-grained sand; trace dark brown mottling.	0.9-1.2 0.9-1.5 1.5-2.1		5 0	Peltonite 0.55-0.8 m Top of sand 0.8 m Top of screen 1.0 m Pre-pack screen
2		***SANDY SILT (2.0-4.5 m)*** Permafrost; hard; interlayered with silty sand.	2.0-2.3 2.1-3.0		5	Bottom of screen 2.5 m Bottom of sand 2.8 m
3		At 3.0-4.5 m: Very hard.	3.0-3.9		5	Bentonite chips 2.8-4.2 m
4			3.9-4.2 3.9-4.5		10	Slough 4.2-4.5 m
4.5 m		End of Borehole				
5						
6						
7						
8						
9						

WorleyParsons
resources & energy

Borehole # BI-13-18

PIEZOMETER # BI-13-18-2.4

PROJECT # 307074-01897

Project Name: Norman Wells 2013 Phase 2
Client: Imperial Oil
Drilled by: All Service Drilling
Drilling Method: Direct Push
Drill Date: 3-Sep-2013
Logged by: HARL

Location: Bear Island Sump 1-5
Coordinate System: NAD27 UTM9
Northing: 7238709
Easting: 598235.6
Elevation: 50.06 mard (ground)

Depth (m)	Description	Sample Depth (m)	Sample Type	Soil Vapour Concentration (ppmv)	Soil Vapour Concentration (% LEL)	Lab Testing Requested
0	Ground Surface					
0	***ORGANIC MATTER (0.0-0.1 m)*** Brown; trace silt; organic material; rootlets.	0.0-0.5		< 5		
0	***CLAYEY SILT (0.1-1.2 m)*** Brown; moist; slightly firm; organic material. At 0.8 m: Permafrost.	0.5-1.0		< 5		
1	***SILTY CLAY (1.2-1.5 m)*** Brown; frozen; hard; organic material. At 1.4 m: Fine-grained sand lens.	1.0-1.5		5		BTEX, F1-F4 SALINITY PACKAGE 4, GRAIN SIZE ANALYSIS
1		1.5-1.9		< 5		
2	***SANDY SILT (1.5-2.2 m)*** Light brown; frozen; hard; fine-grained sand; decreased sand content with depth. Between 2.0-2.4 m: Transition zone; decreased sand, increased clay.	1.9-2.5		20		BTEX, F1-F4 SALINITY PACKAGE 4, GRAIN SIZE ANALYSIS
2	***CLAYEY SILT TILL (2.2-3.0 m)*** Grey-brown; ice crystals; fine-grained sand lens; organic material; coal flecks; shells.	2.5-3.0		15		
3	***SAND (3.0-3.4 m)*** Grey-brown; frozen; trace silt.	3.0-3.5			17 ▽	BTEX, F1-F4 SALINITY PACKAGE 4, GRAIN SIZE ANALYSIS
3	***SANDY SILT (3.4-4.5 m)*** Grey-brown; frozen; trace clay.	3.5-3.9		90		
4		3.9-4.5		100		BTEX, F1-F4 SALINITY PACKAGE 4, GRAIN SIZE ANALYSIS
4	End of Borehole					

Well Data:
- Stickup 0.95 m
- 51 mm ID Sch 40 PVC Pipe
- Direct Push Borehole (127 mm nominal diameter)
- Hydrated Bentonite Chips (0.0-0.6 m)
- Top of Sand at 0.6 m
- Top of Screen at 0.9 m
- 3.05 x 51 mm ID Sch40 PVC 0.51 mm Slot Screen 10/20 Frac Sand
- Bottom of Screen at 2.4 m
- Bottom of Sand at 2.7 m
- Bentonite (2.7-4.5 m)
- T.D. of Borehole at 4.5 m

Project Name: Liability Characterization
Client: Imperial Oil Resources
Location: Norman Wells (Bear I. Battery)
Drilled by: Mobil Augers
Drill Date: 18-Oct-98
Compiled by: M. Dubord/A. Glatiotis

Northing: 7238721.33 m
Easting: 599151.92 m
Elevation: 51.18 masl (Grnd)

KOMEX INTERNATIONAL LTD.
ENVIRONMENTAL AND ENGINEERING CONSULTANTS

Borehole # P98-57A

PROJECT # 4369 BZ

SUBSURFACE PROFILE

Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	VOC % LEL (25, 50, 75) / OVA ppm (100, 200, 300, 400, 500)	Well Data	Lab Analysis or Well Details
0		Ground Surface					
		SAND AND GRAVEL (0.0-0.8 m) Fill, very dark brown, moist, loose on auger, some silt, faint HCO.	0.0-1.0		400		Stick up = 0.70 m. 52 mm (ID) Sch. 40 PVC riser Ground Seal Peltonite
1		***SILT (0.8-2.8 m)*** Fill/disturbed, very dark brown and black mottled, soft, moist, some sand, rare wood fragments, moderate crude oil odour and staining	1.0-2.0		375		10/20 Frac Sand
		Saturated at 1.9 m.					
2		Trace gravel, moist and stiff at 2.0 m.	2.0-3.0		150		0.02 slot PVC Screen 52 mm (ID) Sch 40
		Frozen below 2.4 m.					Water Level, 2.33 m 20-Oct-98
3		***SILT (2.8-3.1 m)*** Natural, grey brown, frozen, some very fine to fine grained sand, no obvious hydrocarbon odour or staining.					
		End of Borehole					
		T.D. = 3.1 m					
		10 cm diameter borehole					
4		Lockable casing protector installed					
		Dedicated bailer installed					
5							

Project Name: Liability Characterization
Client: Imperial Oil Resources
Location: Norman Wells (Bear I. Battery)
Drilled by: Mobil Augers
Drill Date: 18-Oct-98
Compiled by: M. Dubord

Northing: 7238835.69 m
Easting: 599204.71 m
Elevation: 50.96 masl (Grnd)

KOMEX INTERNATIONAL LTD.
ENVIRONMENTAL AND ENGINEERING CONSULTANTS

Borehole # P98-58A

PROJECT # 4369 BZ

SUBSURFACE PROFILE

Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	VOC % LEL / OVA ppm	Well Data	Lab Analysis or Well Details
0		Ground Surface					
		SILT (0.0-0.8 m) Fill/disturbed, medium orange brown, dry to moist, trace clay, rare rootlets and wood fragments, NHCO/S.	0.0-1.0		45		Stick up = 0.65 m. Dry on 20-Oct-98 Ground Seal Peltonite
1		***SAND (0.8-2.9 m)*** Fill ?, medium to dark brown, moist, loose on auger, uniform, fine grained, NHCO/S.	1.0-2.0		35		52 mm (ID) Sch. 40 PVC riser 10/20 Frac Sand
2		As above, but moist and more clay	2.0-3.0		50		52 mm (ID) Sch 40 0.02 slot PVC Screen
		Wet at 2.7 m. Hard drilling at 2.8 m (frozen).					
3		***SILTY CLAY (2.9-3.5 m)*** Natural?, dark brown grey, frozen, trace sand, rare pebbles, NHCS.					Slough
		End of Borehole T.D. = 3.5 m					
4		10 cm diameter borehole Lockable casing protector installed Dedicated bailer installed					
5							

VOC % LEL: 25, 50, 75
OVA ppm: 100, 200, 300, 400, 500

WorleyParsons
resources & energy

Borehole # BIBT1-12-6

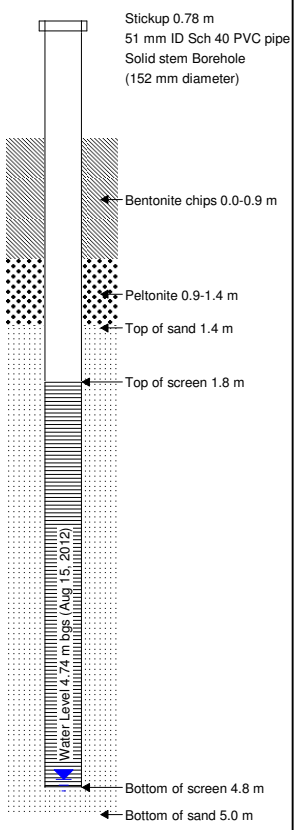
PIEZOMETER # BIBT1-12-3-5

PROJECT # 307074-01333.200

Project Name: Norman Wells Phase II ESA
Client: Imperial Oil Limited
Drilled by: All Service Drilling
Drilling Method: Direct Push/Solid Stem Auger
Drill Date: 23-Jul-2012
Logged by: INBP/GREB

Location: Bear Island BT1
Coordinate System: NAD 27
Northing: 7238681.626
Easting: 598041.959
Elevation: 48.603 (toc)

Depth (m)	Description	Sample Depth (m)	Sample Type	Soil Vapour Concentration (ppmv)	Soil Vapour Concentration (% LEL)	Lab Testing Requested
0	Ground Surface					
	SANDY SILT (0.0-1.8 m) Brown to grey; damp; firm; fine-grained sand; trace organics (roots).	0.0-0.5		35		
		0.5-1.0		25		
1	At 1.3-1.8 m: Trace clay; trace oxidation.	1.0-1.5		15		Sample 1.0-1.5 m: BTEX F1-F4
		1.5-2.0		15		
2	***SAND (1.8-3.7 m)*** Brown; moist; trace silt.	2.0-2.5		25		
	At 2.6-3.4 m: Some silt.	2.5-3.0		25		
3	At 3.4-3.7 m: Sand lens.	3.0-3.5		25		Sample 3.0-3.5 m: BTEX F1-F4
	SANDY SILT (3.7-4.2 m) Moist; loose; trace oxidation.	3.5-4.0		20		
4	***SAND (4.2-5.0 m)*** Grey; saturated; frozen; fine- to medium-grained.	4.0-5.0		30		
5	5.0 m End of Borehole					
6						
7						
8						
9						



Prepack installed in augered borehole

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resources & energy

Borehole # BIBT1-15-8

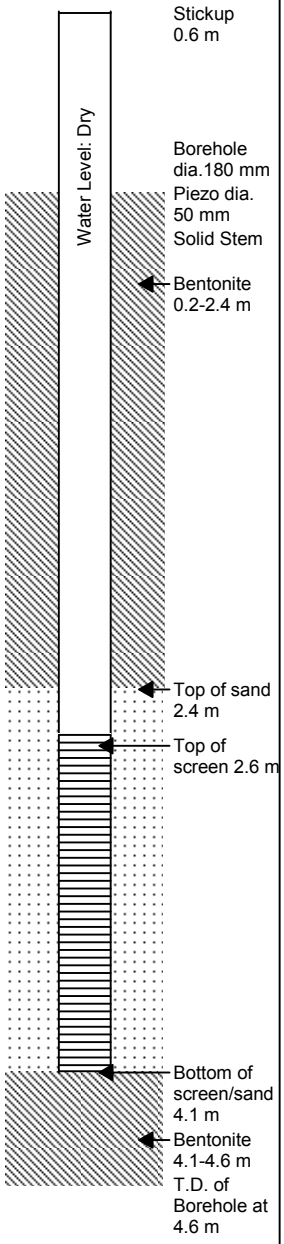
Monitoring Well # BIBTI-15-8-4.1

PROJECT # 307074-01892-100

Project Name: BIBT1 - Phase II ESA
Client: Imperial
Drilled by: Northridge
Drilling Method: Solid Stem
Drill Date: 02-Oct-15
Logged by: A. Haigh

Location: Bear Island, Norman Wells
Coordinate System:
Northing: -
Easting: -
Elevation: -

Depth (m)	Description	Sample Depth (m)	Sample Type	Soil Vapour Concentration • ppmv • (0 250 500)	Soil Vapour Concentration ▽ % LEL ▽ (0 25 50 75 100)	Lab Testing Requested
0	Ground Surface					
	SILT (0.0-3.2 m) Some clay; some organics (rootlets, woody debirs); brown/moist; soft; low plasticity.					
	At 0.6 m: Orange mottling (oxidation).	0.6		20		
1	At 1.2 m: Trace sand.	1.2		20		
		1.8		35		
2	At 2.4 m: Firm.	2.4		15		PHC, Salinity, Metals
	At 2.8 m: Some sand; grey/black staining; odour.	3.0		20		
3	***SILTY SAND (3.2-4.6 m)*** Trace clay; wet; soft; black/grey; odour.	3.6		10		PHC, Salinity, Metals, Grain Size
4	At 4.0 m: Saturated.	4.2		30		
		4.6		10		PHC, Salinity, Metals
5	4.6 m End of Borehole					



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resources & energy

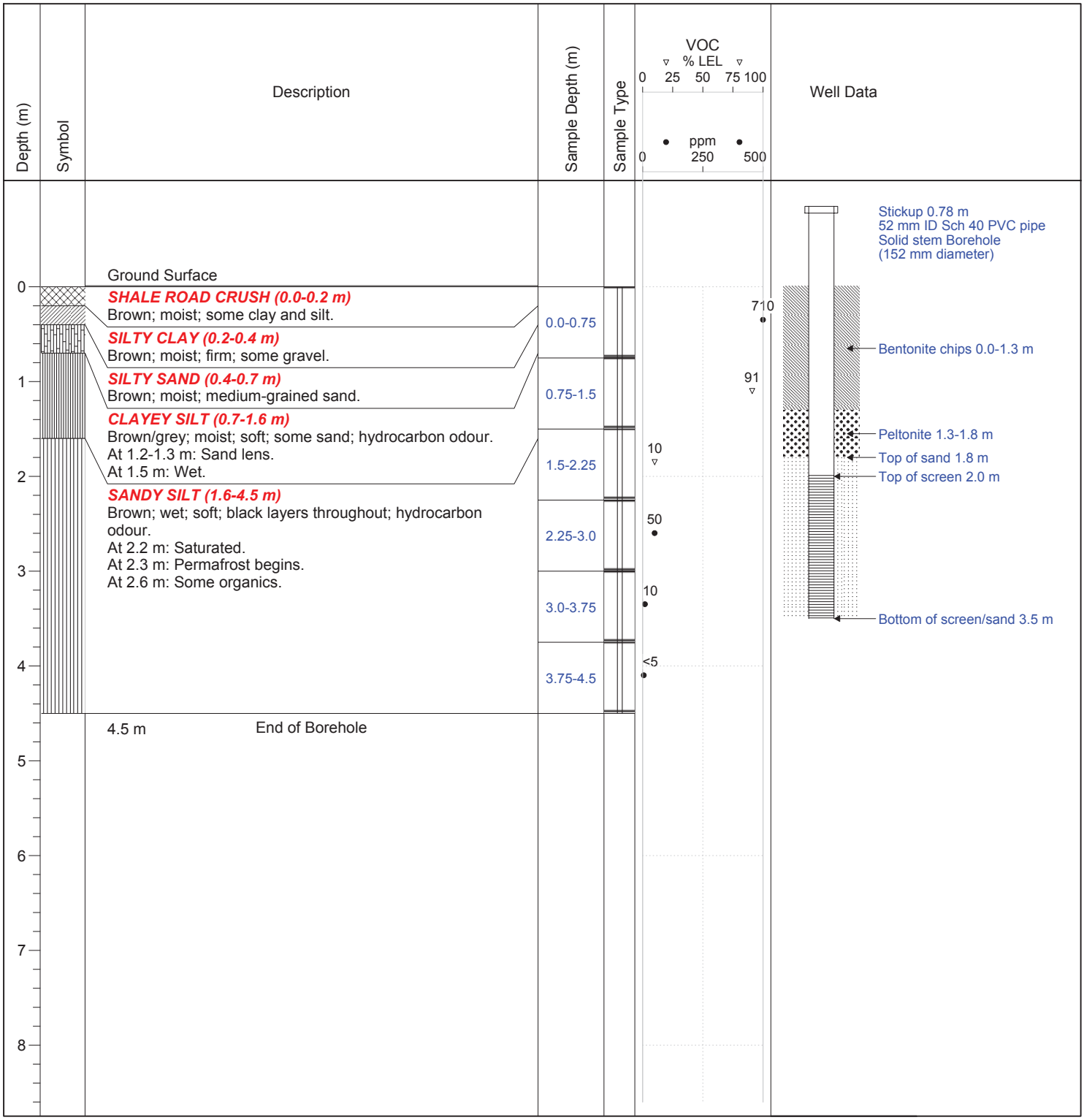
Borehole # BIN42-10-5

PIEZOMETER # BIN42-10-2-4

PROJECT # C53761054

Project Name: Phase II 2010
Client: Imperial Oil Resources
Drilled by: All Service Drilling
Drilling Method: Direct push/Solid stem auger
Drill Date: 23 Aug 10
Logged by: MURH

Location: Bear Island N42
Northing: 7238719
Easting: 599203.7
Elevation: 51.71 (toc)



Advisian
WorleyParsons Group

Borehole # C27-16-1

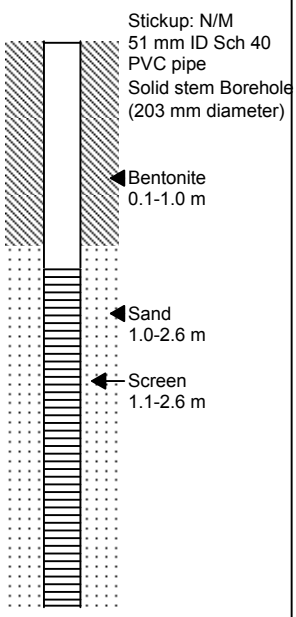
Monitoring Well # C27-16-1-3

PROJECT # 407074-00656-100

Project Name: Norman Wells Phase II ESA
Client: Imperial
Drilled by: Northridge
Drilling Method: Solid Stem Auger
Drill Date: 05-Mar-2016
Logged by: A.Haigh

Location: C-27X
Coordinate System: N/A
Northing: N/M
Easting: N/M
Elevation: N/M

Depth (m)	Description	Sample Depth (m)	Sample Type	Soil Vapour Concentration • ppmv • (0 250 500)	Soil Vapour Concentration ▽ % LEL ▽ (0 25 50 75 100)	Lab Testing Requested
0	Ground Surface					
	SILTY CLAY AND ORGANICS (0.0-0.5 m) Brown; frozen.					
	SANDY CLAY (0.5-1.5 m) Brown; frozen.	0.7-1.0		90		PHC, SALINITY, METALS
1						
	SILTY CLAY (1.5-2.6 m) Brown; frozen.					
2		2.0-2.3		50		PHC, SALINITY, METALS, GRAIN SIZE
	At 2.4 m: Grey; trace gravel.					
	2.6 m End of Borehole					
3						
4						
5						
6						



Advisian
WorleyParsons Group

Borehole # C27-16-2

Monitoring Well # C27-16-2-3

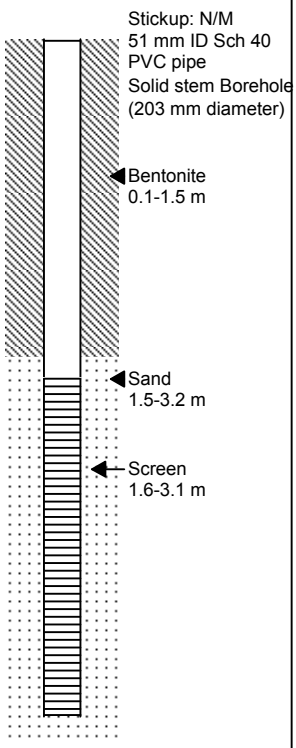
PROJECT # 407074-00656-100

Project Name: Norman Well Phase II ESA
Client: Imperial
Drilled by: Northridge
Drilling Method: Solid Stem Auger
Drill Date: 05-Mar-2016
Logged by: A.Haigh

Location: C-27X
Coordinate System: N/A
Northing: N/M
Easting: N/M
Elevation: N/M

Depth (m)	Description	Sample Depth (m)	Sample Type	Soil Vapour Concentration • ppmv • (0 250 5000)	Soil Vapour Concentration ▽ % LEL ▽ (0 25 50 75100)	Lab Testing Requested
0	Ground Surface					
	SAND (0.0-0.6 m) Brown; moist; soft; some clay.					
1	***SANDY CLAY (0.6-3.2 m)*** Black/brown/grey mottling; moist; firm; some organics. At 1.0 m: No organics; green/brown.	0.6-0.9		20		PHC, SALINITY, METALS,
2	At 1.8 m: Trace orange mottling; frozen.	2.2-2.5		15		
3						PHC, SALINITY, METALS, GRAIN SIZE
	3.2 m End of Borehole					
4						
5						
6						

Well Data



Advisian
WorleyParsons Group

Borehole # C27-16-3

Monitoring Well # C27-16-3-4

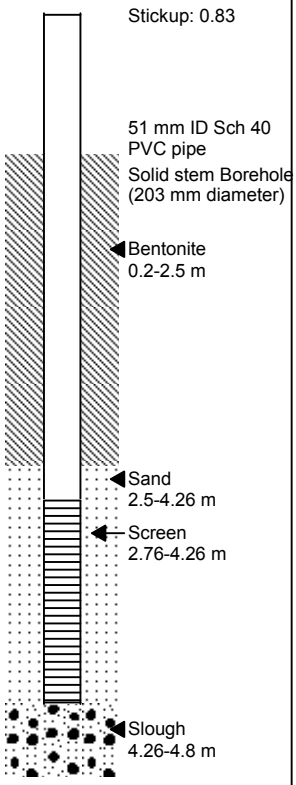
PROJECT # 407074-00656-100

Project Name: Norman Wells Phase II ESA
Client: Imperial
Drilled by: Northridge
Drilling Method: Solid Stem Auger
Drill Date: 06-Mar-2016
Logged by: J. Girling

Location: C-27X
Coordinate System: N/A
Northing: N/M
Easting: N/M
Elevation: N/M

Depth (m)	Description	Sample Depth (m)	Sample Type	Soil Vapour Concentration • ppmv •	Soil Vapour Concentration ▽ % LEL ▽	Lab Testing Requested
0	Ground Surface					
	SILTY CLAY (0.0-4.8 m) Brown; frozen; organics; peat; some sand.	0.0-0.6		<5		
1		1.0-1.6		20		PHC, SALINITY, METALS
	At 1.0 m: No organics or peat.					
2	At 2.6 m: Some silt; firm; brown; not frozen.					
3		2.9-3.2		<5		PHC, SALINITY, METALS, GRAIN SIZE
4	At 4.5 m: Moist.	4.5-4.8		<5		PHC, SALINITY, METALS
	4.8 m End of Borehole					
5						
6						
7						
8						
9						

Soil Vapour Concentration • ppmv •: 0 250 500
Soil Vapour Concentration ▽ % LEL ▽: 0 25 50 75 100



KOMEX INTERNATIONAL LTD. OFFICE REPORT ON SITE INVESTIGATION SHEET 1 OF 1

CONTRACT NO.: 4369AA
BORING NO.: P97-4A
NORTHING:

COMPILED BY: M. Maccagno
LOCATION: CPF
EASTING:

BORING DATE: July 10, 1997
CONTRACTOR:
ELEVATION:

SAMPLE TYPES
A AUGER SAMPLE
W WASH SAMPLE
R ROCK CORE
C CRREL BARREL
S SPLIT SPOON
T SHELBY TUBE
O THIN WALL OPEN
P THIN WALL PISTON
▽ STATIC WATER LEVEL
▼ DYNAMIC WATER LEVEL

SAMPLE CONDITION
DISTURBED
FAIR
GOOD
LOST

TEST INFORMATION
PENETROMETER kg/cm2 (1 2 3 4)
SPT BLOWS/0.3m (10 20 30 40 50)
WATER CONTENT % (plastic limit 10 30 — liquid limit 50 70 90)

DEPTH m	SYMBOL	DESCRIPTION (SOIL/ROCK)	SAMPLES TYPE	SAMPLES CONDITION	SAMPLES NUMBER	WATER LEVEL	PIEZOMETER CONSTRUCTION DETAILS
0.0		SILT: dark brown, damp, low plastic, some organic matter, trace sand, gravel.					1.5 m X 102 mm STEEL PROTECTIVE CASING; HYDRATED GROUND SEAL; HYDRATED PELTONITE
0.8		Very damp.					
1.5		Brownish grey, medium plastic.					1.2 – 1.8
2.3		Grey, damp to wet.					10/20 FRAC SAND
3.5		Ice crystals to 5 mm length.					51 mm I.D. SCH 40 PVC NO. 20 SLOT SCREEN
3.8		Low plastic.					102 mm DIA. HOLE
5.1		SILTSTONE: light greyish green, damp, weathered.					4.8
							5.3 SLOUGH
		TOTAL DEPTH = 5.3 m					

DEPTH (m) OVA (ppm)
0.0 - 0.8 10
0.8 - 2.3 20
2.3 - 3.8 10
3.8 - 5.3 5

KOMEX INTERNATIONAL LTD. OFFICE REPORT ON SITE INVESTIGATION SHEET 1 OF 1

CONTRACT NO.: 4369AB
BORING NO.: P97-21A
NORTHING:

COMPILED BY: M. Maccagno
LOCATION: Tank Farm
EASTING:

BORING DATE: July 10, 1997
CONTRACTOR: Mobil
ELEVATION:

SAMPLE TYPES
A AUGER SAMPLE
W WASH SAMPLE
R ROCK CORE
C CRREL BARREL
S SPLIT SPOON
T SHELBY TUBE
O THIN WALL OPEN
P THIN WALL PISTON
STATIC WATER LEVEL
DYNAMIC WATER LEVEL

SAMPLE CONDITION
DISTURBED
FAIR
GOOD
LOST

TEST INFORMATION
PENETROMETER kg/cm2 (1 2 3 4)
SPT BLOWS/0.3m (10 20 30 40 50)
WATER CONTENT % (plastic limit 10 30 / liquid limit 50 70 90)

DEPTH m	SYMBOL	SOIL/ROCK	DESCRIPTION	SAMPLES TYPE	SAMPLES CONDITION	SAMPLES NUMBER	WATER LEVEL	PIEZOMETER CONSTRUCTION DETAILS
0.0			SILT: dark brown, damp, low to medium plastic, some gravel, trace sand.					1.5 m X 102 mm STEEL PROTECTIVE CASING
0.5								HYDRATED GROUND SEAL
								HYDRATED PELTONITE
0.8			Slightly damp, slight hydrocarbon odour.					
1.1								
1.7								
2.3			Dark greenish brown. Frozen 2.3-2.9 m.					10/20 FRAC SAND
2.9			Unfrozen to 3.8 m, damp to wet, Fine sand lenses, iron oxide staining, low plastic, no odour.					51 mm I.D. SCH 40 PVC NO. 20 SLOT SCREEN
3.8			Water in hole.					
4.7								102 mm DIA. HOLE
								SLOUGH
5.3								
6.0			TOTAL DEPTH = 5.3 m					
7.0								
8.0								
9.0								
10.0								

DEPTH (m) OVA (ppm)
0.0 - 0.8 15
0.8 - 2.3 50
2.3 - 3.8 30
3.8 - 5.3 30

KOMEX INTERNATIONAL LTD. OFFICE REPORT ON SITE INVESTIGATION SHEET 1 OF 1

CONTRACT NO.: 4369AB
BORING NO.: P97-20A
NORTHING:

COMPILED BY: M. Maccagno
LOCATION: Tank Farm
EASTING:

BORING DATE: July 10, 1997
CONTRACTOR: Mobile
ELEVATION:

SAMPLE TYPES
A AUGER SAMPLE
W WASH SAMPLE
R ROCK CORE
C CRREL BARREL
S SPLIT SPOON
T SHELBY TUBE
O THIN WALL OPEN
P THIN WALL PISTON
STATIC WATER LEVEL
DYNAMIC WATER LEVEL

SAMPLE CONDITION
DISTURBED
FAIR
GOOD
LOST

TEST INFORMATION
PENETROMETER kg/cm2 (1 2 3 4)
SPT BLOWS/0.3m (10 20 30 40 50)
WATER CONTENT % (plastic limit 10 30 / liquid limit 50 70 90)

DEPTH m	SYMBOL	DESCRIPTION (SOIL/ROCK)	SAMPLES TYPE	SAMPLES CONDITION	SAMPLES NUMBER	WATER LEVEL	PIEZOMETER CONSTRUCTION DETAILS
0.0		SILT: dark brown to dark greenish brown, slightly damp, low plastic, trace sand, gravel, organic matter, occasional sand					1.5 m X 102 mm STEEL PROTECTIVE CASING
0.4							HYDRATED GROUND SEAL
0.8		lense, greenish yellow, fine, damp. At 0.8 m, damp to occasionally wet in sand lenses.					HYDRATED PELTONITE
0.9							
1.5							10/20 FRAC SAND
3.2		Soft, olive green.					51 mm I.D. SCH 40 PVC NO. 20 SLOT SCREEN
3.8		Dark olive green.					
4.1		Some gravel, low plastic, medium stiff, water in hole.					102 mm DIA. HOLE
4.5							SLOUGH
5.3							
		TOTAL DEPTH = 5.3 m					

DEPTH (m) OVA (ppm)
0.0 - 0.8 50
0.8 - 2.3 70
2.3 - 3.8 175
3.8 - 5.3 425

BOREHOLE LOG

BOREHOLE LOCATION: Norman Wells, NT	REF. NO: 10-11248	BOREHOLE No: **MW-23-35**
CLIENT: Imperial Oil		START DATE: 2023/09/18
		COMPLETION DATE: 2023/09/18
		PAGE 1 of 1

Depth (m)	STRATIGRAPHY	SYMBOL	SAMPLE TYPE	SAMPLE RUN	RECOVERY %	ZONE TESTED	LAB SAMPLE NAME/ LAB ANALYSES	▲ SOIL VAPOUR CONCENTRATION (ppmv) 100 200 300 400	COMMENTS AND MONITORING WELL NOTES	MONITORING WELL	Depth (ft)
0	GROUND SURFACE								Surface Cover: Monument Casing		0
0	ORGANIC MATERIAL (Topsoil) - brown, gravelly, sandy, damp.		G		-		MW-23-35-0.2 / Salinity				
1			G		-						5
2	SILT - black, sandy, trace clay, moist, organics. - gravelly from 0.6 m to 1.2 m. - clayey, trace sand below 1.2 m.		G		-						10
3	CLAY - black, silty, trace sand, moist. - dark gray, trace silt below 3.0 m.		G		-						
4			G		-						15
5	SILT - dark gray, clayey, trace sand, wet.		G		-		MW-23-35-4.9 (DUP-08) / BTEX, PHC F1-F4, PAH, Metals, Salinity				20
6	MUDSTONE (Weathered) - dark gray, silty, clayey, trace sand, damp. - petroleum odour from 5.8 m to 10.4 m.		G		-						
7			G		-						25
8	SILTSTONE (Bedrock) - gray, clayey, trace sand, dry.		G		-						
9			G		-						30
10			G		-						
11	MUDSTONE (Bedrock) - gray, silty, damp.		G		-						35
12			G		-						
12	END OF BOREHOLE at 12.2 m										40
13									Monitoring Well Installed Well Depth 12.2 m Well Diameter 51 mm Well Material PVC Screen Type 10 Slot Screened From 8.7 m Screened To 11.7 m		
14											45
15											
16											50
17											
18											55
19											
20											60
21											
22											65
23											
24											70
25											
26											75
27											
28											80
29											
30											85
31											
											90
											95
											100

START DATE	START DEPTH	HOLE SIZE	EQUIPMENT	CONTRACTOR	GAS METER TYPE: RKI Eagle		
2023/09/18	0.0 m	152 mm	Solid Stem Auger	Midnight Sun Drilling	LOGGED: DY	REVIEW: RM	DRAFTED: DS
					Tlegohti Joint Venture		

10-11248 MW-23-01-MW-23-51 (DS).GPJ PARSONS PE&I REPORT LOG 62 PE&I-CEG DATA V3-R04.GDT PE&I-CEG LIBRARY V3-R12.GLB PREPARED: 2023/10/24 Calgary PRINTED: 12/12/2023

BOREHOLE LOG

BOREHOLE LOCATION: Norman Wells, NT	REF. NO: 10-11248	BOREHOLE No: **MW-23-36**
CLIENT: Imperial Oil		START DATE: 2023/09/18
		COMPLETION DATE: 2023/09/18
		PAGE 1 of 1

Depth (m)	STRATIGRAPHY	SYMBOL	SAMPLE TYPE	SAMPLE RUN	RECOVERY %	ZONE TESTED	LAB SAMPLE NAME/ LAB ANALYSES
0	GROUND SURFACE						
0	ORGANIC MATERIAL (Topsoil) - grayish brown, silty, trace sand, wet. - permafrost from 0.9 m to 4.9 m.		G		-		MW-23-36-0.2 / Salinity
1			G		-		
2	SILT - gray, trace sand, wet.		G		-		
3	CLAY - gray, trace sand, wet.		G		-		
3	SILT - gray, some clay, trace sand, wet.		G		-		
4	- clayey below 4.0 m.		G		-		MW-23-36-4.3 / BTEX, PHC F1-F4, PAH, Metals, Salinity
5	SILTSTONE (Weathered) - gray, wet. - petroleum odour from 4.9 m to 16.8 m.		G		-		
6	SILTSTONE (Bedrock) - gray, wet.		G		-		
7	MUDSTONE (Bedrock) - gray, silty, trace sand, moist.		G		-		
8			G		-		
9	SILTSTONE (Bedrock) - gray, trace clay, wet.		G		-		
10			G		-		
11	MUDSTONE (Bedrock) - gray, some silt, trace sand, damp.		G		-		
12	SILTSTONE (Bedrock) - gray, clayey, trace sand, dry.		G		-		
13			G		-		
14			G		-		
15			G		-		
16			G		-		
17	END OF BOREHOLE at 16.8 m						
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							

▲ SOIL VAPOUR CONCENTRATION (ppmv) — 100 200 300 400

◆ SOIL VAPOUR CONCENTRATION (%LEL) — 20 40 60 80

COMMENTS AND MONITORING WELL NOTES

Surface Cover: Monument Casing

Monitoring Well Installed

Well Depth	16.8 m
Well Diameter	51 mm
Well Material	PVC
Screen Type	10 Slot
Screened From	12.0 m
Screened To	15.1 m

MONITORING WELL

Depth (ft) — 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

START DATE	START DEPTH	HOLE SIZE	EQUIPMENT	CONTRACTOR	GAS METER TYPE: RKI Eagle		
2023/09/18	0.0 m	152 mm	Solid Stem Auger	Midnight Sun Drilling	LOGGED: DY	REVIEW: RM	DRAFTED: DS

Tlegohti Joint Venture

PARSONS PE&I REPORT LOG 62 PE&I-CEG DATA V3-R04.GDT PE&I-CEG LIBRARY V3-R12.GLB PREPARED: 2023/10/24 Calgary PRINTED: 12/12/2023

10-11248 MW-23-01-MW-23-51 (DS).GPJ

BOREHOLE LOG

BOREHOLE LOCATION: Norman Wells, NT	REF. NO: 10-11248	BOREHOLE No: **MW-23-48**
CLIENT: Imperial Oil		START DATE: 2023/09/22
		COMPLETION DATE: 2023/09/22
		PAGE 1 of 1

Depth (m)	STRATIGRAPHY	SYMBOL	SAMPLE TYPE	SAMPLE RUN	RECOVERY %	ZONE TESTED	LAB SAMPLE NAME/ LAB ANALYSES
0	GROUND SURFACE						
0	ORGANIC MATERIAL (Topsoil) - brownish gray, clayey, some silt, trace sand, wet.		G		-		MW-23-48-0.5 / Salinity
1	CLAY - brownish gray, some sand, trace silt, frozen.		G		-		
2			G		-		MW-23-48-1.8 / BTEX, PHC F1-F4, PAH, Metals, Salinity
3			G		-		MW-23-48-2.75 / BTEX, PHC F1-F4, PAH, Metals, Salinity
3	MUDSTONE (Weathered) - gray, some sand, some silt, frozen.		G		-		
4			G		-		
5			G		-		
6			G		-		
7	SILTSTONE (Bedrock) - gray, sandy, some clay, damp.		G		-		
8			G		-		
9			G		-		
9	END OF BOREHOLE at 9.1 m						
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							

▲ SOIL VAPOUR CONCENTRATION (ppmv)
100 200 300 400

COMMENTS AND MONITORING WELL NOTES

Surface Cover: Monument Casing

Monitoring Well Installed

Well Depth	9.1 m
Well Diameter	51 mm
Well Material	PVC
Screen Type	10 Slot
Screened From	3.0 m
Screened To	6.1 m

MONITORING WELL

Depth (ft)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

START DATE	START DEPTH	HOLE SIZE	EQUIPMENT	CONTRACTOR	GAS METER TYPE: RKI Eagle		
2023/09/22	0.0 m	152 mm	Solid Stem Auger	Midnight Sun Drilling	LOGGED: DY	REVIEW: RM	DRAFTED: DS

Tlegohti Joint Venture

10-11248 MW-23-01-MW-23-51 (DS).GPJ PARSONS PE&I REPORT LOG 62 PE&I-CEG DATA V3-R04.GDT PE&I-CEG LIBRARY V3-R12.GLB PREPARED: 2023/10/30 Calgary PRINTED: 12/12/2023

Project Name: Norman Wells
Client: IOR
Location: B38X by TF grade, N side of road
Drilled By: Midnight Sun
Drill Date: Jul. 13, 2003
Compiled By: MD

Northing: 7241471.15m
Easting: 600532.22m
Elevation: 58.59m (Top of pipe)

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ENVIRONMENTAL AND ENGINEERING CONSULTANTS

Borehole #: TF03-01/TF 03-11-4

Project #: C53760317

Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	LEL % (25, 50, 75) / OVA mS/m (100, 200, 300, 400)	Well Data	Comments
							Stick Up = 0.75m
0		Ground Surface					
		CLAY (0.0-0.7m) With organics, black to dark grey, moist, soft, peaty below 0.4m, trace wood fragments, disturbed (fill), no hydrocarbon odour/staining.					Borehole dia. 150mm Piezo dia. 50mm (ID) Water Level 0.44mbgs (Jul. 16, 2003) Bentonite Chips 0.0-0.6m
		SILTY CLAY (0.7-1.6m) Mottled light green and grey, moist, soft, (frozen between 0.9-1.1m, wet below), trace wood fragments, no hydrocarbon odour/staining.	0.0-1.5		180		Peltonite 0.6-1.2m Top of Sand 1.2m 10/20 Frac Sand Top of Screen 1.3m
1							
2		***SILTY CLAY (1.6-4.5m)*** Medium green grey, rare sand, trace gravel from 2.0-2.5m, wet, soft, moderate hydrocarbon odour throughout.	1.5-3.0			500	
3		Grades to blue grey at approx. 3.0m.					
			3.0-4.5				Bottom of Sand and Screen 4.3m Slough 4.3-4.5m
4		4.5m End of Borehole					
		NOTE: Drilled with solid stem auger.					
5							

Project Name: Norman Wells
Client: IOR
Location: S of TF by road
Drilled By: Midnight Sun
Drill Date: Jul. 14, 2003
Compiled By: MD

Northing: 7241435.32m
Easting: 600562.55m
Elevation: 58.63m (Top of pipe)

KOMEX INTERNATIONAL LTD.
ENVIRONMENTAL AND ENGINEERING CONSULTANTS

Borehole #: TF03-02/TF 03-12-3

Project #: C53760317

Depth (m)	Description	Sample Depth (m)	Sample Type	LEL % / OVA mS/m	Well Data	Comments
						Stick Up = 0.65m
0	Ground Surface					
	SHALE FILL (0.0-1.4m) Dark grey, wet, loose, moist in upper 0.3m, moderate hydrocarbon odour.	0.0-1.5		25		Borehole dia. 200mm Piezo dia. 50mm (ID) Bentonite Chips 0.0-0.9m Water Level 0.82mbgs (Jul. 16, 2003) Top of Sand 0.9m 10/20 Frac Sand Top of Screen 1.0m
1						
	SILTY CLAY (1.4-2.0m) Dark grey to black, moist, soft, peaty at base, frozen in lower part.					
2	***SILTY CLAY (2.0-3.7m)*** Green grey, moist, soft, no hydrcarbon odour.	1.5-3.0		55		
	Dark grey at 2.8m (no hydrocarbon odour/staining) and below.					Bottom of Screen 2.8m Bottom of Sand 2.9m
3						
	CLAY SILT (3.7-4.5m) Medium green brown, moist, firm to soft, trace sand at 4.3-4.5m, rare gravel, no hydrocarbon odour/staining.	3.0-4.5		35		
4						
	4.5m End of Borehole					
	NOTE: Hole collapsed to 1.3m - backfilled with chips, moved ahead 1m for piezo installation. Drilled with hollow stem auger.					
5						

Appendix D. Groundwater Surveillance Network Program Wells - Proposed Analytical Schedule

Appendix D

GW-SNP Wells 2024 Groundwater Analytical Schedule

Location	Well Status	New Installs?	Fluid Levels	Field Parameters: pH, Temp, and EC		BTEX, PHC F1, PHC-F2		Major Ions & Routine Potability		Fluoride		Total Metals		Dissolved Metals	
Groundwater				Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall
Mainland West															
CPF-97-7-5	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
CPF-23-1-3	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
C27-16-1-3	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
C27-16-2-3	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
C27-16-3-4	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MW23-35	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MW23-36	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MLW-24-01	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MLW-24-02	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MLW-24-03	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Mainland East															
MTF-97-1-5	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MTF-97-3-5	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
TF-03-11-4	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
TF-03-12-3	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
B42-17-2-4	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MW23-48	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MLE-24-01	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MLE-24-02	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
MLE-24-03	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Bear Island N-42X															
BIB-98-3-4	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BI-N42-09-1-3	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BI-N42-10-2-4	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
N42-24-01	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
N42-24-02	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1

Appendix D

GW-SNP Wells 2024 Groundwater Analytical Schedule

Location	Well Status	New Installs?	Fluid Levels	Field Parameters: pH, Temp, and EC		BTEX, PHC F1, PHC-F2		Major Ions & Routine Potability		Fluoride		Total Metals		Dissolved Metals	
N42-24-03	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Bear Island Q-37X															
BI-13-18-3	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BI-BT1-12-3-5	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BI-BT1-15-8-4	existing well		Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Q37-24-01	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Q37-24-02	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Bear Island BIT-3															
BIT98-1-3	well abandoned 2002, replaced below														
BIT3-24-01	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT3-24-02	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT3-24-03	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT3-24-04	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Bear Island BIT-4															
BIT4-24-01	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT4-24-02	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT4-24-03	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT4-24-04	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT4-24-05	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
BIT4-24-06	new well to install 2025	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Goose Island GIT-7															
GIT7-24-01	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
GIT7-24-02	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
GIT7-24-03	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
GIT7-24-04	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Goose Island GIT-8															

Appendix D

GW-SNP Wells 2024 Groundwater Analytical Schedule

Location	Well Status	New Installs?	Fluid Levels	Field Parameters: pH, Temp, and EC		BTEX, PHC F1, PHC-F2		Major Ions & Routine Potability		Fluoride		Total Metals		Dissolved Metals	
GIT8-24-01	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
GIT8-24-02	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
GIT8-24-03	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
GIT8-24-04	new well to install September 2024	1	Sp, Fa	1	1	1	1	1	1	1	1	1	1	1	1
Totals without QA/QC		**29**		**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**
QA/QC															
DUPLICATE (Trip Blank)						1	1								
DUPLICATE (10% Min)						5	5	5	5	5	5	5	5	5	5
Totals with QA/QC						**54**	**54**	**53**	**53**	**53**	**53**	**53**	**53**	**53**	**53**

Notes: Sp, Fa = Spring, and Fall

Appendix E. Preferred Operating Procedures

PREFERRED OPERATING PRACTICES FOR

BOREHOLE/MONITORING WELL INSTALLATION AND

ASSOCIATED SOIL/GROUNDWATER SAMPLING AT

HYDROCARBON IMPACTED SITES

Imperial Oil
Products and Chemicals Division
Fuels Marketing Services
Engineering, Maintenance & Repair Dept.
Revision 5
May 15, 2002

For Use on Imperial Oil Projects Only

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1) INTRODUCTION

The quality of an environmental assessment or remediation program is primarily dependent on the program design and the quality of the soil and groundwater samples obtained during the implementation of this program. The selection of the soil or groundwater sampling technique is critical in obtaining a sample which is representative of the site conditions. In certain jurisdictions, the soil and groundwater sampling protocols are defined by Provincial Regulations/Guidelines and should be followed explicitly. In those jurisdictions where there are no defined protocols, the installation and sampling guidance procedures contained in this document should be used. In cases where there is a conflict between the recommended protocols presented in this Preferred Operating Practice (POP) and protocols defined by Provincial Regulations or Guidelines, the protocols defined by the Provincial Regulations or Guidelines are to be used by Environmental Consultants working on Imperial Oil sites.

1.1) Scope of Preferred Operating Practice

This document will discuss Preferred Operating Practices (POP's) to be used at operating and non-operating sites, where boreholes are being drilled and/or groundwater monitoring wells are currently installed, or will be installed. In the downstream, the focus will be on marketing sites (eg: services stations, bulk plants, home comfort centres, cardlocks and distribution terminals) where assessment, excavation and bioremediation programs are conducted. In the upstream, the focus will be on production and storage facilities (eg: gas plants, satellites, batteries, well sites and spill sites) where similar types of programs are being conducted. While this POP has been prepared with downstream sites in mind, there is a significant overlap in the preferred practices for borehole drilling/sampling and monitoring well installation/development/sampling at both upstream and downstream sites. Where differences exist in the preferred practices between upstream and downstream sites, these will be highlighted in this POP.

This POP outlines the preferred practices to be used for the drilling and installation of monitoring wells in regular overburden soils. Specialized types of monitoring well installations (eg: the installation of monitoring wells in bedrock or fractured bedrock situations) are not addressed in this POP. In addition, this POP will focus on hydrocarbon impacted sites. While many of the preferred practices discussed in this POP are also applicable at sites where contaminants other than hydrocarbons (eg: metals, salts) are the primary contaminants of concern, the focus in this POP will be on hydrocarbon contamination.

This document outlines POP's for borehole drilling and soil sampling, as well as covering the installation and sampling of groundwater monitoring wells. The development of this POP will accomplish the following goals:

1) provide a guide to Imperial Oil Project Managers and Environmental Consultants retained by Imperial Oil, indicating preferred the drilling and soil sampling methodologies to utilize when installing groundwater monitoring wells.

2) provide guidance on the preferred practices for the design, construction, maintenance monitoring and groundwater sampling of monitoring wells.

3) provide a framework, which ensures that a consistent approach is used for the installation, development and sampling of groundwater monitoring wells at Imperial Oil sites across Canada.

1.2) Limitations of This POP and Disclaimer

The POP's presented here are recommended practices and are not prescriptive. These represent practices Imperial Oil would like to be used, whenever practical. In some cases, use of the preferred practices will not be practical and alternate (non-preferred) practices need to be used. Before utilizing a non-preferred practice at a site, it is recommended that the Environmental Consultant discuss the matter with the Imperial Oil Project Manager and gain concurrence on usage of the non-preferred approach. In cases where the Imperial Oil Project Manager is not available for such discussions and a rapid field decision must be made, the Environmental Consultant can utilize a non-preferred practice when this is the most practicable alternative, based upon their best professional judgement.

Any provincial regulation or guidance document will supercede procedures included in this POP. In some site-specific instances, deviations from the POP may be used with the Imperial Oil Project Manager's approval. This POP is based on industry standard protocols, documented by the United States Environmental Protection Agency (US EPA) and the American Society for Testing and Materials (ASTM).

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1.3) Summary of Generally Preferred Operating Conditions and Practices

Table 1.3-1 summarizes generally preferred practices for borehole drilling and the soil sampling associated with these activities on Imperial Oil projects. Table 1.3-2 summarizes the generally preferred practices for choosing the various components and materials used in the construction of monitoring wells. Table 1.3-3 presents the generally preferred practices for the installation and development of groundwater monitoring wells on Imperial Oil projects. Finally, Table 1.3-4 presents the generally preferred practices for the monitoring/sampling of groundwater and free product from groundwater monitoring wells.

The handy summaries contained in these four tables indicate where various topics are discussed in this POP. They can also be used as preferred operating practice "cheat sheets" by field personnel when performing borehole drilling/sampling or groundwater monitoring well installation, development or sampling for Imperial Oil projects.

Table 1.3-1

Summary of Generally Preferred Practices for Borehole Drilling and Soil Sampling

Borehole Activity	Section	Generally Preferred Practices
Borehole Drilling Methodologies	2.1	- the use of a hollow-stem auger drilling method is a preferred practice, whenever practical - the direct push drilling method is preferred when there is low clay/till or cobble content and the drilling equipment is cost effective/available - the sonic drilling method is a preferred practice when there is high cobble content. An ODEX auger should be used if a sonic rig is not available; the use of a Becker hammer is not preferred in these circumstances - the use of a solid-stem auger is not a preferred practice - before each borehole is drilled, all downhole drilling equipment should be cleaned. In non-potable aquifers, cleaning with a brush is sufficient. In potable aquifers, more stringent cleaning procedures (cleaning with soapy water, followed by tap water rinses) must be applied to downhole equipment that will be used below the water table - use of any greases or lubricants on downhole drilling equipment is prohibited - when borehole drilling, it is preferred to start in the least contaminated area of the site and finish in the most contaminated area

Table 1.3-1 (continued)

Summary of Generally Preferred Practices for Borehole Drilling and Soil Sampling

Borehole Activity	Section	Generally Preferred Practices
Borehole Sampling Methodologies	2.2	- a clean bottom must be obtained for every borehole - the use of a steel or stainless steel split spoon sampler is the preferred practice. The split spoon should be driven (as per ASTM D 1586-99) and the number of blow counts recorded - discrete interval sampling of the borehole will be performed - taking disturbed samples from the hollow stem auger flights is acceptable if driving a split spoon is not possible and more suitable drilling equipment is not available - prior to taking a sample of the split spoon core, the outer layer of the core should be removed (if the soil core is consolidated) - soil samples for field vapour and chemical analyses are taken by longitudinally splitting the core - representative discrete samples are taken from each distinct zone (based on soil type and level of contamination) within the core - composite sampling is not allowed for the laboratory analysis of volatiles - after each use of the split spoon, the sampler should be cleaned - samples being submitted to the laboratory for organics analysis cannot come into contact with plastic materials - soil used for field vapour screening must not be submitted for laboratory analysis of organic parameters. It can be submitted for the analysis of inorganic parameters - a minimum of one (1) sample per borehole should be sent to the laboratory for analysis at downstream sites; this is not required at upstream sites

Table 1.3-1 (continued)

Summary of Generally Preferred Practices for Borehole Drilling and Soil Sampling

Borehole Activity	Section	Generally Preferred Practices
Soil Field Screening (Physical Observations)	2.3.1	- visual observations (eg: staining) should be made of the soil and summarized in the borehole logs. - olfactory observations (eg: odours) should be made of the soil and summarized in the borehole logs. The soil should not be "sniffed" in order to make these observations - visual/olfactory observations should only be recorded in borehole logs and not be mentioned in the main body of the report
Soil Field Screening (Organic Vapour Monitoring)	2.3.2	- a catalytic explosimeter with methane exclusion capability (eg: the Gastech 1238ME or equivalent) is the preferred instrument for field screening. The explosimeter is commonly referred to as an Organic Vapour Monitor (OVM) - PID, FID, colourmetric and amino assay detection methods are not acceptable field screening methods for petroleum hydrocarbons - the OVM must be calibrated (at least daily) prior to use in the field - the methane exclusion efficacy of the OVM should be measured quarterly - the preferred practice for measuring the soil vapour is to fill a plastic bag 1/4 full and allow the broken up soil to equilibrate for 30 minutes at a minimum of 15°C, before measurement of the peak headspace vapour concentration - an acceptable practice for measuring the soil vapour is to fill a glass bottle 1/4 full and allow the broken up soil to equilibrate for 30 minutes at a minimum of 15°C, before measurement of the peak headspace vapour concentration - consistent procedures for field OVM measurements are key to enable meaningful comparisons between measurements

Table 1.3-1 (continued)

Summary of Generally Preferred Practices for Borehole Drilling and Soil Sampling

Borehole Activity	Section	Generally Preferred Practices
Soil Fields Quality Assurance Sample Requirements	2.4	- field duplicate samples will be included for every sampling event that has >2 soil samples being submitted to the lab. For larger submissions, one field duplicate will be submitted for every 10 original samples submitted to the lab - one field blank (acid washed silica) will be included for every sampling event where a trace organic (eg: PAH's) is sampled
Borehole and Monitoring Well Log Methodology	2.5	- each borehole and/or monitoring well should be individually logged, using either the Canadian Soil Classification System or Unified Soil Classification System (USCS) - as much as possible, graphical depictions of borehole logs are preferred - specific details of the well construction and elevations, with respect to a local geodetic reference, should also be included in the borehole log

Table 1.3-1 (continued)

Summary of Generally Preferred Practices for Borehole Drilling and Soil Sampling

Borehole Activity	Section	Generally Preferred Practices
Borehole Backfilling and Monitoring Well Decommissioning Methodology	2.6	- boreholes where monitoring wells aren't being installed must be backfilled immediately - boreholes should be backfilled with bentonite chips to 1.3 metres below grade; the next 1 metre is filled with a hydrated bentonite seal; and the last 0.3 metres is backfilled with topsoil. Borehole cuttings should not be used to backfill the borehole - overdrilling is the preferred practice for removal of the monitoring well casing - an acceptable practice is to cut the PVC casing at grade - removing the monitoring well casing using a hydraulic lifting device is not a preferred practice - the monitoring well hole should be backfilled with bentonite chips to 1.3 metres below grade; the next 1 metre is filled with a hydrated bentonite seal; and the last 0.3 metres is backfilled with topsoil. - filling the monitoring well casing with rapid setting concrete is not a preferred practice - chlorination of the monitoring well during decommissioning should only be performed if required by the provincial regulator - in the downstream, the preferred practice is to decommission all monitoring wells at a site, before the site is sold to a third party

Table 1.3-2

Summary of Generally Preferred Practices for Monitoring Well Components

Monitoring Well Component	Section	Generally Preferred Practices
Monitoring Well Schematic	3.1	- the schematic of a typical monitoring well (and its components) installed with a monument casing is presented
Well Casing Materials	3.2	- Schedule 40 PVC casings should be used for all monitoring wells - PVC casings used should meet the requirements of ASTM Standard F 480-00 - the PVC casings used should have threaded, flush-joint ends with square profile threads and an o-ring seal - the use of tapes or glues on the joints of PVC casing are not recommended - only use PVC casings that have not been marked with any foreign materials - for most monitoring well applications, 2 inch ID PVC casing should be used

Table 1.3-2 (continued)

Summary of Generally Preferred Practices for Monitoring Well Components

Monitoring Well Component	Section	Generally Preferred Practices
Well Screening and Filter Pack Materials	3.3	- PVC well screens should be used (consistent with the well casing material) - using well screens of slot size 10, with 1/8 inch spacing between the horizontally oriented slots is the preferred practice for general applications, where there is little information on the formation - the well screen should straddle the piezometric surface, with the highest water table measurement no more than 2/3 of the way up the screen length (unless confined aquifers are being assessed). Unless circumstances warrant, the standard screen length used should be 3 metres (10 feet) - a screw-on end cap should be used at the bottom of the well screen if a screen of standard length is being use. Otherwise, a slip-on end cap should be used and secured in place using stainless steel screws - the use of a filter sock over the monitoring well screen is not a preferred practice, except in a limited number of well-defined circumstances - a fine graded silica sand with a uniformity coefficient of 1.1-1.7 and an effective size of 1.5-3.0 mm (eg: K&E Well Pack #2 or #3 Silica Sand) is a sufficient filter pack material for general applications, where there is little information on the formation - if the standard installation described here results in monitoring wells where the groundwater is highly turbid, additional wells at the site should be installed using the protocols contained in ASTM D 5092. This will allow proper sizing of the well screen and the sand filter pack, in order to minimize the amount of fine sediments entering the monitoring well

Table 1.3-2 (continued)

Summary of Generally Preferred Practices for Monitoring Well Components

Monitoring Well Component	Section	Generally Preferred Practices
Well Annulus Packing Materials	3.4	- borehole cuttings are not to be placed back in the well annulus - dry chipped bentonite is used to fill the annulus from the top of the sand pack to approximately 1 metre below grade - hydrated bentonite is used to seal the annulus from the top of the chipped bentonite to the ground surface. Use of concrete is not recommended
Well Protection Materials	3.5	- flush mount wells should be protected by installing a manhole. If the well is installed in a high traffic area (eg: a roadway), the manhole installed must meet AASHTO Standard M306-89 - aboveground risers should be protected by steel monument casings that have been sealed into the ground with bentonite. Use of PVC monument casings is acceptable in areas where there is no traffic - monument casings are allowed in areas where surface traffic will not interfere or damage any aboveground structure - allowing unprotected PVC risers to stick out above the ground is allowable, if a number of pre-conditions are met (ie: the site is fenced/locked, there is no traffic on site and permission has been obtained from the Imperial Oil Project Manager for this type of installation) - all monitoring wells should be locked (either the caps or the casings) to prevent entry by unauthorized personnel - in the upstream, specific procedures have been developed to protect and mark wells contained in monument casings, which must be followed by the Environmental Consultant

Table 1.3-3

Summary of Generally Preferred Practices for Monitoring Well Installation

Monitoring Well Activity	Section	Generally Preferred Practices
Monitoring Well Installation	4	- monitoring wells should be installed only in properly drilled boreholes (unless there is no other alternative to installation of monitoring wells inside test pits) - one monitoring well should be installed per borehole. For nested wells, each well will require its own borehole - monitoring well construction materials should be handled such that the potential for contamination is minimized - hand protection should be worn during installation of the monitoring well - the casing and screen should be placed in centre of borehole. A centralizer should be used (if required) for deeper boreholes - the filter pack and bentonite are added to the borehole annulus using gravity free fall. A tremie pipe should be used to add these materials, if required - temporary casings or augers should be removed in short increments, to prevent borehole collapse - monitoring wells should be surveyed into a recognized survey datum or an arbitrary site-specific datum
Monitoring Well Development	5	- developing of monitoring wells will be conducted by removing 3 well volumes of groundwater or by pumping the well to dryness three times. If possible, this should occur over a one day period (to avoid repeated site visits) - use of a surge block is recommended for the development of wells in fine-grained soil formations, where rapidly obtaining low turbidity samples is critical - purged water must be handled following all provincial guidelines or regulations (or by industry standards in that province, if no guidelines exist)

Table 1.3-4

Summary of Generally Preferred Practices for Groundwater Sampling

Monitoring Well Activity	Section	Generally Preferred Practices
Field Vapour Monitoring of Groundwater Monitoring Wells	6.1	- a catalytic explosimeter with methane exclusion capability (eg: the Gastech 1238ME or equivalent) is the preferred instrument for field screening. The explosimeter is commonly referred to as an Organic Vapour Monitor (OVM) - PID, FID, colourmetric and amino assay detection methods are not acceptable field screening methods for petroleum hydrocarbons - the OVM should be calibrated prior to use in the field (at least daily) - measurement of the peak organic vapour concentration should take place as soon as the cap to the well is removed, with the sample tube located 6-12 inches below Top Of Pipe (TOP)
Groundwater Level and Free Product Thickness Measurement	6.2	- the groundwater level should be measured from the TOP using an industry accepted water level measurement device. The level should be determined during every groundwater sampling event - notch the top of the PVC casing to indicate the exact point of measurement - if free product is present in the monitoring well, measurement of the thickness of this phase should be performed using an industry accepted interface meter, before purging - measurement of the groundwater level should be conducted prior to purging of the monitoring well - hand protection must be worn during the measurement of groundwater and/or free product levels in the monitoring well - field equipment should be cleaned after each downhole measurement, to prevent cross-contamination between monitoring wells - a field log book should be used to record observations and measurements

Table 1.3-4 (continued)

Summary of Generally Preferred Practices for Groundwater Sampling

Monitoring Well Activity	Section	Generally Preferred Practices
Standard Monitoring Well Purging	6.3	- dedicated equipment is used to purge the groundwater before sampling - an inertial pump (eg: Waterra) is the preferred sampling and purging device - a dedicated or disposable bailer is an acceptable sampling and purging device - purging of monitoring wells will be conducted by removing 3 well volumes of groundwater, or pumping the well to dryness, or pumping the well until the temperature/pH/conductivity of the water has stabilized - a field log book should be used to record observations and measurements during the purging, monitoring and sampling of the well - purged water must be handled following all provincial guidelines or regulations (or by industry standards in that province, if no guidelines exist)

Table 1.3-4 (continued)

Summary of Generally Preferred Practices for Groundwater Sampling

Monitoring Well Activity	Section	Generally Preferred Practices
Standard Sampling Procedures	6.4	- the inertial pump (eg: Waterra) is the preferred sampling device - a dedicated or disposable bailer is also an acceptable sampling device - samples should be taken from the centre of saturated zone of the monitoring well screen interval - sample bottles must have zero headspace (except for the gravimetric determination of oil/grease) - unless specified by the Provincial Regulations or Guidelines, the Imperial Oil preferred practice is to sample for dissolved metals, rather than total metals. This requires field filtration of the sample using a 0.45 μm, disposable, in-line filter - the samples should be placed in an ice-chilled cooler immediately after sampling and kept at <10°C until delivery to the laboratory - the analytical Chain of Custody (CoC) form must be completed following sampling and a copy of the CoC must accompany the samples to the lab - a field log book should be used to record observations and measurements - sampling water seeping into test pits or excavation is not a preferred practice - sampling groundwater from wells containing free product is not recommended, but can be performed under special circumstances

Table 1.3-4 (continued)

Summary of Generally Preferred Practices for Groundwater Sampling

Monitoring Well Activity	Section	Generally Preferred Practices
Non-Standard Purging and Sampling Procedures	6.5	- "no-purge" or "low-flow purging and sampling" methodologies may be considered in special cases (eg: when high turbidity groundwater samples may be causing positively biased results for dissolved parameters) - filtering samples to remove turbidity is not allowed for organic analyses - requirements for sample filtration, sample shipping, CoC's and field logs are the same for non-standard sampling as they are for standard sampling - regulatory buy-in is required before using one of these non-standard purging/sampling methodologies
Sample Bottles & Preservation	6.6	- all provincial guidelines or regulations regarding sample preservation that are required for the specific site take precedence over Imperial Oil preferred practices - sample bottles with appropriate preservatives are provided by the Imperial Oil approved contract laboratory - prior to the sampling event, a bottle order must be sent to the contract laboratory specifying the parameters and number of bottles required - trip blanks, field blanks, spiked trip blanks and extra bottles for field duplicates must also be ordered from the lab at this time

Table 1.3-4 (continued)

Summary of Generally Preferred Practices for Groundwater Sampling

Monitoring Well Activity	Section	Generally Preferred Practices
Groundwater Field Quality Assurance Sample Requirements	6.7	- one travel blank is required for each sampling event - field duplicate samples will be included for every sampling event that has >2 groundwater samples being submitted to the lab. For larger submissions, one field duplicate will be submitted for every 10 original samples submitted to the lab - where required by provincial regulations (eg: Ontario), a spiked trip blank will also be included in the sampling event

2) BOREHOLE DRILLING AND SOIL SAMPLING

Prior to the installation of a groundwater monitoring well, a boring is advanced into the ground by means of a drill rig and soils are typically taken. The drilling method needs to be selected on the basis of the local geology, size/depth of the monitoring well to be installed, the local availability of equipment and the available expertise. Preferential drilling methods are those that do not use drilling fluids, that advance the casing as the drilling proceeds, that minimizes smearing of the soil along the length of the borehole as the drilling proceeds and also allows discrete soil samples to be taken as the borehole is advanced. In cases where boreholes are advanced solely for the purpose of installing monitoring wells (ie: no soil samples are to be taken), the Environmental Consultant should re-prioritize drilling methods and select the preferred methodology based upon the specific job requirements.

2.1) Borehole Drilling Methodologies

When choosing a borehole drilling methodology for Imperial Oil projects, the preferred operating practices are:

- the use of a hollow-stem auger drilling method is a preferred practice, whenever soil conditions make the use of this methodology possible.
  + 1.5 metre (5 foot) flights are the preferred lengths for the hollow-stem augers.

- the utilization of hollow-stem augers has many advantages:
  + this type of auger has lower cost and higher availability than many other types of drilling equipment.
  + the equipment is relatively mobile and the drilling is moderately fast (a characteristic of auger drilling).
  + drilling fluids are not normally used, which is advantageous.
  + the casing is advanced as the drilling proceeds. This prevents collapsing of the borehole.
  + it allows collection of a discrete soil sample from the borehole with a relatively high degree of confidence of the sample depth.

- there are also disadvantages associated with the use of hollow-stem augers:
  + the borehole can be smeared by previously drilled clay.
  + the borings are limited to relatively shallow depths in overburden soils.
  + the drilling is difficult in saturated soils (most prevalently in sandy soils) and soils containing very coarse gravels, cobbles or boulders.
  + this drilling method generates drill cuttings that must be dealt with.
  + limited sample volumes are available from the split spoon samplers typically used with hollow stem augers.

  + in some cases, potable water must be added to the borehole to stop soil (under hydrostatic pressure) from heaving or blowing back into the hollow stem auger. While it is preferable to avoid adding water to the borehole, in some cases there is no alternative to adding the water to counter-balance the hydrostatic pressure. Addition of this water may change the chemistry of the nearby formation water; this problem can be minimized by proper monitoring well development.

- the direct push drilling method is preferred when there is low clay, till or cobble content in the formation being drilled; and the drilling equipment is cost effective and available.

- advantages of the direct push drilling method include:
  + drilling fluids are not used, which is advantageous.
  + cuttings are not generated. The only wastes generated are from the scraping of soils from the outside of soil cores.
  + drilling is fast and equipment is highly mobile.
  + undisturbed soil samples can be obtained by installing a sleeve inside the direct push tube.

- disadvantages of the direct push drilling method include:
  + installation is limited to overburden soils, such as fairly uniform silty and sandy soils. There is poor penetration through dense soils (eg: clays and tills) or soils containing cobbles and boulders.
  + in many parts of Canada, there are few (or no) local suppliers of direct push technology. This can make the technology expensive or simply unavailable.

- the sonic drilling method is the preferred practice when there is high cobble content in the formation being drilled. It is also the preferred practice for use in dense soil materials (eg: glacial till, clay soils with very low silt content) where the binding of auger flights is a problem.

- advantages of the sonic drilling method include:
  + drilling fluids are usually not used, which is advantageous. Note that in some cases, the addition of small quantities of potable water to the borehole is required to cool the drill bit.
  + drilling and sampling is possible in media containing boulders, wood, concrete and other construction debris.
  + drilling is possible in soft rocks such as sandstone, limestone, shale and slate with high percentage of recovery.
  + obtaining large sample volumes, with good visualization of the stratigraphy, is possible.

- disadvantages of the sonic drilling method include:
  + it is sometimes necessary to use water as a drilling fluid to cool the drill bit.
  + extraction of the casing can cause smearing of borehole wall with silt or clay.

  + soil may be displaced into the borehole wall during drilling.
  + the equipment may not be readily available in many parts of Canada and is much more expensive than the use of hollow stem augers.
  + a large volume of cuttings is generated by this drilling method.
  + there is sometimes a low degree of confidence of the depth at which a sample was recovered, due to elongation or shrinkage of the core.

- the use of a solid-stem auger is not a preferred practice.
  + Environmental Consultants are not to use solid stem augers on Imperial Oil projects, unless there is no other methodology available that will allow drilling of the borehole. This will very rarely be the case.

- advantages of the solid stem auger drilling method include:
  + this type of auger has lower cost and higher availability than many other types of drilling equipment.
  + the equipment is relatively mobile and the drilling is moderately fast (a characteristic of auger drilling).
  + drilling fluids are not normally used, which is advantageous.
  + solid stem augers can advance through somewhat tighter soils than hollow stem augers.

- disadvantages of the solid stem auger drilling method include:
  + the potential for smearing contamination from the contaminated zone through the length of the borehole is unacceptably high.
  + boreholes are susceptible to collapse in saturated soils and/or coarse-grained soils.
  + the sand pack and bentonite used to fill the annulus around the monitoring well grout seal may be difficult to install.
  + borings are limited to a relatively shallow depth in normal overburden soils.
  + drilling is difficult in saturated soils and soils containing very coarse gravels, cobbles or boulders.
  + the use of solid stem augers does not easily allow the collection of discrete soil samples. The collection of discrete samples is only possible if the auger is removed from the borehole and the split spoon is driven in front of it. This process is time consuming and subject to problems associated with complete or partial borehole collapse when the solid stem auger is removed.
  + this drilling method generates drill cuttings that must be dealt with.
  + limited sample volumes are available from the split spoon samplers typically used with solid stem augers.

- the use of a Becker Hammer drill (specifically designed for use in sand, gravel and boulders) is not a preferred practice for typical sites. Despite its capability of drilling in soils with coarse gravels, cobbles or boulders, there are several disadvantages to using the Becker Hammer:

+ due to the contact of the drill bit with cobbles and gravel, there is a potential for a large amount of heat to be generated during the drilling process. In addition, forced air is used to return the samples to grade. These two factors result in an unacceptable negative bias in the results for any soil samples submitted for the analysis of volatile organic contaminants (such as BTEX).
+ if a open bit is used for obtaining disturbed samples, the samples are mixed for each depth interval. This makes soil characterization from discrete levels within the borehole impossible
+ to collect discrete soil samples, drilling must be halted and samples collected through the inner barrel using a split-spoon or coring techniques. This is impractical/impossible if large cobbles or boulders are encountered during the soil sampling process.

- it is preferred that a Becker Hammer should only be used when an ODEX auger is not available and there is no other available methodology to advance a borehole in the soil.
  + this drilling methodology is effective when the main goal is to install a monitoring well in a cobbly substrate.
  + volatile organics analysis of the soil samples collected when drilling a borehole with a Becker Hammer should be considered suspect.

- at sites where coarse gravel, cobble and boulders make the use of other borehole drilling methodologies impractical, use of an ODEX auger is recommended.
  + like a Becker Hammer, an ODEX auger is classified as a "hammer drill". Thus, it has all the inherent disadvantages listed above for the Becker Hammer.
  + the main advantage of the ODEX auger is the situation where there are overburden soils above a layer of cobbles or boulders; and it is required to advance the borehole through both strata. In these situations, the borehole can be started with a hollow stem auger and discrete split spoon samples can be taken from the first soil stratum. When the cobble or boulder layer is reached, the ODEX augers can be attached and the drilling continued. From this point forward, samples will be composited from a depth zone (ie: obtaining discrete samples is not possible). This flexibility is not available with a Becker Hammer; if you need to finish the borehole with the Becker Hammer, you must also start the borehole with the Becker Hammer.

- after finishing the drilling of each borehole, all drilling equipment (augers, rods and plug) should be manually cleaned using a brush.
  + gross soil should be removed from all drilling equipment with a brush, to minimize the potential for cross-contamination between boreholes.
  + in areas where boreholes are being advanced into aquifers that <u>are not</u> being utilized as a potable water source, this level of cleaning is sufficient. Typically, the applicable groundwater criteria for hydrocarbon contaminants are fairly generous in non-potable areas. Thus, the low levels of cross-contamination between boreholes that is possible (since the drilling equipment has not been

thoroughly washed between boreholes) should have a negligible effect on the data collected.

+ if hydrocarbon residues (from gross hydrocarbon contamination of the soil) and/or residual soil are still adhering to the drilling equipment and cannot be removed by brushing, set the contaminated equipment aside and do not use for the remainder of the drilling. If the equipment must be re-used at the site, it must be washed using the procedure described in the next point.
+ the soil generated by equipment cleaning should be disposed of in a manner that is consistent with the Provincial Regulations or Guidelines. Where Provincial Regulations or Guidelines are silent on this manner, the soil should be disposed of in a manner that is consistent with the industry standards in that province.

- at sites where boreholes are being advanced in an aquifer that is a potable water source, more scrupulous cleaning of all drilling equipment (augers, rods and plug) is required.
  + typically, the applicable groundwater criteria for hydrocarbon contaminants are very stringent in potable water areas. Thus, the low levels of cross-contamination between boreholes that are possible if the drilling equipment has only been cleaned with a brush will potentially have a deleterious effect on the data collected.
  + gross soil should be removed from all drilling equipment with a brush.
  + the plug and any auger flights that may come into contact with groundwater must be thoroughly cleaned. In practice, this will usually mean that the plug and first two flights of the auger will need to undergo additional cleaning.
  + the additional cleaning (beyond the brushing) will consist of scrubbing the equipment with a brush and soapy water to remove hydrocarbon residuals or stubborn soil. The equipment being cleaned should then either be steam cleaned (generates the smallest volume of water for disposal), cleaned with a power nozzle or rinsed at two (2) times with tap water (generates the largest volume of water for disposal).
  + this level of cleaning is required to ensure that contaminated soil particles from a previously drilled borehole cannot possibly contaminate the new borehole being drilled.
  + the drilling equipment and the water used to wash it should not come into contact with the ground. A drill rod stand (preferable) or trough should be used to collect the soil and water generated from cleaning of the drilling equipment. This will avoid the possible contamination of surface soils with the soil and water generated from cleaning of the drilling equipment.
  + if hydrocarbon residues and/or residual soil are still adhering to the drilling equipment and cannot be removed, set the contaminated equipment aside. Do not use for the remainder of the drilling.
  + the excess soil and wash water generated by equipment cleaning should be disposed of in a manner that is consistent with the Provincial Regulations or Guidelines. Where Provincial Regulations or Guidelines are silent on this

manner, the wash water and soil should be disposed of in a manner that is consistent with the industry standards in that province.

- the use of grease, lubricants or any other petroleum based products (eg: WD-40) on any downhole drilling equipment is prohibited.
  + these products can contaminate the borehole, leading to false positive soil and groundwater analytical results for petroleum hydrocarbon parameters.

- when drilling boreholes at the site, it is preferred that boreholes are first drilled in the areas of the site that are suspected to have the lowest levels of hydrocarbon contamination. Areas of the site that are suspected to have the highest levels of hydrocarbon contamination should be drilled last. This precaution will reduce the probability that clean boreholes could be cross-contaminated by equipment that had just been used to drill a borehole in a heavily impacted area of the site.
  + if test pitting has already occurred at the site, use this data to decide the order in which the boreholes should be drilled.
  + if no intrusive assessment data is available, use Phase I assessment data to determine which areas of the site have the highest and lowest probability of hydrocarbon impacts. Plan and implement the borehole drilling program accordingly.

2.2) Borehole Sampling Methodologies

Sampling devices are typically attached to drill rig equipment to facilitate sampling of the soil during the borehole drilling process. The preferred practice involves sampling the soil in a solid core device, for which a distinct depth can be associated with a high degree of confidence. When choosing a borehole sampling methodology for Imperial Oil projects, the preferred operating practices are:

- boreholes should be advanced until a clean bottom is reached. A clean bottom is defined as the point where field observations indicate there has been no hydrocarbon contamination of the soil.
  + in some jurisdictions, it is a requirement that a clean bottom is reached (eg: this is required by British Columbia regulations).
  + in cases where hydrocarbon impacted soils are not encountered, the borehole should be advanced to a depth of 8 metres, or until the borehole has been advanced 1 metre below the lowest expected seasonal water table level, or until refusal is reached; whichever of these three conditions is satisfied first.
  + in cases where hydrocarbon impacted soils are encountered, the borehole should be advanced through the zone of contamination, until a clean bottom sample is reached. This will allow the vertical extent of the contamination to be delineated. Since the contaminated smear zone will typically be at or below the water table, advancing the borehole to a clean bottom underneath the smear zone should

ensure that the borehole has been drilled deep enough that the monitoring well screen can be installed, so that it is straddling the water table.

+ termination of a borehole in a contaminated zone, without reaching a clean bottom is strongly discouraged. It is expected that a borehole will be advanced until a clean bottom (beneath the zone of hydrocarbon contamination) is reached, or the auger experiences refusal, even if this means drilling the borehole to a depth of >8 metres. The Environmental Consultant is not expected to discuss this decision with the Imperial Oil Project Manager; they should proceed with drilling to >8 metres in order to obtain a clean bottom. If a clean bottom is not reached, this means that vertical delineation of the contaminated zone is not complete and an accurate estimation of contaminated soil volume cannot be made.
+ in cases where drilling deeper than 8 metres is required to reach the water table, the Environmental Consultant should discuss the matter with the Imperial Oil Project Manager. Site-specific drilling strategies will be developed for such sites.

- the use of a steel or stainless steel split spoon sampler is the preferred practice when sampling soils.
  + the split spoon sampler is a hollow tube comprised of two halves clamped together during sampling. The split spoon sampler can come equipped with or without inner liners; it can come equipped with or without a flap valve (ie: a sand trap).
  + use of a split spoon sampler with a 0.38 metre (1.5 inch) inner diameter is preferable when working with a hollow stem auger.
  + 0.6 metres (2 feet) is the preferred length for the split spoon sampler, as outlined in ASTM D 3550-01. Note that ASTM D1586-99 specifies that split spoon samplers used in soil sampling must have a length in the 0.45-0.75 metre (1.5-2.5 feet) range.
  + when sampling unconsolidated soils (eg: sands or some saturated soils), the preferred practice is to use a split spoon sampler equipped with a sand trap. This sand trap should be constructed from metal. The use of sand traps constructed from plastic is not allowed.
  + in cases where continuous interval sampling of soil over the entire length of the borehole is required, the use of 0.75 metre split spoon samplers is recommended. This means that two successive split spoon samples will be driven over the 1.5 metre length of a standard hollow stem auger flight.

- driving the split spoon sampler into sample soils should follow the procedures outlined in ASTM D 1586-99. Briefly, this methodology is described below:
  + the split spoon sampling tube is driven into the soil ahead of the cutting bit, at the bottom of the auger flight.
  + the driving force is provided by a 63.5 kg (140 pound) weight dropped through a 0.76 m (30 inch) interval.
  + the drill rod should be marked in three successive 0.15 metre (6 inch) increments. The number of blows required to drive the split spoon sampler each of these three 0.15 metre increments should be recorded on the borehole log sheet. For

consistency, the three 0.15 metre increments where the blow counts are being recorded should be the last 0.45 metres of the split spoon sampler. This will ensure that the blow counts are being recorded in soils that have experienced minimal disturbance from the borehole drilling process.

+ blow counts can be presented in their raw form in the borehole logs of the report (preferable, since this is easiest to understand for laymen reading the report), or reported as "N" values (this is also acceptable).
+ the split spoon sampling tube is retrieved. The soil sample that is removed from the split spoon can be used for constructing the borehole log and also be submitted for chemical/physical analyses.
+ the use of inert (6 inch long brass or stainless steel) inserts within the split spoon sampler is a technically acceptable manner to collect soil samples. These inserts can be capped at both ends and submitted to the laboratory for analysis (minimizing volatiles losses, due to sample handling). If this method of soil sampling is to be used on Imperial Oil sites, provincial regulators must have already recognized this as an acceptable methodology for soil sampling.

- discrete interval split spoon sampling of the borehole will be used.
  + one split spoon interval sample (typically 0.6 metres in length) will be collected for every 1.5 metre auger flight length in the borehole. If the soil stratigraphy is complex and more frequent sampling is required in the best professional judgement of the Environmental Consultant, the decision to perform this extra sampling should be made by the field personnel.
  + continuous interval sampling of the borehole, achieved by taking two successive 0.75 metre split spoon samples for every 1.5 metre auger flight will not typically be used. This type of sampling will only be performed when it is considered to be required in the best professional judgement of the Environmental Consultant.

- site conditions may make the use of split spoon samplers impractical (eg: cobbles or glacial till make it impossible to drive the split spoon sampler). While it is preferred to utilize another borehole drilling method at such sites (eg: Sonic, ODEX), in some case this is not possible. Under these conditions, the Environmental Consultant must try to obtain the best possible soil samples with the standard auger equipment available at the site and take disturbed soil samples from the auger flights.
  + collection of disturbed samples from the auger flights is typically not recommended, since it is not possible to reliably obtain a discrete soil sample over a defined depth interval. However, if soil conditions (eg: cobbles, dense till) make driving the split spoon impossible, collection of soil samples from the auger flights may be the only option available.
  + the soil sample can also be smeared when withdrawing the auger flight through a discrete contaminated zone located above the zone being sampled (leading to false positive results).
  + to avoid smearing issues, the outer 1/8 inch of soil should be removed from the soil sticking to the auger flights, before taking the soil sample that will be used for field screening and be submitted to the laboratory for chemical analysis. In

addition, sampling of soil in direct contact with the auger flights should also be minimized (to avoid the potential of cross-contamination with soil adhering to the auger from a previously drilled borehole).

- upon retrieval from the borehole, the split spoon should be placed on a clean sampling surface for examination of the soil and subsampling of the core.
  + once the split spoon is opened, the length of soil core in the sampler is measured and recorded on the borehole log. This allows a calculation of the recovery.
  + soil classification and observations are made of the core and recorded in the borehole log. Note that soil observations should be made on a freshly exposed surface of the core sample.
  + the soil should not be touched with the bare hand or by gloves that may be contaminated. Contact or handling of the soil should be minimized at all times.
  + do not leave the soil exposed for an extended length of time (ie: >2 minutes) if the soil is to be used for vapour measurements or chemical analysis.

- prior to taking a sample of the core for field vapour screening or chemical analysis, the outer layer of the core should be removed. This should only be performed if the soil core sample is consolidated.
  + there is a possibility of smearing contamination along the outer layer of the core if the split spoon sampler is advanced through a contaminated layer into a non-contaminated layer. The inside of the core is typically unaffected by this smearing effect.
  + if the first approximately 1/8 inch of soil is removed from the core, this smearing effect should be minimized.
  + a decontaminated putty knife, stainless steel spoon or similar implement should be used to remove the outer layer of soil from the core.
  + this procedure should not be performed on unconsolidated core samples. It could result in mixing or smearing of the unconsolidated core sample, which would have an adverse effect on the integrity of the sample.

- representative soil samples should be taken for field vapour screening and chemical analyses over the entire length of the split spoon sample.
  + it is recommended that the sample be split longitudinally, along the length of the split spoon sampler. One half of the core sample can be used for OVM field screening measurements and the other half of the core can be submitted to the lab for chemical analysis.
  + samples being submitted to the laboratory from the second half of the core should be taken from several spots located over the entire length of the core, in order to obtain a representative sample of the core. This type of sampling is used when there is no significant difference of visual/olfactory contamination or soil classification within the specified length.
  + if varying levels of contamination and/or varying soil types are observed within the length of the split spoon core sample, then a sample should be taken from each distinct zone within the split spoon sample (ie: more than one sample should be

taken from within the split spoon sampler) for both field screening and laboratory analysis. This will ensure that major contaminant pathways (eg: thin sand seams within a silty clay soil) will be sampled and characterized.
  + every split spoon sample taken from the borehole will undergo field vapour screening measurement (assuming that there is sufficient sample recovery). Exceptions to this preferred practice will be discussed below.
  + not every split spoon sample taken from a borehole will be submitted for laboratory analysis. Guidance regarding which samples should be submitted for laboratory analysis will be discussed later in this section.
  + when there is insufficient sample recovery in the split spoon to provide enough soil for both field vapour screening and filling sample bottles for lab analysis, use the available sample to fill the bottles for submission to the laboratory.

- samples being submitted to the laboratory for volatiles analysis (eg: BTEX or TPH fractions of $<C_{10}$) should not be composited or mixed in the field.
  + these samples should be collected into bottles from a location that best represents the contamination of the zone being sampled.
  + bottles being submitted to the laboratory for volatiles analysis must have "zero headspace".
  + with extremely stiff, dense soils (eg: glacial tills and clay), obtaining zero headspace in the sample bottle is extremely difficult. In this case, field personnel should make their best efforts in order to minimize the amount of headspace contained in the sample bottle.
  + if there is sufficient recovery in the split spoon sampler, sample bottles being submitted for non-volatile organic analyses should also be filled so that they contain zero headspace.

- after each use, the split spoon sampler must be cleaned.
  + cleaning includes using a brush with soapy water until all visual contamination and/or soil adhering to the split spoon has been removed, followed by a clean tap water rinse. The detergent used to prepare the soapy water should be phosphate-free (eg: Alconox).
  + the split spoon sampler should also have as much residual tap water removed as possible by free draining and/or evapouration before re-use.
  + in winter conditions, it is permissible to blot the residual water from the split spoon using a paper towel.. This will avoid the problem of water freezing on the split spoon, due to cold temperatures.
  + a final methanol rinse of the split spoon sampler may be required after the tap water rinse. This should only be performed if it is required by the regulator (ie: as it is in Ontario) or if the standard washing methodology described above cannot remove all residual organic material from the split spoon.
  + if a provincial regulator has specified a different cleaning methodology outlined from the one described above (eg: use of methanol and/or distilled water), the Environmental Consultant must utilize the cleaning methodology specified by the regulator.

  + water generated by split spoon cleanings should be disposed of in a manner that is consistent with the Provincial Regulations or Guidelines. Where Provincial Regulations or Guidelines are silent on this manner, the water should be disposed of in a manner that is consistent with the industry standards in that province.

- samples being submitted to the laboratory for chemical analysis must be submitted in the sample bottles provided by the laboratory.
  + submission of any samples in plastic bags will be considered a deficiency by Imperial Oil. This includes the submission of samples for inorganic parameters such as salinity and total metals. Samples must be submitted in the proper sample bottles, in order to ensure that data generated is legally defensible.
  + soil samples submitted for physical analysis (eg: particle size analysis) can be submitted in plastic bags. Submission of the sample in a plastic bag will not have a deleterious effect on the results of physical characterization tests.

- samples being submitted to the laboratory for organic chemical analysis should have contact with plastic materials minimized.
  + plastic sampling tools and plastic bags should not be used when sampling soils for organic chemical analyses.
  + for soils being analyzed for trace organics (ie: PAH's, pesticides, herbicides, dioxin/furans), the soil should never be touched by a glove made from a plastic material (ie: latex, nitrile). The soil should only be in contact with a clean metal sampling device (eg: a putty knife or a spoon).
  + for soils to be analyzed for standard organics (ie: TPH, BTEX, oil/grease) contact with the soil by clean glove materials should be minimized.

- do not use soil from field vapour screening (ie: soils in plastic bags or soil screening jars) for laboratory analysis of volatile or non-volatile organic parameters.
  + a negative bias for VOC analysis is obtained if the soil sample is submitted to the laboratory after the measurement of headspace vapours during field screening. Positive biases are possible for some non-volatile parameters (eg: phthalate esters) due to contact with the plastic bag.
  + if there is insufficient recovery of soil for both vapour and organic chemical analyses, submit the soil for chemical analysis, without conducting a field vapour screening measurement.
  + it is an acceptable practice to submit soil used from field screening to the lab for the analysis of inorganic parameters (eg: salinity, metals). This should only be done if insufficient soil volume has been recovered from the split spoon for all lab analysis requirements.

- place the filled sample container into a cooler containing ice, to reduce the sample temperature as soon as possible.
  + ice cubes or chunks should be utilized. Use of a solid block of ice is not preferred.

- in the downstream, the preferred practice is to send a minimum of one (1) sample per borehole to the laboratory for analysis.
  + if hydrocarbon is not detected in the borehole samples based on vapour screening results or visual/olfactory observations, the sample from the uppermost portion of the saturated zone should be selected for laboratory analysis, since this is the sample that has the highest probability of containing hydrocarbons.
  + for soil samples where hydrocarbon is detected by vapour screening or physical observation, the sample with the highest apparent contamination should be selected for laboratory analysis. In addition, the first non-impacted sample underneath the contaminated layer should be selected for laboratory analysis, in order to provide vertical delineation of the contamination.
  + if there is some confusion as to what actually is the first clean sample beneath the contaminated zone, sample what is suspected to be the first clean interval below this zone. Also send the sample from the bottom of the borehole in for analysis (this will mean that three samples will be taken from this borehole). If the suspected first clean sample underneath the contaminated zone is in fact contaminated, this procedure will ensure that at least an upper bound on the maximum thickness of the contaminated zone will have been determined.
  + for boreholes where hydrocarbon contamination has been identified, additional samples may be taken. These samples could be used to identify major contaminant pathways.

- in the upstream, sending a minimum of one (1) sample per borehole to the laboratory for analysis is not required.
  + upstream properties typically have much larger acreage than downstream sites.
  + for some boreholes, the screening of borehole soil samples based on vapour screening results or physical observation is all that is required when delineating a large area.
  + the Environmental Consultant should discuss site specific sampling requirements with the Imperial Oil Project Manager.

2.3) Soil Field Screening

As stated in Section 1.1, this POP focuses on hydrocarbon-contaminated sites. As such, this section will concentrate on field screening methods for hydrocarbon contamination. Field screening methodologies (eg: conductivity meter, mercury vapour analyzer) for other types of contaminants (eg: salinity, metals) will not be addressed in this POP.

Field screening activities typically utilize rapid, low-cost methods to indicate the presence or absence of substances of interest relative to specific threshold values. When drilling boreholes, field screening tools are used primarily to select which samples are to be submitted to the laboratory for chemical analysis. The two types of field screening of soil samples typically used on Imperial Oil projects will be physical observation and organic vapour monitoring.

2.3.1) Physical Observations

Physical observations of soil samples are used as a screening technique to indicate the presence or absence of hydrocarbon in a soil sample. Physical observations cannot be compared directly to regulatory criteria. However, they can be used to delineate the extent of soil contamination and direct which samples will be submitted for laboratory analysis. When performing physical observation of soils for Imperial Oil projects, the preferred operating practices are:

- visual observations of soil samples should be made and the results recorded in the field technician's logbook.
  + visual observations should include any evidence of staining or free product in the soil sample.
  + observations on soil texture and soil colour should be included.
  + results of visual observations should be included in borehole logs that are included in the report prepared to summarize the field work.

- olfactory observations of soil samples should be made and the results recorded in the field technician's logbook.
  + olfactory observations should include any evidence of hydrocarbon odours in the soil sample.
  + "sniffing" the soil samples to determine if there are hydrocarbon odours is not condoned. For occupational health reasons, the inhalation of hydrocarbon vapours should be minimized.
  + instead, olfactory observations should discuss any hydrocarbon odours detected during the normal handling and field screening of the sample.
  + results of olfactory observations should be included in borehole logs included in the report prepared to summarize the field work. Field personnel should restrict themselves to recording the presence or absence of petroleum hydrocarbon odours. No attempt should be made to qualify these odours (eg: no use should be made of words like "faint", "strong" or "weak"). No attempt should be made to identify the type of contamination (eg: no use should be made of words like "gas", "diesel" or "lube oil").

- visual and olfactory observations should only be recorded in the borehole logs of the assessment report. This data is useful in determining the depth of potential hydrocarbon impacts in the soil.
  + visual and olfactory observations are qualitative. They relate to aesthetic concerns and cannot be accurately correlated to regulatory criteria. As such, visual and olfactory observations should not be mentioned in the main body of the assessment report. Only quantitative data (eg: lab data) or semi-quantitative data (eg: OVM measurements) should be presented in the main body of the report.

2.3.2) Organic Vapour Monitoring

Field soil Volatile Organic Compounds (VOC) measurements are used as a screening technique to indicate the approximate level of volatile organic contamination in soil. The field VOC measurements are determined using an Organic Vapour Monitor (OVM). The OVM field measurements cannot be compared directly to regulatory criteria. However, they can be used as field measurements to estimate the degree of soil contamination and direct which samples will be submitted for laboratory analysis. When conducting organic vapour monitoring for Imperial Oil projects, the preferred operating practices are:

- a catalytic explosimeter, with methane exclusion capability, is the preferred instrument to use for field screening.
  + this type of OVM utilizes a catalytic combustion sensor to measure %LEL and/or ppmv of combustible hydrocarbon in the headspace above a soil sample.
  + this type of OVM is extremely rugged and well suited to work in the field.
  + the OVM must have methane exclusion capability and be operated in this mode.
  + the Gastech 1238ME or equivalent OVM should be used.

- photoionization (PID), flame ionization (FID), colourmetric (ie: Draeger Tubes) and amino assay (ie: Petro Flag) methodologies are not acceptable for the field monitoring of petroleum hydrocarbons on Imperial Oil sites.
  + some consultants favour the use of PID detectors. These are not to be used on Imperial Oil projects. This type of OVM is delicate (the calibration shifts easily and detector response is affected by climatic conditions, such as humidity). The response is also dependent on the composition of the hydrocarbon vapours (PID response is excellent for aromatics, but poor for saturates). Finally, the lamps used are prone to burn-out, making these instruments expensive to operate. These deficiencies make PID instruments poorly suited for field work on Imperial Oil sites.

- the OVM must be calibrated prior to use in the field.
  + at a minimum, calibration of the OVM should be conducted at the start of each day.
  + more frequent calibration will be required if a large number of samples with extremely high vapours have been measured. Under such conditions, the calibration of catalytic explosimeter OVM's have been known to drift.
  + calibration should include two (2) known standards of hexane in air. It is recommended that these standards be in the mid-ppmv range (eg: 400 ppmv) and mid-%LEL range (eg: 40% LEL).
  + if the calibration standard measurement disagrees with known standard value by more than 10% of the standard value, adjust the calibration of the instrument until it reads the exact concentration of the standard.
  + record the original measurement of the standard measured at the start of every calibration procedure. If recalibration of the OVM was required, record the

measurements of the known standards both before and after the calibration adjustment.

- the methane exclusion efficacy of the OVM should be measured quarterly.
  + monitor the methane exclusion efficacy using an air gas standard that contains 400 ppmv hexane and 400 ppmv methane in air.
  + if the methane reduction is <80%, the explosimeter should not be used at Imperial Oil sites.
  + contact the manufacturer to resolve the problem.

- all calibration and methane exclusion efficacy measurements should be recorded in a logbook.
  + this calibration logbook should be kept with the OVM in the field, at all times.
  + the calibration logbook should be available to Imperial Oil personnel for verification checks, upon request.

- the preferred practice for measuring the soil vapour is the following ATHM (ambient temperature headspace methodology):
  + fill a sealable plastic "ziplock" bag 1/4 full with soil and close the ziplock.
  + the soil should be broken apart inside the bag, by kneading the closed bag and breaking apart the soil chunks inside the bag.
  + allow the soil to equilibrate for 30 minutes, at a minimum of 15°C. The time and temperature restrictions <u>are critical</u> to ensure consistency of readings between samples.
  + insert the OVM probe into the bag.
  + record the <u>peak</u> headspace vapour concentration measured (in units of either ppmv or %LEL).
  + placing the soil bags in direct sunlight (for an extended period of time) <u>is not</u> recommended.
  + stockpiling field screening samples until the end of the day and measuring them all at once <u>is not</u> a preferred practice.

- an acceptable practice for measuring the soil vapour is the following ATHM (ambient temperature headspace methodology):
  + fill a glass jar 1/4 full with soil and close the lid (this lid will have a hole in it).
  + between the lid and the jar, place some plastic material, to act as a septum (this will ensure that vapours do not escape from the hole in the lid of the jar).
  + the soil should be broken apart as it is placed in the bottle, then agitated after the jar is closed.
  + allow the soil to equilibrate for 30 minutes, at a minimum of 15°C. The time and temperature restrictions <u>are critical</u> to ensure consistency of readings between samples.
  + insert the OVM probe through the hole in the lid, puncturing the plastic septum beneath it

  - + record the peak headspace vapour concentration measured (in units of either ppmv or %LEL).
  - + placing the soil glass jars in direct sunlight (for an extended period of time) is not recommended.
  - + jars may be reused, after they have been thoroughly cleaned of all soil remaining in them from the previous sample. Before reuse, the bottles must be proofed. Proofing involves closing the lid of the cleaned jar (with the plastic seal in place) and allowing 30 minutes equilibration. The organic vapour levels in the jar are then measured with an OVM. If organic vapours >20 ppmv are detected, the bottle cannot be reused.
  - + stockpiling field screening samples until the end of the day and measuring them all at once is not a preferred practice.

- once the field vapour measurements are taken, the soil is returned to the excess soil (ie: the cuttings) from the original borehole.
  - + cuttings from boreholes (along with excess sample from the OVM screening of the soil) should be disposed of in a manner that is consistent with the Provincial Regulations or Guidelines.
  - + where Provincial Regulations or Guidelines are silent on this manner, cuttings should be disposed of in a manner that is consistent with the industry standards in that province.

2.4) Soil Field Quality Assurance Sample Requirements

To ensure that Imperial Oil's contract analytical laboratory is producing data of acceptable quality, the Environmental Consultant is required to submit field Quality Assurance (QA) samples with every laboratory submission.

When submitting soil samples taken from boreholes for laboratory analysis for Imperial Oil projects, the preferred operating practices for the submission of field QA samples are:

- field duplicate samples will be required in every sample submission that contains at least three soil samples.
  - + a field duplicate is an additional sample collected at the same time as another in a manner that minimizes the differences between the two samples (ie: the original and the field duplicate).
  - + for non-volatile parameters, split the soil sample from a composite of the isolated zone being sampled between the two sample bottles (ie: the original sample and field duplicate).
  - + field duplicates for volatile parameters are the exception. The duplicate bottles must be filled without homogenizing, with the bottles being capped immediately after sampling each bottle. The field duplicate should be taken from a location as close to the original sample's as possible, in order to minimize sampling variability between the original sample and the field duplicate.

- a minimum of one (1) field duplicate sample should be taken during each sampling event for every ten (10) soil samples being submitted to the laboratory for analysis.
  + for sampling events where <3 soil samples are being sent to the lab in a single sample submission, the submission of a field duplicate sample by the consultant is not required.
  + a field duplicate should be submitted for each group of 10 samples. For example, a sample submission containing 32 soil samples would require the submission of 4 field duplicate samples to the laboratory.
  + whenever possible, soil samples where hydrocarbon impacts are suspected from field observations should be chosen for submission as field duplicates. Limited information on field duplicate reproducibility can be obtained when samples containing non-detectable levels of the parameters of concern are submitted for analysis.

- at least one (1) field blank should be included for each sampling event when sampling for trace organics (eg: PAH's)
  + a field blank is a sample of acid washed silica (sometimes called acid washed sea sand). This material will be provided to the Environmental Consultant by Imperial Oil's Contract Laboratory. Each batch of material will be proofed by the laboratory (ie: a sample of the material will be analyzed to ensure that it has not been contaminated by any of the analytes of interest).
  + the sea sand is placed into the trace organics bottles at the sampling site by the field technician.
  + this takes place at the same time and location that the other sampling is occurring.
  + the submission of a field blank is not required for other organic parameters (ie: BTEX or TPH).
  + this QA sample will help identify the presence of contamination due to field handling and/or laboratory sources.

2.5) Borehole and Monitoring Log Methodology

Complete documentation of the drilling and/or sampling process should be accurately recorded in a field notebook and transferred to a borehole log. Notations about weather, drilling equipment, personnel on the site, sampling techniques, subsurface geology and hydrogeology should be recorded. Lithology descriptions should be based on visual examination of the cuttings and samples; these descriptions should be consistent with either the Canadian Soil Classification System or the Unified Soil Classification System (USCS). When preparing a borehole log for Imperial Oil projects, the preferred operating practices are:

- each borehole should be individually logged.

- graphical depictions of the borehole logs and descriptions consistent with the Agriculture Canada's "Soil Classification System" are preferred [Agriculture Canada, 1998].
  + use of the visual-manual method of the USCS [ASTM D2488-00] is also acceptable.

- an "as-built" construction diagram or descriptions should be provided for each monitoring well, including nested piezometers.
  + the preferred practice is to include the construction diagram or description on the borehole log sheet. However, a separate diagram is also acceptable.

- observations of seepage, free water, and water levels should also be noted on the borehole log.

- if a local surveyed geodetic reference datum is nearby, specific details regarding the construction of the monitoring well (including both depths below grade and elevations) should be surveyed into this datum.
  + the surveyed data should be included in the borehole log. All elevations should be expressed in metres above sea level (MASL).

- in cases where a local surveyed geodetic reference datum <u>is not</u> readily available, specific details regarding the construction of the monitoring well and elevations with respect to an arbitrary local datum (eg: the top of the north nut on the base of a nearby fire hydrant) should also be included in the borehole log. All elevations should be expressed relative to this arbitrary benchmark.
  + at the vast majority of sites, an arbitrary local datum will be used rather than a surveyed geodetic datum.

- at a minimum, each borehole log should contain the following information:
  + client name (eg: Imperial Oil).
  + date borehole drilled.
  + in the downstream, the street address and town of drilling location name (eg: 207 Main Street, Calgary) should be provided.
  + in the upstream, the legal land description of the property should be provided. Most upstream sites will not have a street address.
  + Environmental Consultant's name (eg: ABC Consulting).
  + sample loggers name (eg: Joe Smith).
  + drilling contractor's name (eg: XYZ Resources).
  + drilling method (eg: hollow stem auger).
  + drilling equipment used (eg: truck-mounted CME55).
  + borehole ID (eg: BH-101).
  + borehole depth (either via description or use of a vertical scale).
  + borehole elevation (either via description or use of a vertical scale).
  + borehole diameter.
  + sample type (eg: split spoon, disturbed) and depth.

+ blow counts (every 0.15 metres, as per ASTM D1586) or "N" values.
+ sample recovery (for each split spoon sample obtained).
+ soil type descriptions and observations (for each sample obtained).
+ sample ID's with associated depths (for each sample obtained).
+ soil vapour measurements in either ppm or %LEL (for each sample obtained).

- if a monitoring well is being installed in borehole, additional information should be included in the borehole log (the preferred practice is to express this data graphically):
  + monitoring well ID (eg: MW-101).
  + casing type and diameter (eg: 2 inch ID PVC casing).
  + type and slot size of screen used (eg: Size 20 Slot Screen).
  + if filter sock is used, specify the type and length (eg: 100% polyester filter sock covering the screen).
  + top-to-bottom elevation of screen (shown on diagram or written description)
  + top-to-bottom elevation of filter pack (shown on diagram or written description).
  + top-to-bottom elevation of each annular sealant (shown on diagram or written description).
  + ground elevation (relative to local datum or arbitrary benchmark).
  + top of pipe elevation (TOP).
  + groundwater elevation immediately prior to developing (relative to local datum or arbitrary benchmark) and date this measurement was taken.
  + groundwater elevation immediately prior to sampling (relative to local datum or arbitrary benchmark) and date this measurement was taken.
  + dedicated sampling equipment, if present (eg: Waterra Inertial Pump and HDPE tubing).

2.6) Borehole Backfilling and Monitoring Well Decommissioning Methodology

When performing an intrusive investigation, monitoring wells may not be installed in all of the boreholes drilled. Where monitoring wells are not installed, the boreholes should be filled in after soil samples have been taken. Otherwise, these open boreholes could cause safety issues or act as a direct conduit of surface water to the groundwater.

Even in cases where a monitoring well has been installed in a borehole, it may become necessary to abandon and decommission the groundwater monitoring well. There are a number of reasons why a monitoring well may be abandoned:

1) the monitoring well has been damaged or destroyed due to surface construction or vehicular traffic.
2) the monitoring well has been damaged due to weather conditions (eg: the freeze-thaw cycle of soil has heaved the casing).
3) silt and annulus material has entered the well, plugging the screen and making the collection of representative formation groundwater difficult.

4) the monitoring well is no longer necessary and removing the well will ensure there is no chance of surface water impacting the groundwater (ie: by removing the conduit between the surface and the groundwater).
5) the monitoring well has been damaged due to vandalism.

The primary objectives of the decommissioning procedure for both boreholes and monitoring wells are to eliminate physical hazards and prevent groundwater contamination.

When decommissioning a borehole for Imperial Oil projects, the preferred operating practices are:

- fill the borehole with dry bentonite chips to a depth 1.3 metres below grade, then fill the next 1.0 metres with hydrated bentonite. Finally, fill the remainder of the borehole (to grade) with clean topsoil.
  + the bentonite may be hydrated using tap water.
  + soils removed from the borehole may be hydrocarbon impacted and should not be returned to the borehole. Clean topsoil from a non-impacted portion of the site or purchased from a gardening shop should be used to fill the last 0.3 metres of the borehole.
  + this methodology should ensure that there is no conduit for surface water to shortcut to the groundwater aquifer. It also ensures that bentonite is not exposed at the surface of the borehole, allowing vegetation to quickly re-grow over top of the borehole.
  + if there are provincial regulatory requirements for borehole decommissioning, then the provincial protocols must be used instead of this recommended procedure.

ASTM has defined an number of acceptable practices for the decommissioning of groundwater wells in ASTM D 5299-99 ("Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes and Other Devices for Environmental Activities"). When decommissioning a monitoring well for Imperial Oil projects, the preferred operating practices are:

- overdrilling to remove the casing is a preferred practice for decommissioning of a monitoring well.
  + a large diameter auger is used to drill out the casing. The larger diameter auger is less likely to veer off during the drilling.
  + the hollow-stem auger should be at least two (2) inches in diameter larger than the casing that is being removed.
  + the auger should drill to the full depth of the previous boring. All the debris from the auger interior should be cleaned out.

- the borehole must be filled, once overdrilling to remove the casing has been completed.

  + chipped sodium montmorillonite (ie: bentonite clay) of 3/8 inch diameter (eg: HOLEPLUG® or equivalent) is the recommended backfill material.
  + the borehole should be filled with dry bentonite chips to a depth 1.3 metres below grade, then fill the next 1.0 metres with hydrated bentonite. Finally, fill the remainder of the borehole (to grade) with clean topsoil.
  + an alternative to using dry bentonite chips is to pump grout (a mixture of cement and bentonite) into the borehole, up to the level of the hydrated bentonite plug.
  + the top metre of the bentonite plug will be hydrated using tap water.

- an acceptable practice is to cut off the top of the PVC well casing at ground level and simply fill the casing.
  + the casing must be filled in the same manner as described above, for an overdrilled borehole.

- using rapid setting concrete or filter pack sand to fill an overdrilled well or a well that has been cut off at the surface decommission a groundwater monitoring well <u>is not</u> a preferred practice to decommission a monitoring well.
  + this practice will not result in an acceptable barrier to communication between surface waters and the groundwater. These materials will not swell to completely fill the borehole and may act as a conduit for surface water to shortcut to the groundwater aquifer.
  + concrete has a propensity to shrink as it hardens. This will result in the creation of an annular space between the well casing (or the borehole annulus, if the well casing has been overdrilled out) and the concrete. This annular space can act as a conduit between the surface and the groundwater aquifer.

- removing the casing using a hydraulic lifting device <u>is not</u> a preferred practice.
  + the most typical lifting device would be a backhoe or excavator. Usually, a hole is drilled through the casing to which a chain is attached. The chain is then connected to the hydraulic arm of the backhoe or excavator and the casing is lifted straight up.
  + for a PVC monitoring well that has been properly installed and sealed into the borehole, pulling of the entire casing should not be possible. If attempted, the most likely scenario is that the top length of PVC riser will break off from the monitoring well at the first threaded joint.
  + when pulling on the casing, it could suddenly crack or break. This is a safety issue, which could potentially cause injury. Thus, the pulling of PVC well casings is not recommended on Imperial Oil projects.
  + when removing a potable water well with a steel casing from a site, pulling the casing is an acceptable practice. The probability of the steel casing breaking or separating as it is being pulled from the borehole is very low compared to the risk with a PVC casing.

- some jurisdictions require chlorination of the groundwater contained in the monitoring well, as part of the decommissioning procedure. The preferred practice is to not perform this chlorination procedure, unless provincial regulatory requirements make this step mandatory.

- in the downstream, it is preferred that all monitoring wells installed at a site be properly decommissioned before the site is released for sale to a third party.
  + the Environmental Consultant will be informed by the Imperial Oil Project Manager if and when to decommission the monitoring wells.

3) MONITORING WELL COMPONENTS

3.1) Monitoring Well Schematic

A schematic of a typical monument groundwater monitoring well (with a monument casing installed) is shown in Figure 3.1-1. This schematic will be referred to in discussions throughout the remainder of Section 3.

3.2) Well Casing Materials

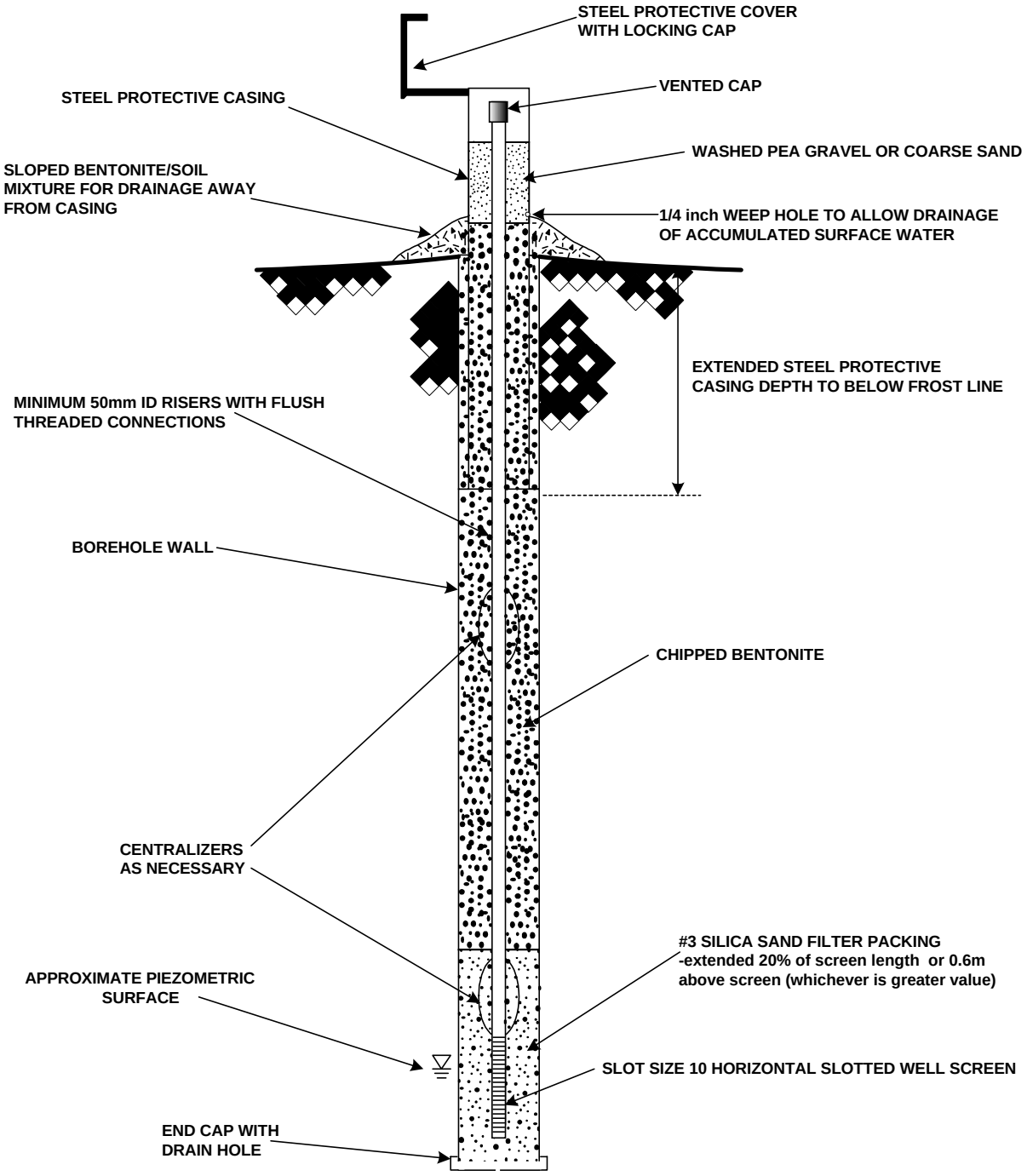
The casing is installed in a monitoring well to provide access from the surface to a sampling location (ie: the well screen) in the subsurface. The casing (and associated seals and grout) prevent collapse of the borehole and interzonal hydraulic communication. The casing permits the well to be used for both piezometric head measurements and to obtain samples to measure the quality of the groundwater formation.

When choosing the well casing materials, it is crucial that these materials do not either sorb or leach contaminants from the groundwater that will later be sampled from the monitoring well that is being installed. This could lead to "false negative" or "false positive" results being reported for the chemical analysis of the groundwater. It is also important that the materials have the strength (tensile, compressive and collapse) that will resist forces exerted on the casing by the surrounding geologic formations and the forces exerted during well installation. Finally the casing material should be durable enough to maintain the structural integrity of the monitoring well for the expected duration of the groundwater monitoring program.

When choosing well casing materials for Imperial Oil projects where hydrocarbon impacts are expected, the preferred operating practices are:

Figure 3.1-1

Typical Monitoring Well Schematic (Monument Casing Depicted)



- casings constructed from polyvinyl chloride (PVC) should be used for all monitoring wells. PVC is a thermoplastic material.
  + fluoropolymer materials (eg: polytetrafluorethylene) are not recommended for use. These materials are an order of magnitude more expensive than PVC and more difficult to handle (ie: they are heavier and more slippery than PVC).
  + metallic materials (eg: steel, galvanized steel or stainless steel) are not recommended for use. These materials are susceptible to corrosion, which can lead to analytical bias for certain parameters in groundwater samples taken from wells constructed with these casing materials.
  + other thermoplastic materials (eg: ABS plastic) are not recommended for use in monitoring wells. Unlike PVC, little is understood about the potential chemical interferences in groundwater samples taken from wells constructed from these materials. However, these materials may be used for the construction of groundwater recovery wells (the primary function of these wells is to remove groundwater from the formation, not sample the groundwater contained in the formation for chemical analysis).
  + under unusual circumstances (eg: acidic groundwaters, tidal zones) alternate materials to PVC may be required for well construction. This should be discussed with the Imperial Oil Project Manager, so that a site-specific plan for monitoring well construction can be devised.

- PVC casings used for all monitoring wells should be Schedule 40.
  + use of PVC casings with other Standard Dimension Ratios (eg: Schedule 80) should be approved by the Imperial Oil Project Manager. Typically, these stronger materials will only be used for deep well installations, where the utilization of higher collapse strength materials is warranted.

- PVC casings used should meet the requirements of ASTM Standard F 480-00.

- PVC casings used for groundwater monitoring wells should be fabricated from PVC plastic resin that is suitable for use with potable water.
  + this PVC resin should meet or exceed the requirements for PVC with a cell classification of 12545C, 14333C or 14333D that are described in ASTM Standard D 1784-99a.

- the PVC casings used should have threaded, flush-joint ends. This will allow lengths of casing to be joined together directly, without the use of a separate coupling.
  + the use of casings with threaded ends that require separate threaded couplings to join lengths of casings is an acceptable alternative to using threaded, flush-joint ends. However, it <u>is not</u> the preferred practice.
  + the use of casings that require solvent welding (ie: the use of glue), heat welding or frictional fitting (eg: bell end casings) to join lengths of casing <u>is prohibited</u> in monitoring well installations on Imperial Oil projects. Heat welding in the field is logistically difficult and the use of glue at casing joints can result in the

contamination of the groundwater contained in the monitoring well with organic solvents. Note that the use of this type of joint is allowed when constructing headers for recovery well installations.

- the threaded, flush-joint ends PVC casings should utilize square profile threads. The coupling should be equipped with an o-ring, which will prevent leakage of water into the riser.
  + the use of casings with tapered threads is not recommended.
  + the o-ring should be fabricated from Viton (most inert) or Buna-N material that will not impact the water sample for the contaminants of concern.
  + the use of PTFE (Teflon) tape on the square profile threads on the flush-joint ends is not recommended.
  + the use of any other tape materials (eg: tape wrapped around the outside of the flush-joint coupling, to give the coupling extra support) is not recommended. The adhesive from this tape is a possible source of contaminants that can enter the monitoring well.

- the preferred practice is to use PVC casings that have not been marked with any foreign material (eg: ink).
  + it is acceptable to use markings only if the manufacturer has performed testing to ensure that this material will not contaminate groundwater samples taken from this well.

- for most monitoring well applications, PVC casing with a nominal inner diameter of two (2) inches should be used.
  + when it is anticipated that the well will be used as a recovery well, well casings of >2 inches diameter can be installed if a large borehole has been drilled to accommodate this larger casing.

3.3) Well Screening and Filter Pack Materials

The well screen is installed in a monitoring well to provide a subsurface point where groundwater can be sampled from the zone of the aquifer that requires monitoring. The well screen is surrounded by a filter pack inside the annulus of the borehole.

When choosing the well screen and filter pack materials, it is crucial that these materials do not either sorb or leach contaminants from the groundwater that will later be sampled from the monitoring well that is being installed. This could lead to "false negative" or "false positive" results being reported for the chemical analysis of the groundwater sampled from the monitoring well.

The well screen is a section of well casing that has a series of slots cut in it. These slots allow groundwater to flow into the well from the adjacent formation. The filter pack is composed of uniform grain size materials that are coarser and have a higher permeability than the natural

formation. This allows groundwater to freely flow into the well from the adjacent formation, while minimizing the entrance of fine-grained sediments into the well.

When choosing well screen and filter pack materials for Imperial Oil projects, the preferred operating practices are:

- well screen constructed of polyvinyl chloride (PVC) should be used for all monitoring wells. The PVC used in the construction of the screen should meet the same requirements for Standard Dimension Ratios, resin specifications, fabrication specifications, coupling requirements and marking specifications that were discussed in Section 3.2 for well casing materials.

- circumferential (ie: horizontally) slotted well screens should be used.
  + the slot size should be small enough to ensure that material from the filter pack and sediments from the formation cannot enter the well casing.
  + when performing the initial intrusive assessment of a site (where there is limited information about the formation in which the monitoring wells are being installed), the preferred practice is that a well screen with a slot size of 10 (ie: the slots are ten one-thousandths of an inch wide) be installed. This slot size will minimize the amount of fine solids entering the well and should be adequate for environmental monitoring wells in most formations.
  + if the first generation of wells installed/developed at a site produce high turbidity groundwater samples (due to the presence of fine solids), low flow sampling techniques (see Section 6.5) should be used to minimize the turbidity of samples collected from these wells. If additional monitoring wells are to be installed at this site, the preferred practice is to use the methodologies discussed in ASTM D5092-90 to optimize the well screen slot size and filter material pack size, in order to minimize the amount of fines entering the well screen from the formation.

- the length of the screen chosen should straddle the piezometric surface of the water table. It is strongly recommended that as part of the Phase I assessment, the Environmental Consultant should determine the approximate depth to local groundwater (and any information that can be obtained about local groundwater fluctuations).
  + standard screen lengths of 10 feet (3 metres) should be used. This will ensure the well will not go dry if there are seasonal water table fluctuations.
  + screen lengths <10 feet (3 metres) may be used as part of a nested set of monitoring wells that are installed in different aquifers.
  + the use of screen lengths >10 feet (3 metres) is discouraged, since this may misrepresent the chemistry of a dissolved contaminant plume by mixing impacted and non-impacted groundwater from different depths within the aquifer.
  + in some cases, a screen length of 10 feet (3 metres) may not be appropriate. The Environmental Consultant must use professional judgement to decide when field conditions make the use of a different screen length preferable. For example, in areas where there are large seasonal fluctuations in the groundwater table, the

installation of well screens longer than 10 feet (3 metres) may be required so that the monitoring well is not dry for large portions of the year.

+ the target is that the screen should be installed so that 2/3 of the screen is below the average water table height at the site and 1/3 of the screen is above the average water table height. Note that this practice should not be followed when the monitoring well is intended to assess a deeper confined aquifer beneath a shallow aquifer.
+ in most cases, the screen will be extended to about 0.3 metres above the base of the borehole. The space between the base of the borehole and bottom of the screen should be filled with filter pack material.
+ the well casing material above the screen should be a solid riser constructed of polyvinyl chloride (PVC) and meet specifications discussed in Section 3.1 for well casing materials. It is recommended that this riser be a minimum of 1.0-1.5 metres (3-5 feet) in length, to ensure that a hydrated bentonite layer can be installed that is thick enough to create a good seal between the surface and the groundwater aquifer.
+ screening the entire length of the borehole (except for the riser section associated with the top bentonite seal in the well) <u>is not</u> a preferred practice.

- an end cap should be used at the bottom of the monitoring well casing.
  + the end cap should be constructed of polyvinyl chloride (PVC) and meet specifications discussed in Section 3.2 for well casing materials.
  + if the well screen installed is of a standard length, then use of a screw-on end cap is recommended.
  + if the screen length must be cut to a non-standard length to accommodate its installation, screw-on end caps cannot be used. In this case, slip-on end caps will need to be installed. It is recommended that stainless steel screws should be used to securely fasten the slip-on end cap to the well screen.
  + it is recommended that a 1/8 inch hole be drilled in the bottom of the end cap. This will allow groundwater contained in the well to drain out of the well, if the groundwater level drops below the bottom of the well. This will ensure that time will not be wasted purging water that has been trapped in the well, only to discover that the well is dry after this stagnant water has been purged.

- the filter pack should consist of an inert granular material with a grain size and gradation selected to stabilize the hydrologic unit adjacent to the screen and permit only the finest soil grains to enter the screen during well development. When choosing the filter pack material, the requirements of Section 6.3.1 of ASTM Standard D 5092 ("Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers") should be considered.
  + when performing the initial intrusive assessment of a site (where there is limited information about the formation in which the monitoring wells are being installed), the preferred practice is that a fine graded silica sand with a uniformity coefficient of 1.1-1.7 and an effective size of 1.5-3.0 mm (eg: K&E Well Pack #3 Silica Sand or K&E Well Pack #2 Silica Sand) be used as the filter pack material.

+ both K&E Well Pack #3 Sand and Well Pack #2 Sand are coarser than what is recommended by the ASTM Standard (eg: ASTM recommends that a 60 Slot Screen be used with Well Pack # 3 Sand, while this POP recommends a 10 Slot Screen be used). However, these two sand materials are the most readily available with drillers (a special order is not required). They settle much quicker than finer filter pack materials (making installation of the filter pack quicker and easier than with a finer material). Experience has shown these materials to be suitable in all but the finest grained formations. As such, use of these materials has become the *de facto* industry standard among drillers and Environmental Consultants. Thus, the choice of this material compromises between ease of use and what is recommended by the ASTM Standard.
+ if the first generation of wells installed/developed at a site produce high turbidity groundwater samples (due to the presence of fine solids), low flow sampling techniques (see Section 6.5) should be used to minimize the turbidity of samples collected from these wells. If additional monitoring wells are to be installed at this site, the preferred practice is to use the methodologies discussed in ASTM D5092-90. This will allow optimization of the filter pack material size and well screen slot size for that particular formation, in order to minimize the amount of fines entering the well screen from the formation.
+ in extremely fine-grained formations where there have been historical problems with monitoring well development, the Environmental Consultant may decide to use a finer grained filter pack material, based upon their professional judgement.

- for a typical 2 inch monitoring well casing, the filter pack thickness should be a minimum of 2 inches and a maximum of 8 inches between the formation and the screen.
  + the sand pack should extend 20% of the screen length or 2 feet (whichever value is the greatest) above the slotted well screen, unless conditions warrant less.
  + if installing larger wells (eg: 4 inch diameter recovery wells), the filter pack thickness must be varied accordingly.

- the installation of a polyester filter sock over the monitoring well screen to reduce the amount of fine solids entering the well screen <u>is a controversial subject</u>. Imperial Oil consulted two experts in the area (Dave Rudolph of the University of Waterloo and Jeff Johnston, formerly with the US EPA) to provide guidance in this area. Advantages of filter socks include:
  + the filter sock will help keep fine-grained soil particles from entering the well casing. Soil particles have been known to cause false positive results when analyzing groundwater samples for organic parameters that require a full bottle solvent extraction (eg: TPH and PAH's).
  + the polyester filter sock material is inert. Contrary to popular mythology, the adsorption of hydrocarbons by this material is negligible.
  + the average filtration opening size of most filter sock is 100 -150 µm. The filter sock will have no effect on measuring hydraulic conductivity in fine-grained formations.

- filter socks also have several disadvantages:
  + the filter sock may reduce the measured hydraulic conductivity (especially when performing slug tests) in coarse-grained formations.
  + droplets of free product can become physically entrapped (this is not the same as being adsorbed) by the filter sock mesh. This is prevalent when dealing with highly weathered hydrocarbon products that have a high viscosity. Leaching of dissolved hydrocarbon contaminants from the entrapped free product can then bias groundwater analytical results from the well, compared to the actual water quality of the aquifer.
  + while filter socks can reduce the amount of solids entering the well screen, proper development of the well is a much more effective method of ensuring that the amount of solids entering the wells screen is minimized.
  + for wells installed in very fine-grained formations, the use of low flow sampling techniques is more effective (and thus, the preferred technique) than using filter socks to ensure that the amount of solids obtained in groundwater samples is minimized.

- the use of filter socks is not a preferred practice on Imperial Oil projects.
  + filter socks should only be used when fine particulates are adversely affecting analytical results and all other methods of reducing these fines in the groundwater sample (eg: optimizing the sand filter pack/well screen slot size combination, or trying alternate well development methods) have failed and the regulator will not allow the use of low flow sampling methods to reduce the amount of fines in the groundwater samples collected.

3.4) Well Annulus Packing Materials

The well annulus packing is a low permeability material placed in the annulus between the well casing or riser pipe and the borehole wall to maintain alignment of the casing and riser. It also prevents communication between surface water and groundwater and/or between two different aquifers, using the annular space between the well casing and the borehole as a conduit for this communication. There will be cases where the well annulus packing instructions given in this section may not be appropriate (eg: at sites where the water table is very close to the surface). In these cases, the Environmental Consultant must use professional judgement to decide when field conditions dictate that alternate annulus packing methods should be used.

When choosing well annulus packing material for Imperial Oil projects, the preferred operating practices are:

- borehole cuttings should not to be placed back in the well annulus.
  + without analytical data from the laboratory, it is impossible to ensure that contaminated cuttings have been properly segregated from clean cuttings.

+ borehole cuttings are to be handled following Provincial Regulations or Guidelines. For cases where these regulations or guidelines do not address the disposition of borehole cuttings, the industry standard for that jurisdiction should be applied.

- dry chipped sodium montmorillonite (bentonite clay) of 3/8 inch diameter should be used as a sealant from the top of the sand filter pack surrounding the well screen to a depth of 1 metre (3 feet) below grade.
  + recommended primary annulus material is HOLEPLUG® or equivalent.
  + providing alignment for the well casing is the major function for the annulus packing material in this zone of the annulus.
  + the bentonite should be added carefully to the annulus, so that bridging (and leaving a void space in the annulus) is avoided. Periodic sounding of the annular space with a weighted tape measure is recommended as a method to ensure that bridging of the bentonite is not occurring in this space.
  + the use of silica sand as a replacement for bentonite is not a preferred practice. This material has a much higher hydraulic conductivity than bentonite and can act as a conduit between the surface and the groundwater aquifer. In addition, sand will not prevent short circuiting between different hydrostratigraphic units, when nested wells are being installed.

- the last 1 metre (3 feet) of the borehole should be sealed with hydrated bentonite clay chips.
  + the recommended material is HOLEPLUG® or equivalent.
  + potable tap water can be used to hydrate the bentonite.
  + this section of bentonite acts as a seal, to prevent surface water from entering the monitoring well annulus.
  + in high traffic areas, the use of concrete (instead of bentonite) to finish filling the annulus to grade is not recommended. Concrete can shrink when it hardens, leaving a conduit between the surface and the groundwater aquifer.

3.5) Well Protection Materials

Well protection refers specifically to installations made at the ground surface to deter unauthorized entry to the monitoring well, to protect the monitoring well from damage and to prevent surface water from entering the annulus. There are two monitoring well configurations, flush mount and monument casing, that are recommended for use on Imperial Oil projects.

When installing well protection on monitoring wells for Imperial Oil projects, the preferred operating practices are:

- leaving an unprotected PVC riser sticking above the ground surface is not a preferred practice on Imperial Oil projects.

  + this is only allowed if the site is completely fenced and the gate is locked; there is no traffic in the area of the well that could damage the riser; and the consultant has obtained permission of the Imperial Oil Project Manager to install monitoring wells at this site in this manner. If any of these pre-conditions is missing, this practice is not allowed.

- flush mount monitoring wells should be used in areas where an above ground casing could be damaged by traffic or in areas where the low profile of the flush-mount unit is preferable due to aesthetic reasons.
  + a lockable cap should be installed atop the riser, inside the flush mount. This will discourage sabotage or vandalism of the monitoring well.
  + when installed in the street or any other area with high vehicular traffic, the flush mounting should meet AASHTO Standard M306-89.

- above-ground risers, enclosed inside monument casings are allowed in areas where surface traffic will not interfere or damage any above-ground structure.
  + these wells will be easier to locate than flush mounted units. This is advantageous if groundwater sampling in the winter months is envisioned.

- above-ground risers <u>should be</u> protected by steel monument casings that have been sealed into the ground with hydrated bentonite.
  + the steel monument casing should have a lockable cap.
  + the PVC riser should be capped inside the monument casing. However, if the monument casing is locked, the cap inside the monument casing does not require a lock.
  + install a sloped bentonite/soil mixture around the base of the steel monument casing to provide surface water drainage.
  + ensure a 1/4 inch weep hole has been installed in the monument casing, to ensure that accumulated surface water can drain away from the riser.
  + for sites that are completed fenced and have a locked gate, the installation of PVC monument casings is acceptable. Note that these PVC monument casings must also be lockable.
  + monument casings (both steel and PVC) should not be cemented into the ground. Concrete can shrink and/or crack, causing a conduit between the surface and the groundwater aquifer. In addition, concrete plugs can heave with the frost, potentially damaging the well casing.

- in the upstream, specific procedures have been developed for the protection and marking of monitoring wells.
  + monitoring wells are typically installed with monument casings and are located in open areas (such as fields), where the public has access.
  + monitoring wells need to be protected from damages occurring during interactions with livestock (who destroy wells by using them as a scratching post), farm machinery (collision damage) and recreational vehicles (collision damage).

+ monitoring wells also need to be marked to the avoid injury of personnel using farm machinery and recreational vehicles. This marking must be effective in all seasons (especially in winter, to avoid problems with snowmobiles).
+ the latest version of the protection and marking procedures has been provided to all Environmental Consultants working in the upstream. Any changes to these procedures will be communicated to the upstream Environmental Consultants by Imperial Oil Resources personnel.

4) MONITORING WELL INSTALLATION

Monitoring wells are installed to provide a means to measure the elevation/movement of formation water and remove formation water for chemical analyses. When installing groundwater monitoring wells for Imperial Oil projects, the preferred operating practices are:

- monitoring wells should be installed in a proper borehole.
  + the installation of monitoring wells in test pits is strongly discouraged. Groundwater samples obtained from monitoring wells installed in this manner are likely not representative of groundwater found in the formation. This method of monitoring well installation should only be used as a last resort, when there is no other alternative installation method available.
  + installation of the monitoring well in a test pit makes the provision of a filter pack impossible. This can result in high levels of sediments entering the well screen when groundwater samples are taken. As discussed in Section 3.3, this can result in false positive results for TPH and PAH's in groundwater samples.
  + groundwater recovery wells, which are not used to measure the quality of formation groundwater, may be installed in test pits.

- one monitoring well should be installed per borehole.
  + when installing nested wells, one borehole will need to be drilled for each borehole that is being installed. The installation of multiple monitoring wells in a single large borehole is not a preferred practice.

- keep monitoring well materials (eg: PVC risers and screens) in the original manufacturers plastic sleeves as long as possible during installation.
  + this will reduce the incidence of well material contamination prior to completion of the monitoring well.

- hand protection should be worn during installation of the monitoring well.
  + latex, nitrile or cotton gloves are acceptable to use while handling monitoring well materials.
  + if hand protection becomes contaminated with petroleum hydrocarbons during the installation of the monitoring well, the gloves should be removed and discarded.

At no time during monitoring well installation should the monitoring well materials come into contact with petroleum hydrocarbon contamination.

- before installing the well, 0.3 metres of sand filter pack should be added to the borehole.
  + this will act as a spacer between the well screen and the bottom of the borehole.
  + this will reduce the amount of sediments entering the well screen and make development of the well easier.
  + this is especially important in fine-grained soil formations.

- the monitoring well screen and riser should be placed in the centre of the borehole.
  + centralizers should be used, if in the professional judgement of the Environmental Consultant, they are needed to ensure the pipe remains in the centre of the borehole during addition of the annulus material.

- the sand filter pack should be added once the monitoring well screen and riser have been located in the centre of the borehole.
  + the sand can be added using gravity free fall. The sand should be added slowly to minimize bridging or void formation within the filter pack. Periodic sounding of the annular space with a weighted tape measure is recommended as a method to ensure that bridging of the sand is not occurring in this space.
  + a tremie pipe (a 1.5 inch diameter rigid tube) should be used to introduce the filter pack to the well annulus, if the professional judgement of the Environmental Consultant indicates that it is needed. The tremie pipe is placed at the bottom of the borehole and the filter pack is added through a funnel to the pipe; this minimizes bridging or void formation within the filter pack. The tremie pipe is raised periodically to allow the filter pack material to evenly fill the annular space.
  + the sand pack should extend 20% of the screen length or 2 feet (whichever value is the greatest) above the slotted well screen, unless conditions warrant less (in the professional judgement of the Environmental Consultant).

- dry bentonite chips (HOLEPLUG®) are then added following the same procedure as the filter pack.
  + These should be added to the annular space from the top of the sand pack to a depth of 1 metre below grade.
  + addition of a bentonite slurry <u>is not</u> recommended. The clean water associated with this slurry can cause chemical alteration of the adjacent formation water and pose long-term questions about the representativeness of water samples collected from the well.

- hydrated bentonite is then used to fill the annulus to grade, using gravity fall.
  + approximately 15 cm of dry bentonite chips should be added. This is then hydrated using potable water. This process is repeated several times, until the hydrated bentonite seal reaches grade.

- temporary casings or augers should be removed in short increments, as the annulus packing material is added, to prevent borehole collapse or material sloughed from the borehole wall mixing with the filter pack or bentonite seal.
  + for unconsolidated materials, the temporary casing or hollow stem auger should be withdrawn until the lower most point of the auger or casing is at least 30 cm (1 foot) but not more than 60 cm (2 feet) above the annulus material being filled.
  + for consolidated materials, the temporary casing or hollow stem auger should be withdrawn until the lower most point of the auger or casing is at least 0.5 metres (2 feet) but not more than 1.5 metres (5 feet) above the annulus material being filled.
  + after each increment, the sand filter pack or bentonite should be checked to ensure they have not been displaced during the removal of the temporary casing or hollow stem auger.

- monitoring wells should be surveyed into a recognized survey datum (if one is readily available) or an arbitrary site-specific datum.
  + when an arbitrary site-specific datum is used, its location must be described in detail (eg: top the southernmost nut at the base of the fire hydrant at northeast corner of the site).
  + contour lines from a topographical map should not be used as a site-specific datum.

5) MONITORING WELL DEVELOPMENT

A groundwater monitoring well must be developed after installation and prior to the first sampling event. The development serves to remove the finer grained material from the well screen and filter pack that may otherwise interfere with water quality analyses. Development also restores the groundwater properties disturbed during the drilling process, improves the hydraulic characteristics of the filter pack and improves the hydraulic communication between the well and the groundwater formation adjacent to the well screen. There are three primary factors that influence the development of a monitoring well:

1) the type of geologic material.
2) the design and completion of the well.
3) the type of drilling technology employed.

If recommended procedures cannot be followed due to site-specific conditions, the following references should be checked to validate the proper procedures:

"Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells", US EPA 160014-891034, March 1991, page 115.

"Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers", ASTM D5092, Section 9.

"Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers", ASTM D 5521-94.

When developing groundwater monitoring wells for Imperial Oil projects, the preferred operating practices are:

- during the development process, the initial water removal should be slow and gentle. Water should be removed with increasing vigor as the well is developed.
  + well development requires a sufficient application of energy to disturb the filter pack, freeing the fine particles and allowing them to be drawn into the well. The coarser fractions then settle and stabilize the well screen.

- the industry standard methodology for developing monitoring wells is the removal of three well volumes of groundwater (or pumping the well to dryness) three times over a 1-2 day period.
  + the groundwater in the monitoring well should be allowed to reach water level equilibrium before subsequent purging. Note that this may not be practical in some fine-grained formations, where the recovery time for the groundwater in the well to reach equilibrium can be days.
  + if monitoring well development is restricted by time (remote site location or tight geologic formation such as clay), the monitoring well should be pumped to dryness. The removal of accumulated water three times in one day is recommended. Sampling of the well can occur after this amount of development has occurred.
  + water generated by well development activities should be disposed of in a manner that is consistent with the Provincial Regulations or Guidelines. Where Provincial Regulations or Guidelines are silent on this manner, the water should be disposed of in a manner that is consistent with the industry standards in that province.

- the formula used to calculate the purge volume of a monitoring well is:

$$V_p = 3 \times (\pi/4) \times (h_b - h_s) \times d_w^2/1000$$

where: V_p = minimum developing volume (L)
h_b = depth to base of well (m)
h_s = depth to static water level in well (m)
d_w = diameter of well casing (mm)

The factor of 3 is included as a rule of thumb to ensure that all of the groundwater contained in the pores of the sand pack has been removed and it can be ensured that formation water is being sampled from the well screen [US EPA, 1991b].

- the development of monitoring wells by using a surge block to move groundwater into and out of the formation is another acceptable method of developing a monitoring well. This should be accompanied by the removal of groundwater from the monitoring well once use of the surge block has been completed.
  + use of a surge block is very useful in fine-grained soil formations (it is effective way to quickly develop a well and minimize the amount of fine solids infiltrating the well screen).
  + surging methodologies described in ASTM D 5521-94 ("Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers") should be used. If properly performed, the use of surge blocks is not "dangerous" and will not damage PVC wells.

- there are drawbacks to the use of surge blocks.
  + manual surging is not practical, since field personnel will become exhausted long before development is complete.
  + not all drill rigs have the capability to move the surge block up and down at progressively increasing speeds (which is required when developing the well). In some regions, well rigs that have this equipment are not available.
  + the surge block is not dedicated and must be thoroughly cleaned between use at different wells, to avoid problems with cross-contamination.
  + due to these issues, the use of surge blocks is recommended in cases where the rapid development of wells with extremely low turbidity is required.

- using either of the two approaches discussed above, the well development process should continue until the groundwater being generated from the monitoring well is relatively free of turbidity.

- monitoring well development is performed after the initial installation of the well. Subsequent sampling events still require proper purging of the well before sampling.

- deviations to the recommended monitoring well development process should be communicated to the Imperial Oil Project Manager in the field installation report.

6) MONITORING WELL SAMPLING

6.1) Field Vapour Monitoring of Groundwater Monitoring Wells

Field vapour measurements may be taken from inside the casing of a monitoring well, to indicate the potential for contamination of the groundwater by volatile organic compounds. This data is only semi-quantitative and should not be used for risk assessment or compliance reporting purposes. The field vapour analysis is a measurement of the volatile hydrocarbons in the stagnant air contained in the well casing (which is not air-tight). Thus, the result does not truly represent the concentration of volatile hydrocarbons in the headspace above the air/groundwater interface.

When conducting groundwater monitoring well field vapour analysis for Imperial Oil projects, the preferred operating practices are:

- a catalytic explosimeter, with methane exclusion capability, is the preferred instrument to use for field screening.
  + this type of OVM utilizes a catalytic combustion sensor to measure %LEL and/or ppmv of combustible hydrocarbon in the headspace above the air/groundwater interface within the well casing.
  + the OVM should have methane exclusion capability and be operated in this mode.
  + the Gastech 1238ME or equivalent OVM should be used.

- photoionization (PID), flame ionization (FID), colourmetric (ie: Draeger Tubes) and amino assay (ie: Petro Flag) methodologies <u>are not</u> acceptable on Imperial Oil sites for the field monitoring of petroleum hydrocarbons.

- the OVM should be calibrated prior to use in the field following procedures detailed in section 2.3 of this document.

- the vapour concentration is measured by placing the OVM nozzle inside the monitoring well casing no less than 6 inches below the top of pipe (TOP) and no more than 12 inches below TOP.
  + the OVM reading should be taken immediately after the cap has been removed from the top of the monitoring well casing, in order to minimize the loss of volatiles from within the casing (which will result in a negative bias for the result). The <u>peak</u> OVM reading should be recorded.

6.2) <u>Groundwater Level and Free Product Thickness Measurement</u>

Water levels are taken during a sampling event to determine the height of the water table (relative to the top of the monitoring well) prior to sampling. The measurement is converted to a groundwater elevation and compared with data from other wells in the monitoring program. A potentiometric surface map can be constructed using this data. Groundwater flow direction and hydraulic gradient can be estimated using the potentiometric surface map. Caution should be used when preparing the potentiometric surface to ensure that only those wells which are screened in the same hydraulic zone be included.

It is also possible to measure the thickness of any free product encountered in the well, during a sampling event.

When measuring groundwater levels and free product thickness for Imperial Oil projects, the preferred operating practices are:

- groundwater and free product level monitoring should be performed every time that a monitoring well is sampled.

- if pressure has built up inside the monitoring well, allow the monitoring well to equilibrate to atmospheric pressure before proceeding with any measurements.
  + check the vent hole in the well plug, to ensure it is not blocked.

- the groundwater level should be measured from the Top Of Pipe (TOP) using an industry accepted water level device (eg: Solinst Model 101 or equivalent)
  + inert tape, traceable to national standards, should be used to measure depth to water table.
  + only the probe end of the apparatus should come into contact with the water. The device is not intended to measure the bottom of the monitoring well.
  + use of an inert measuring tape, smeared with water-indicating paste, is an acceptable (but not a preferred) measurement method.

- the top of the PVC casing (TOP) should be notched to indicate the exact point of measurement.
  + to ensure reproducible data, all subsequent readings should be taken from the same notched point in the PVC casing.
  + this should not be marked with ink or felt tipped marker.

- if free product is present in the monitoring well, an industry accepted interface meter (eg: Solinst Model 122 or equivalent) should be used.
  + monitoring well measurements should include depth to free product, depth to water table and the thickness of free product layer.
  + use of an inert measuring tape with two phase detection paste is an acceptable (but not preferred) measurement method.
  + this measurement should be performed before the product is removed or the monitoring well is purged.
  + the use of a bailer to measure the level of free product in the monitoring well <u>is not</u> an acceptable practice.

- measurement of the groundwater level should be conducted prior to purging of the monitoring well.
  + monitoring well water levels rarely return to the original water level after purging of the monitoring well, so the measurement after purging would not represent the true equilibrated water table height.

- hand protection should be worn during use of the groundwater level measurement equipment.
  + latex gloves are acceptable to use while handling measurement equipment.
  + minimize the contact between the latex gloves and the measurement probe.
  + immediately dispose of any hydrocarbon contaminated gloves.

- the groundwater level measurement equipment should be cleaned after each measurement to prevent cross-contamination between monitoring wells.
  + the manufacturers recommended cleaning method for the probe should be used.
  + discussions with Solinst (manufacturer of the Model 101 water level device) indicates if there is no presence of free product, rinse the probe with distilled water and dry with a clean disposable paper towel.
  + if free product is present (even just a sheen), Solinst states that the probe should be rinsed with a compatible solvent (methanol is considered a compatible solvent), dry probe and then follow with three rinse/dry cycles of distilled water. Methanol should be collected in a separate container and disposed of following provincial regulations.

- the interface meter used to measure free product levels should also be cleaned after each measurement to prevent cross-contamination between monitoring wells.
  + the manufacturers recommended cleaning method for the probe should be used.
  + discussions were held with Solinst, regarding cleaning procedures for their Model 122 interface meter with a 5/8 inch probe equipped with a carbonate window. If there is no presence of free product, Solinst recommends to rinse the probe with distilled water and dry with a clean disposable paper towel.
  + if free product is present (even just a sheen), Solinst recommends to rinse the probe with methanol, dry the probe and then follow with three rinse/dry cycles of distilled water. Methanol should be collected in a separate container and disposed of following provincial regulations.

- a water measurement log should be kept. At a minimum, it should contain the following information:
  + the date and time the water level was measured.
  + who performed the measurements.
  + method or equipment used for measuring the depth to water.
  + decontamination method used on these instruments.
  + the depth to water in each well, and relative elevation to a reference point of known elevation (either geodetic datum or an arbitrarily assigned benchmark).
  + reference point from where the measurement was taken (ie: ground surface, TOP).
  + presence and estimated thickness of free product.
  + total depth of the well from historical or actual measurement.
  + record all units of measurement.

- as a general rule, groundwater samples for chemical analysis should not be taken from monitoring wells that contain free product.
  + it is assumed that groundwater from these sampling locations would fail any generic groundwater criteria for hydrocarbon parameters.
  + should it be necessary to obtain a groundwater sample from a well that contains free product, specialized sampling techniques will need to be used.

6.3) Standard Monitoring Well Purging

The objective of monitoring well purging is to remove standing/stagnant water that has been in contact with the well casing and atmosphere prior to sampling. During purging of the monitoring well, water that is geochemically representative of the formation water enters the well through the screen and is available for sampling. After purging and prior to sampling, the groundwater should be allowed to recover to 90% of static levels (whenever this is practical). If the well is sampled before static levels are reached (ie: the groundwater is stressed), inaccuracies in determining the actual concentrations of chemical parameters in the formation water may occur.

When purging a monitoring well prior to groundwater sampling for Imperial Oil projects, the preferred operating practices are:

- dedicated sampling equipment should be used to purge the groundwater prior to groundwater sampling.
  - + use of non-dedicated pumps (eg: submersible pumps) is not recommended, due to the cleaning/decontamination requirements as this equipment is moved from one monitoring well to another.

- the inertial pump (eg: Waterra) is the preferred sampling and purging device. The Waterra inertial pump consists of a Delrin™ foot valve attached to the end of 5/8 inch high density polyethylene (HDPE) tubing.
  - + the Waterra Inertial pump is acceptable for monitoring well depths up to 175 feet below grade, producing flow rates ranging from 1 - 2 gpm for a maximum 4 inch diameter well.
  - + the foot valve is moved up and down in the water column, forcing the water to rise in the tubing.
  - + the use of low density polyethylene (LDPE) tubing is not a preferred practice. While easier to work with than HDPE (due to its higher flexibility), LDPE has a much higher propensity to adsorb and leach organic contaminants than HDPE.

- a dedicated or disposable bailer is an acceptable sampling and purging device.
  - + the bailer consists of a long plexiglass tube ,with a PVC check ball in the lower end to allow water to enter (but not exit) the bailer.
  - + a regular sample release or low flow sample release device should be used to release the sample from the bottom of the bailer.
  - + the use of bailers is often advantageous in situations where groundwater contained in the monitoring well is quite turbid. Bailers tend to disturb less sediment in the bottom of the well during the purging activity (when compared to the performance of an inertial pump).

- purging of monitoring wells can be conducted by using one of three acceptable methods:
  - + by removing three well volumes of groundwater from the well.

  + by pumping the well until the pH/temperature/conductivity of the water being removed has stabilized (indicative that formation groundwater is entering the well). Environmental; Consultants will use their best professional judgement to determine when these parameters have stabilized and formation water is entering the monitoring well.
  + by pumping the well to dryness one time.

- the water generated by monitoring well purging should be disposed of in a manner that is consistent with the Provincial Regulations or Guidelines. Where Provincial Regulations or Guidelines are silent on this manner, the water should be disposed of in a manner that is consistent with the industry standards in that province.

- the formula used to calculate the volume of a monitoring well is as follows:

$$V_p = 3 \times (\pi/4) \times (h_b - h_s) \times d_w^2/1000$$

  where: V_p = minimum developing volume (L)
  h_b = depth to base of well (m)
  h_s = depth to static water level in well (m)
  d_w = diameter of well casing (mm)

  The factor of 3 is included as a rule of thumb to ensure that all of the groundwater contained in the pores of the sand pack has been removed and it can be ensured that formation water is being sampled from the well [US EPA, 1991b].

- a field purging log should be kept. At a minimum, it should contain the following information:
  + the date and time the purging was performed.
  + who performed the purging.
  + the type of equipment used to purge the well.
  + the calculated purge volume for the well.
  + the total volume of water removed (indicate if the well was purged to dryness).
  + all measurements taken during purging (water levels, organic vapours).
  + appearance of the water before and after purging.
  + record all units of measurement.

6.4) Standard Sampling Procedures

Groundwater monitoring wells are one of the more important tools for delineating contamination plumes at operating and non-operating sites. They provide early warning of groundwater contamination at existing operating sites, baseline information of groundwater quality at all sites and demonstrate efficacy in groundwater remediation programs. The goal in sampling groundwater monitoring wells is to obtain samples that are truly representative of the aquifer or groundwater in question.

When performing standard sampling of groundwater for Imperial Oil projects, the preferred operating practices are:

- follow all provincial guidelines or regulations, which are required for the specific site being sampled.
  + Imperial Oil preferred operating practices are to be followed only in absence of provincial guidelines/regulations or where specific details are not provided.

- the monitoring well should be allowed to reach 90% of static water level equilibrium before sampling, whenever this is practical.
  + low recovery wells (eg: clay formations) should be sampled at the end of the day, whatever percentage of the static water level equilibrium has been reached.
  + the exception to this practice is when the field technician is returning to the site the next day. In this case, sampling of the monitoring well the next morning is also acceptable (this will give the well more time to recover), even for volatile organic parameters.

- use the sampling devices as described in section 6.2 of this document.
  + the Waterra Inertial pump is the preferred sampling method. The Waterra pump and tubing should be dedicated and left in the well between sampling events.
  + dedicated or disposable bailers are acceptable, but are not the preferred sampling method, unless free product is present.

- the groundwater sample should be taken from the centre of the saturated zone within the monitoring well screen interval.
  + this will ensure that the groundwater sample will be representative of the entire screened water column.

- all groundwater sample bottles are to be filled to zero headspace.
  + sample bottles being submitted for gravimetric oil/grease analysis are the exception. Due to the analytical requirement of adding an extraction solvent to the sample bottle, the bottles should be filled to approximately 80% of their total volume with groundwater.

- aspiration of the groundwater sample should be kept to a minimum when sampling for volatiles.
  + a VOC sampling tube for the Waterra should be used when sampling volatiles. The tube is an eight foot length of 1/4 inch Teflon tubing inserted into the larger 5/8 inch Waterra tubing.
  + the VOC sampling tube is placed in the 40 ml VOC vial while the remaining water is collected in a waste container.
  + the split sampling procedure described here prevents the severe agitation of the sample during filling of the VOC bottles, minimizing any loss of volatiles from the sampling process.

- samples being submitted for total metals analysis should not be field filtered. The sample should be introduced directly into the sample bottle which already has the proper preservative added.

- samples being submitted for dissolved metals analysis require field filtration using a 0.45 μm disposable in-line filter, prior to introduction into the sample bottle, which already has the proper preservative added.
  + laboratory filtering of the samples is not an acceptable practice. If filtration is required, it must be performed in the field.
  + if (and only if) sufficient groundwater is available, conditioning the 0.45 μm disposable in-line filter with 500 ml of groundwater before taking the sample is a preferred practice.
  + unless specified otherwise by the provincial regulations, the Imperial Oil preferred practice is to sample for dissolved metals (rather than total metals).

- the samples should be placed in an ice-chilled cooler immediately after sampling and kept at <10°C until delivery to the laboratory.
  + collecting all the samples during the day and placing them all in a cooler at the end of the day is not an acceptable practice.

- the analytical chain of custody form must be completed following groundwater sampling.
  + all samples including the QA/QC samples must be recorded on the chain of custody sheet.
  + sampling date and time along with the name of the sampler must also be recorded on the chain of custody sheet.
  + the chain of custody sheet must be signed and dated upon release of the coolers to the shipping company or the laboratory if the samples are delivered directly to the lab.

- a groundwater sampling log should be kept. At a minimum, it should contain the following information:
  + site name. In the downstream, this is the street address and town. In the upstream, this will be the legal description of the property.
  + sampling team members.
  + physical condition of wells.
  + well identifications.
  + field measurement data (eg: pH, dissolved oxygen, conductivity), if collected.
  + well vapour measurements.
  + QA/QC data for field measurement instrument (if used).
  + sampling equipment used to take samples.
  + decontamination and QA/QC checks for non-dedicated sampling equipment.
  + any deviations from sampling and analysis program.

  + analytes for which samples are being collected.
  + general appearance of sample (eg: turbidity, colour).
  + method of filtration and filter specifications.
  + note any problems or unusual events during sampling.
  + date and approximate time sample was taken.
  + method and time of sample shipment.
  + type and number of shipping containers.
  + field QA sample identifications.

- the collection of groundwater samples from water seeping into excavations or test pits and submitting these samples for laboratory analysis is not a preferred practice.
  + these samples are not representative of the quality of the formation water.
  + there is a high potential that these samples could be contaminated by soil from upper levels of the excavation/test pit falling into this water, or from contamination adhering to the excavator bucket itself.

- sampling of groundwater from a monitoring well containing free product is not a preferred practice.
  + this can be done using special techniques, with reasonable certainty, if absolutely required.
  + as a general rule, it will be assumed where free product is present in a monitoring well, that the groundwater in this area of the site will not meet generic criteria.

6.5) Non-Standard Purging and Sampling Procedures

In certain cases, non-standard methods of groundwater sampling (such as "low flow purging and sampling" or "no-purge sampling") are sometimes considered. For example, the solids associated with highly turbid samples can result in false positive results for dissolved PAH or extractable hydrocarbon concentrations in the groundwater sample. To minimize the potential for this positive bias, the sampling method chosen should minimize the turbidity of the sample collected. Note that sediment cannot be filtered out of samples that are being sent for organics analysis.

Before using non-standard purging and sampling methodologies at a site, the Environmental Consultant must discuss the use of these methods with the Imperial Oil Project Manager. There is no point in using these non-standard methodologies if regulatory buy-in has not been obtained.

When performing non-standard sampling of groundwater for Imperial Oil projects, the preferred operating practices are:

- follow all provincial guidelines or regulations, which are required for the specific site being sampled.
  + Imperial Oil preferred operating practices are to be followed only in absence of provincial guidelines/regulations or where specific details are not provided.

  + note that in many jurisdictions, the use of "low-flow" or "no-purge" sampling methodologies may not be allowed by the regulator.

- "no-purge" groundwater sampling may be considered for situations where high turbidity samples may cause positive bias in the analytical results.
  + the typical procedure for "no-purge" sampling involves slowly lowering a dedicated or disposable bailer into the groundwater, allowing the bailer to fill and then slowly retracting the bailer.
  + "no-purge" sampling has been studied for sites impacted by gasoline components only. If the contamination is not limited to gasoline or if the geology consists of relatively low-permeability formations, this procedure should not be used.
  + this is not a recommended practice for sampling groundwater under conditions where the groundwater already has low turbidity.

- "low-flow purging and sampling" may be considered in critical situations, where the positive biases caused by high turbidity samples may have a large regulatory compliance and/or financial impact on the corporation.
  + "low-flow purging and sampling" was developed for situations where high turbidity groundwater is produced by standard purging and sampling techniques. The high turbidity in the groundwater samples may cause positive bias in the analytical results.
  + "low-flow purging and sampling" involves a minimum drawdown of the well during both purging and sampling activities. The pump intake should be placed in the middle of the water column within the well. Continuous monitoring of parameters such as dissolved oxygen and redox potential are required, to ensure that formation water is actually being sampled.
  + "low-flow purging and sampling" requires the use of dedicated bladder pumps, which is not generally cost effective. Sharing of bladder pumps between groundwater monitoring wells is not a preferred practice, since this is a potential source of cross-contamination between different monitoring wells.
  + this is not a recommended practice for sampling groundwater under conditions where the groundwater already has low turbidity.

- samples being submitted for total metals analysis do not require field filtration. The sample should be introduced directly into the sample bottle which already has the proper preservative added.

- samples being submitted for dissolved metals analysis require field filtration using a 0.45 μm disposable in-line filter, prior to introduction into the sample bottle, which already has the proper preservative added.
  + unless specified otherwise by the provincial regulations, the Imperial Oil preferred practice is to sample for dissolved metals (rather than total metals).

- the samples should be placed in a cooler and kept at <10°C immediately after sampling.

  + collecting all the samples during the day and placing them all in a cooler at the end of the day is not an acceptable practice.

- the analytical chain of custody form must be completed following groundwater sampling.
  + all samples including the QA/QC samples must be recorded on the chain of custody sheet.
  + sampling date and time along with the name of the sampler must also be recorded on the chain of custody sheet.
  + the chain of custody sheet must be signed and dated upon release of the coolers to the shipping company or the laboratory if the samples are delivered directly to the lab.

- a groundwater sampling log should be kept. At a minimum, it should contain the same information discussed for a standard sampling log (see Section 6.4).

6.6) Sample Bottles & Preservation

The preservation of samples is a measure designed to stop or slow the ongoing effects of chemical and biological change once a sample has been collected. Since sample analysis is very specific, the preservation techniques required to ensure sample integrity are also specific.

Imperial Oil has a contract with an analytical laboratory. As part of the contract, sample bottles with appropriate preservatives are to be provided to the Environmental Consultant conducting the sampling program.

When ordering sample bottles for Imperial Oil projects, the preferred operating practices are:

- prior to the sampling event, a bottle order should be sent to the contract laboratory specifying the parameters and number of bottles required.
  + enough lead time should be given to the laboratory to prepare and ship the bottle order, packing materials and coolers.
  + long-term storage of these bottles is not recommended, since the preservatives have a limited shelf life.

- trip blanks, field blanks, spiked trip blanks (when required) and extra bottles for field duplicates should also be ordered.

6.7) Groundwater Field Quality Assurance Sample Requirements

In order to ensure that Imperial Oil's contract analytical laboratory is producing data of acceptable quality, the Environmental Consultant is required to submit field Quality Assurance (QA) samples with every laboratory submission. Note that whether standard sampling methods

(see Section 6.4) or non-standard sampling methods (see Section 6.5) are used, the field QA sample requirements stay the same.

When submitting groundwater samples for laboratory analysis for Imperial Oil projects, the preferred operating practices for the submission of field QA samples are:

- at least one (1) travel blank should be included for each sampling event
  + a travel blank is a sample of reverse osmosis deionized (RODI) water prepared and filled in the bottles of interest by the laboratory, brought to the sampling site, then shipped back. The travel blank must not be opened.

- at least one (1) field blank should be included for each sampling event
  + a field blank is a sample of laboratory provided RODI water. This water is poured into the bottles of interest at the sampling site, by the field technician, at the same time and location that the other sampling is occurring.
  + the field blank should be prepared in the general vicinity of the groundwater monitoring wells. The RODI water should be passed through a piece of new sampling equipment (eg: Waterra pump, disposable bailer, piece of HDPE tubing) as it is being added to the bottle.
  + this sample will help identify the presence of contamination due to field handling.

- where required by provincial regulations, one (1) spiked trip blank will also be included in the sampling event.
  + a spiked trip blank is a sample of RODI water to which a known amount of the analyte of interest and appropriate preservative have been added by the laboratory.
  + this sample makes the round trip from the laboratory to the field and back, without ever being opened.
  + the spiked trip blank must be prepared a short time before accompanying the containers required for sampling at the site. This will ensure that the spiked blank sample will be analyzed within the hold time for the analyte of interest.
  + the spiked trip blank must be spiked with solutions containing all the target parameters required to be analyzed at a level of 5-10X the concentrations of interest at the specific site.
  + the frequency that spiked blank samples should accompany sample shipments varies with jurisdiction. Imperial Oil will inform consultants about the frequency that spiked blank samples will be required in the jurisdictions using a methodology other than this.

- a minimum of one (1) field duplicate sample should be taken during each sampling event for every ten (10) groundwater samples being submitted to the laboratory for analysis.
  + a field duplicate is an additional sample collected at the same time as another, in a manner that minimizes differences between the two samples.

+ for non-volatile parameters, split the groundwater sample as it is being removed from the monitoring wells between the two bottles (ie: sample and field duplicate). Filling each bottle sequentially is not acceptable.
+ field duplicates for volatile parameters are the exception. The duplicate bottles should be filled sequentially, with the bottles being capped immediately after sampling each bottle.
+ for sampling events where <3 groundwater samples are being sent to the lab in a single sample submission, the submission of a field duplicate sample by the consultant is not required.
+ a field duplicate should be submitted for each group of 10 samples. For example, a sample submission containing 32 groundwater samples would require the submission of 4 field duplicate samples to the laboratory.
+ whenever possible, groundwater samples where hydrocarbon impacts are suspected from field observations should be chosen for submission as field duplicates. Limited information on field duplicate reproducibility can be obtained when samples containing non-detectable levels of the parameters of concern are submitted for analysis.

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PREFERRED OPERATING PRACTICES FOR

THE QUALITY REVIEW OF ENVIRONMENTAL

ANALYTICAL LABORATORY DATA

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EXECUTIVE SUMMARY

It is of paramount importance that data generated in environmental projects is of the highest quality, considering that this data is used to make decisions concerning the initial status of the sites, possible remediation options and in determining the status of sites following remediation. In some cases, the analytical results generated during some assessment or remediation programs are ultimately considered in arbitration or courts of law.

Contract Laboratories utilized by Imperial Oil/ Exxon Mobil Canada are contractually obligated to analyze laboratory QC samples (eg: method blanks, matrix duplicates, matrix spikes and Laboratory Control Samples) with every batch of samples, as well as surrogate spikes within each individual sample (for selected organic parameters). If the laboratory QC samples do not meet certain acceptance criteria (which are presented for a large number of analytes and matrices in this POP), the laboratory is required to issue a Data Quality Waiver (DQW) request. A DQW request must also be issued when a number of other data quality issues are encountered during the analysis of samples (eg: samples exceed hold time due to laboratory issues, results are reported outside the calibration range, etc). This POP also presents alert limits used to evaluate data quality in conjunction with the analysis of field QC samples.

Environmental Consultants utilized by Imperial Oil/ Exxon Mobil Canada are contractually obligated to provide an independent quality review of data generated by the laboratory. To facilitate this review, a standardized Data Quality Review process has been developed. This process and instructions on its use are presented in this POP. In addition, Environmental Consultants are contractually obligated to review all DQW requests issued by the laboratory. Based upon the criticality of the end use of the data and closeness of the data to the applicable regulatory criteria, the consultant can decide to grant the DQW request for all, some, or none of the samples for which the Data Quality Waiver request was issued. Numerous examples are provided in this POP to provide guidance to Environmental Consultants and Imperial Oil Project Managers on when DQW requests should be granted and when they should not.

The POP's presented here represent practices that are to be applied in conjunction with the best professional judgement of the Environmental Consultant. As such, they should not be considered prescriptive. In addition, any data quality review practices that are mandated by provincial regulators will supercede the POP's presented in this document.

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1) INTRODUCTION

The quality of an environmental assessment, remediation or monitoring program is primarily dependent on the program design and the quality of the soil and/or groundwater samples obtained during the implementation of this program. It is also dependent on the quality of the laboratory analysis performed on these samples. Thus, it is crucial to have both high quality field sampling methodologies and high quality laboratory analysis in order to obtain reliable data upon that will determine the site conditions. It is of paramount importance that this data is of the highest quality, considering that this data is used to make decisions concerning the initial status of the sites, possible remediation options and in determining the status of sites following remediation. One additional factor is that the analytical results generated during some assessment or remediation programs are ultimately considered in arbitration or courts of law.

In certain jurisdictions, data quality review protocols may be specified by Provincial Regulations and/or Guidelines. In these jurisdictions, the data quality review protocols defined by the regulator must be followed explicitly. In those jurisdictions where there are no defined protocols, the data review procedures contained in this document should be used. In cases where there is a conflict between the recommended protocols presented in this Preferred Operating Practice (POP) and protocols specified by Provincial Regulations or Guidelines, the protocols defined by the Provincial Regulations or Guidelines are to be used by Environmental Consultants working at Imperial Oil sites.

This POP describes Imperial's approach to data quality, its expectations for third-party environmental data reporting and the interpretation/validation of the reported results (including QC reportables). It also provides guidance (by the use of example case studies provided in the POP) concerning what actions are to be taken by the Environmental Consultant when data reported by the Contract Laboratory is considered suspect.

1.1) Imperial Oil Data Quality Requirements

In order to ensure that data of the highest possible quality is generated and used by the corporation, Imperial Oil has adopted the ExxonMobil Data Integrity Assurance Framework (DIAF). The contract job specifications for all Contract Environmental Analytical Laboratories and Environmental Consultants used by Imperial Oil contain a DIAF clause. These vendors are contractually obligated to adhere to the stipulations of the DIAF clauses of their contracts, without exception**.**

1.1.1) Data Quality Requirements for Environmental Analytical Contract Laboratories

To meet legal and ethical standards, Imperial Oil insists upon obtaining data of the highest quality from all internal and external laboratories. Test procedures prescribed by government testing authorities, industry testing authorities, or laboratory Standard Operating Procedures (SOP's) that are based upon accepted reference methods, must be fully and meticulously followed, with the results being accurately reported. **Corporate**

expectations require that the results submitted by Contract Laboratories be competent, complete and responsible. To ensure these goals are met, all Imperial Oil laboratories must comply with the elements of the corporation's Data Integrity Assurance Framework (DIAF). To ensure that third party laboratories used by Imperial Oil are generating data that meets the expectations of DIAF, a data integrity clause has been developed that is included in the contracts for all third party laboratories. For contract environmental testing laboratories, the clause has been modified slightly from that used for hydrocarbon product testing laboratories. The DIAF clause for contract environmental analytical laboratories is as follows (presented in italics):

> *The Contract Laboratory shall be accountable for the integrity of any test or measurement data, including the generation, recording, reporting and retention, provided by the Contract Laboratory, its agents or any Subcontractors to the Imperial Oil, or any third party(s) on behalf of Imperial Oil. The Contract Laboratory agrees:*
>
> *a) that measurement activities and information reported from measurement shall be complete, accurate and timely.*
>
> *b) that test methods and instrument calibration procedures specified by the contract lab SOP's shall be used without modification. If an alternate test method is used (ie: one not listed in the job specification), it must be approved by Imperial Oil.*
>
> *c) to be registered to the CAEAL Laboratory Accreditation Program, or the MENV Laboratory Accreditation Program (in Quebec). These registrations/accreditations are granted by an acceptable certification organization such as the Standards Council of Canada, CAEAL or the Quebec MENV.*
>
> *d) to meet the requirements of ISO Standard 17025 requirements for the Competence of Calibration and Testing Laboratories, or equivalent of, for the analytical parameters listed in the job specification.*
>
> *e) to maintain an internal quality control program, including statistical quality control charts, for the analytical parameters listed in this job specification.*
>
> *f) to participate in recognized industry test exchange programs, such as CAEAL, Quebec MENV, EPA and Environment Canada.*
>
> *g) to allow periodic site assessment, as per Imperial Oil requests, to verify the functioning of Data Integrity.*

1.1.2) Data Quality Requirements for Environmental Consultants

To meet legal and ethical standards, Imperial Oil insists upon obtaining data of the highest quality from all environmental assessment, remediation and monitoring activities.

Field sampling and sample preservation methodologies prescribed by Provincial regulators, industry practices or Imperial Oil's Preferred Operating Practices must be fully and meticulously followed. **Corporate expectations also require that the analytical results generated from samples submitted by the Environmental Consultant to Imperial Oil's Contract Laboratories be competent, complete and responsible.** To ensure these goals are met, all Environmental Consultants are required to follow the sampling and sample handling protocols specified by Imperial Oil, in order to ensure that data generated by Imperial Oil's designated Contract Laboratory will comply with the elements of the corporation's Data Integrity Assurance Framework (DIAF). For Environmental Consultants, this DIAF clause is as follows (presented in italics):

> *"The Environmental Consultant shall be accountable for the integrity of any test or measurement data, including the generation, recording, reporting and retention, provided by the Environmental Consultant, its agents or any Subcontractors to the Imperial Oil, or any third party(s) on behalf of Imperial Oil. The Environmental Consultant agrees:*
>
> *a) that measurement activities and information reported from all field measurement performed by the Environmental Consultant shall be complete, accurate and timely.*
>
> *b) that sampling methodologies, field screening test methods and instrument calibration procedures used by the Environmental Consultant meet the requirements of Provincial regulatory authorities and follow best industry practices. In the absence of any local regulatory requirements, the guidelines specified by Imperial Oil (in various Preferred Operating Practices) shall be used by the Environmental Consultant without modification. If an alternate protocol is used by the Environmental Consultant (ie: it is not included in one of the Imperial Oil's POP's), its use must be approved in writing by Imperial Oil.*
>
> *c) to maintain an internal quality control program, including statistical quality control charts, as required by Imperial Oil's POP's.*
>
> *d) to allow periodic site assessment, as per Imperial Oil requests, to verify the functioning of Data Integrity."*

Certificates of Analysis (CoA's) are generated by Imperial Oil's designated Contract Laboratory, to report the data obtained from analysis of samples submitted by the Environmental Consultant. In addition to complying with the terms of the DIAF clause, Section 2.12 of the Environmental Consultant's contract requires the consultant to perform an independent quality review of the data presented in the Contract Laboratory's CoA's, based upon the guidelines presented in this POP. Also, the Environmental Consultant is contractually required to review all Data Quality Waiver (DQW) requests issued with the CoA's. The Environmental Consultant must either fully grant, partially grant or reject the DQW request and sign off that they have done so, using the guidelines presented in this POP to aid in their decision making.

1.2) Scope of Preferred Operating Practice

This document will discuss Preferred Operating Practices (POP's) to be used to review environmental analytical data generated at operating and non-operating sites (for both downstream and upstream sites), where soil, groundwater or air samples have been taken as part of an environmental assessment, remediation or monitoring program. The primary focus of this POP will be the quality review of data generated for contaminant parameters associated with hydrocarbon impacted soils, groundwater or air. However, the principles discussed in this POP can also be applied when reviewing the data quality for other contaminants (eg: metals or salts) in various matrices.

Acceptance and use of environmental data from a third-party laboratory must be performed with caution. Care must be exercised to ensure that all the data deliverables are included and that the quality of the data complies with Imperial Oil requirements. The person who accepts the data must critically review the Certificate of Analysis to ascertain that data quality is assured. If there is a possibility that data quality has been compromised, action must be taken to resolve the deficiency. This POP outlines the various Imperial Oil requirements for data reporting from the third-party laboratory; it also provides information on the interpretation and review of the data, as well as guidance for resolving data quality issues.

While this POP has been prepared with downstream operations in mind, there is a significant overlap in the preferred data quality review practices between the upstream and the downstream. Where differences exist in the preferred practices between upstream and downstream sites, any such differences will be highlighted in this POP.

This document outlines POP's for the review of environmental analytical data generated by a Contract Laboratory for an Environmental Consultant. The development of this POP will accomplish the following goals:

1) provide a guide to Imperial Oil Project Managers and Environmental Consultants retained by Imperial Oil, indicating preferred data review methodologies and data quality objectives.

2) provide a framework, which ensures that a consistent approach is used for data quality review at Imperial Oil sites (both upstream and downstream) across Canada.

1.3) Limitations of This POP and Disclaimer

The POP's presented here represent practices that are to be applied in conjunction with the best professional judgement of the Environmental Consultant. Environmental Consultants are contractually required (see Clause 2.12 of the Contract Job Specification) to comply with the data review provision of this POP. Significant deviation from the data review practice contained in this POP is only possible if the Environmental Consultant

has discussed the matter with the Imperial Oil Project Manager and gained concurrence on the usage of an alternate data review approach.

This POP should only be used by trained personnel, who have sufficient technical knowledge of the subject matter to make informed decisions about the reliability of the data presented in the laboratory Certificates of Analysis (CoA's), Chain of Custody's (CoC's) and Data Quality Waiver requests.

This document has been prepared by Imperial Oil. It is intended for the sole and exclusive use of Imperial Oil, its affiliated companies and their respective employees, agents and advisors. As such, this document may be utilized by firms under contract to Imperial Oil, for use on Imperial Oil projects only. Any use or reliance made by any person other than Imperial Oil based on this document is the sole responsibility of such other person. Imperial Oil makes no representation or warranty to any other person with regard to the contents of this document and accepts no duty of care to any other person or any liability or responsibility whatsoever for any losses, expenses, damages, fines, penalties or other harm that may be suffered or incurred by any other person as a result of the use of, reliance on, any decision made or any action taken based on this POP or the work referred to in this POP. Other than by Imperial Oil, copying or distribution of this POP or use of or reliance on the information contained herein, in whole or in part, is not permitted without the express written permission of Imperial Oil.

2) LABORATORY AND FIELD QUALITY CONTROL SAMPLES

Results for individual sample surrogate recoveries, laboratory QC samples and field QC samples will be compared to two types of criteria in this section.

The more stringent of these criteria is "acceptance criteria". Acceptance criteria are applied to QC samples that are largely under the care and control of the laboratory (ie: surrogates and lab QC samples). Since outside influences on these QC results are minimal, acceptance criteria can be set. Failure to meet acceptance criteria will result in the issuance of a Data Quality Waiver (DQW) request by the laboratory. Acceptance criteria for laboratory QC samples are almost always specified by the primary reference method (eg: APHA, US EPA, various federal or provincial jurisdictions) that the laboratory's Standard Operating Procedure (SOP) for a given test method is based upon. If not based upon the reference method, the acceptance criteria are based upon standard values that have been obtained from industry or corporate (ie: the laboratory corporation) sources, or they have been statistically-derived by the laboratory.

The less stringent of these criteria is "alert limits". Alert limits are applied to QC samples that are not entirely under the care and control of the laboratory (ie: field QC samples). Since influences outside of laboratory influence can have large effects on the field QC results, acceptance criteria cannot be set and less stringent alert limits must be used. Exceedance of an alert limit indicates that there is potentially either a problem with the laboratory analysis and/or the field sampling methodologies used to obtain the samples. Exceedance of an alert limit "prompts" the Environmental Consultant to examine both the lab and field QC data, in order to determine if the source of the data quality issue lies with the laboratory (eg: instrument contamination problems) or in the field (eg: soil sample heterogeneity issues).

2.1) Laboratory QC Results for Individual Samples

For most organic analyses, surrogates standards are added to each sample being analyzed. Surrogates are defined as "a*n organic compound which is similar to the target analyte(s) in chemical composition and behavior in the analytical process, but which is not normally found in environmental samples"* [US EPA, 1992]. The recoveries of the surrogates are monitored for each sample. Analytical results from the samples are considered acceptable if the reported surrogate recoveries fall within a specified acceptance criteria range. The acceptance criteria depend on the analytical parameters. The surrogate recovery acceptance criteria for organic parameters commonly analyzed on Imperial Oil projects are presented in Tables 2.1 - 2.10.

If a surrogate recovery outside of the acceptance criteria occurs, corrective action (eg: re-analysis of the sample) must be taken, or a DQW request issued by the laboratory. Since surrogate addition to samples is entirely under the care and control of the laboratory, acceptance criteria can be applied to surrogate recovery limits.

Surrogates are generally added to individual samples prior to the commencement of sample preparation and are carried through the entire analytical process. For the purposes of the following discussions, these surrogates will be referred to as "extraction" surrogates. One exception to this general rule is soil BTEX or VOC's analysis, where (in some jurisdictions) the soil is extracted with methanol prior to purge & trap GC/MS analysis. In this procedure, an aliquot of the methanol extract is added to a purge & trap vial filled with purged, ultrahigh purity water; the vial is then placed in the autosampler. The autosampler then adds surrogates during the sampling of the vial, immediately before the sample is injected into the GC/MS instrument. For the purposes of the following discussions, these surrogates will be referred to as "instrument" surrogates. For BTEX or VOC's in soil analysis, the laboratory also adds an additional surrogate at the time of methanol extraction. For the purposes of the following discussions, this surrogate will be referred to as the "extraction" surrogate.

For VOC and BTEX analysis of water samples, no sample preparation proceeds analysis. Thus, addition of the surrogates at the time of sampling tracks the entire analytical process, since the sample is taken by the autosampler directly from the vial in which it was submitted. This means that while instrument surrogate results are reported for water samples, no extraction surrogate results are reported for these samples.

Finally, for samples that contain high levels of analytes, dilution of the sample may be required to bring the sample within the calibration range of the instrument. When a dilution of the sample is re-analyzed, the surrogate may become "diluted out" (ie: the concentration of the surrogate in the diluted sample is too low to detect on the instrument). Imperial Oil's Contract Laboratory is contractually not allowed to report surrogate recoveries as "diluted out". Instead, they are required to re-analyze the sample (including re-extraction, if required) with a higher concentration of surrogates added, which will avoid dilution issues and allow a surrogate recovery to be reported. Reporting of "diluted out" surrogate recoveries is only allowable in situations where insufficient sample remains to allow a complete re-analysis, or the analytical hold time for the sample has been exceeded before re-analysis was possible.

2.1.1) Instrument Surrogates

An "instrument surrogate" is spiked into the sample following the extraction process, but prior to the instrumental analysis of the sample. Instrument surrogates typically are only used for VOC test methods in soils, where mass spectrometry (MS) analyses are utilized.

For MS analyses, deuterated analogues or uncommon halogenated compounds are generally used as instrument surrogates. A minimum of three instrument surrogates are used with any MS analysis. For example, *d8*-toluene (where all eight hydrogen atoms of the toluene molecule have been replaced by deuterium atoms), *d4*-1,2-dichloroethane (where all four hydrogen atoms of the 1,2-dichloroethane molecule have been replaced by deuterium atoms) and bromofluorobenzene (where one bromine and one fluorine have replaced two of the six hydrogen atoms of the benzene molecule) are commonly used as instrument surrogates in the analysis of volatile organic compounds (such as BTEX).

The percent recovery of the instrument surrogates allows for determination of whether the instrument was capable of acceptably quantifying the analytes of interest (ie: it is a measurement of the accuracy of the analysis in a given matrix). The percent recovery of the instrument surrogates is determined using the following equation:

$$\text{Instrument Surrogate Recovery (\%)} = \frac{SSR}{SA} \times 100\%$$

SSR = observed concentration of instrument surrogate from sample analysis
SA = expected concentration of instrument surrogate, based on amount spiked into sample

Analysis of instrument surrogate spikes gives an indication of the accuracy of results generated by the instrument (and only the instrument) in the sample matrix analyzed. The instrument surrogate spike recovery results must meet the specified acceptance criteria presented in Tables 2.1 - 2.10.

On the laboratory Certificate of Analysis, the recovery for the instrument surrogates is listed on the same page as the sample results. For example, for BTEX in soil, the acceptance criteria for the calculated recovery of the three instrument surrogates (ie: *d8*-toluene, bromofluorobenzene and *d4*-1,2-dichloroethane) is 60-140%. In other words, the recovery for these three instrument surrogates should be at least 60% and not greater than 140% of the expected concentrations. Surrogate recoveries outside this range indicate potential quality issues due to analytical bias. Low recovery of an instrument surrogate indicates sample results may be biased low, while high recoveries indicate that the sample results could be biased high. Potential causes of high or low recoveries are poor instrument performance or matrix interferences.

Observance of an instrument surrogate that is outside of acceptance criteria will result in the laboratory issuing a DQW request for the affected sample. In the case where three or more instrument surrogates are used, it is acceptable for a maximum of one of the surrogates to not meet the recovery criteria, without the issuance of a DQW request. If two or more of the instrument surrogates are outside acceptance criteria, then a DQW request must be issued.

2.1.2) Extraction Surrogates

An "extraction surrogate" is added to the sample prior to the extraction process. This is used to track the recovery of the analyte through the entire analytical process, including sample preparation and extraction, as well as analysis. Extraction surrogates are typically used for all organic test methods, not just those where MS detection is used. Extraction surrogates are used on sample matrices (eg: soils) where extraction of the sample with a solvent is required, with the analysis then being performed on the solvent extract. If extraction of the samples is not required (eg: water samples for volatiles analysis, where purge and trap methodologies are utilized), extraction surrogates are not used or reported.

For MS analyses of organic parameters in solid matrices, deuterated analogues or uncommon halogenated compounds are generally used as extraction surrogates. Typically, only one extraction surrogate is used with any MS analysis. For example, *d10*-ethylbenzene (where all ten hydrogen atoms of the ethylbenzene molecule have been replaced by deuterium atoms) is commonly used as an extraction surrogate in the analysis of volatile organic compounds (such as BTEX) in soil samples.

For organic parameter test methods in solid matrices where detection systems other than MS are used, such as flame ionization detectors (FID's), photoionzation detectors (PID's) or electron capture detectors (ECD's), extraction surrogates are also utilized. Since these detectors are not sensitive to differences in mass, deuterated analogues are not utilized as extraction surrogates. Instead, compounds that are not commonly found in environmental samples are used as extraction surrogates. For extractable TPH compounds in soils quantified by GC-FID, extraction surrogates include compounds such as 1-chlorooctadecane and 5α-androstane.

The percent recovery of the extraction surrogate is determined using the following equation:

$$\text{Extraction Surrogate Recovery (\%)} = \frac{\text{SSR}}{\text{SA}} \text{ x } 100\%$$

where : SSR = observed concentration of extraction surrogate from sample analysis
SA = expected concentration of extraction surrogate, based on amount spiked into sample

Analysis of extraction surrogate spikes gives an indication of the accuracy of results generated by the test method (including the sample preparation, extraction and instrumentation) in the sample matrix analyzed.

In cases where only an extraction surrogate(s) is run with the sample, the percent recovery of the extraction surrogate(s) allows for determination of whether the combined sample extraction and analytical procedure was efficient in both extracting and analyzing the analytes of interest. Recoveries within acceptance criteria indicate sufficient efficiency in the combined extraction/analysis process. Recoveries outside acceptance criteria indicate issues in the combined extraction/analysis process. Since only extraction surrogates have been analyzed with the sample, it is not possible to determine whether the issue is associated with the extraction procedure, or the analytical procedure, or both.

In cases where both an extraction surrogate and instrument surrogates are run, the following scenarios are possible:

1) the extraction surrogates and instrument surrogates are both within acceptance criteria. This implies it is highly likely that both the sample extraction procedure and the analytical procedure were efficient in analyzing the analytes of interest.

2) the extraction surrogates are outside of acceptance criteria, but the instrument surrogates are within acceptance criteria. This implies that there were likely issues with the sample extraction procedure (eg: matrix interferences, spiking errors, etc), but that the analytical procedure was efficient in analyzing the analytes of interest.

3) the instrument surrogates are outside of acceptance criteria, but the extraction surrogates are within acceptance criteria. Since the extraction surrogates represent the combined extraction/instrumental efficiency, if the extraction surrogates are within acceptance criteria, it would usually be expected that the instrument surrogates should also be within acceptance criteria. One possible explanation for this scenario is the erroneous spiking an incorrect amount of instrument surrogates into the sample. Another explanation is offsetting effects (eg: instrument recoveries are high due to instrumental issues and outside acceptance criteria, but extraction efficiencies are low. These two effects offset each other and result in an extraction surrogate recovery that is within acceptance criteria).

4) the extraction surrogates and instrument surrogates are both outside acceptance criteria. This implies that instrumental issues (eg: calibration errors) are highly likely to be the cause of both extraction and instrument surrogate recoveries being outside of acceptance criteria.

The extraction surrogate spike recovery result must meet the specified acceptance criteria presented in Tables 2.1 - 2.10. If the specified acceptance criteria are not met, the laboratory will issue a DQW request.

On the laboratory Certificate of Analysis, the recovery for the extraction surrogates is listed on the same page as the sample results. For example, for BTEX in soil, the calculated recovery of the extraction surrogate (ie: *d10*-ethylbenzene) should fall between 30-130%. Extraction surrogate recoveries outside this range indicate potential quality issues due to analytical bias.

Low recovery of an extraction surrogate indicates sample results may be biased low. Potential causes of low recovery are ineffective extraction of the associated sample and/or poor instrument performance. Extraction surrogate recoveries greater than the acceptance criteria suggest that instrument performance may be an issue, or that a matrix interference may be present in the sample.

Observance of an extraction surrogate that is outside of acceptance criteria will result in the laboratory issuing a DQW request for the affected sample.

2.2) Laboratory QC Results for Sample Batches

Laboratory Quality Control (QC) samples are prepared and analyzed by the contract lab, in order to ascertain the accuracy and precision of the analytical results reported for a given analytical test method, for a given batch of samples. The accuracy and precision are monitored by comparing the analytical results obtained for the laboratory QC samples to "acceptance criteria". If exceedance of an acceptance criterion occurs, corrective action (eg: re-analysis of the sample) must be taken. Since laboratory QC samples are under the care and control of the laboratory, the quality of the results obtained are free of outside influences (with the possible exception of lab duplicate samples, where sample inhomogeneity from poor field sampling techniques can have a deleterious effect on the reported analytical precision). Thus, the more stringent acceptance criteria can be used with laboratory QC samples.

Laboratory QC samples are run with every batch of samples analyzed by Imperial Oil's Contract Laboratories. A batch consists of twenty individual samples or less. The following subsections describe the various laboratory QC samples analyzed and reported by the environmental analytical laboratory, as well as descriptions of how the samples are prepared and the purpose of analyzing the QC samples. The nomenclature and definitions are based on United States Environmental Protection Agency documentation [US EPA, 1992]. Note that the terminology used for laboratory QC samples varies depending on the jurisdiction. Throughout this POP, the US EPA definitions will be used. Text taken verbatim from the cited US EPA documentation in the following subsections is italicized.

All results from the analysis of the laboratory QC samples are assessed as to whether they meet the acceptance criteria discussed in the following subsections. For laboratory QC samples that do not fall within the acceptance criteria, corrective actions must be taken. This could involve re-analyzing the batch of samples associated with the QC sample acceptance criteria failure. It will also involve the issuance of a Data Quality Waiver (DQW) request, if the corrective action does not produce a result that meets the acceptance criteria. DQW requests will be discussed in more detail in Section 3.

2.2.1) Method Blank Samples

A method blank is defined as *"an analyte-free matrix to which all reagents are added in the same volumes or proportions as used in sample processing. The method blank should be carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination resulting from the analytical process"* [US EPA, 1992]. A minimum of one method blank is analyzed with each batch of samples by the Contract Laboratory.

Method blank analysis is performed to identify laboratory contributions (eg: glassware, reagents and/or instrumentation) to the measured analyte level in the samples. Low or non-detectable results in the method blank sample provide assurance that results reported

for samples analyzed in the batch associated with this method blank sample are not false positive results.

For water samples, the method blank is an ultrahigh purity (UHP) water sample. Typically, this is city tap water that has undergone reverse osmosis treatment, followed by treatment with deionization cartridges. As a final step, the water is polished (ie: air purged and/or carbon treated), to remove residual volatile organic compounds (eg: trihalomethanes and chloroform) that are byproducts of the chlorination process at the city waterworks.

For soil samples, acid-washed or baked silica sand (as appropriate) is used as the method blank. This material is typically a sea sand that has been sieved to meet a specified particle size range.

Method blank results must meet the specified acceptance criteria presented in Tables 2.1 - 2.10. If the analyte is detected in the method blank, the concentration should not exceed the specified acceptance criteria. Data generated from sample batches where method blanks exceed the acceptance criteria indicate that contamination of samples contained in the batch may have occurred during the course of analysis in the laboratory.

Method blank criteria vary with matrix and analyte. For most analytes and matrices, the acceptance criteria is that the method blank must have a result <5X the Method Detection Limit (MDL). In some cases, a more stringent criteria may be used (eg: the method blank acceptance criteria is <2X MDL for CCME F1 hydrocarbons and CCME F2-F4 hydrocarbons, in both soil and water matrices). More stringent criteria are used in cases where the regulatory limits are set at very low concentrations and a value of 5X MDL would exceed the regulatory criteria for the analyte. In such cases, an acceptance criterion that is below the regulatory limit is set. Typically, the goal is to set a method blank acceptance criteria that is <50% of the regulatory limit.

Method blank results may in some cases exceed the acceptance criteria established for the particular parameter and matrix. Results reported for these samples analyzed in the same batch as this method blank are to be considered suspect, since results for all samples in the analytical batch may be biased high. In cases where results are reported by the laboratory and the method blank acceptance criteria is exceeded, the laboratory must issue a DQW request. For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. If the method blank result for any single analyte is outside the acceptance criteria, the results for all samples in the analytical batch for this particular analyte should be considered suspect and the laboratory must issue a DQW request. Results for other analytes that met the acceptance criteria should not be considered suspect.

Experience has shown that results for method blank QC samples seldom exceed the acceptance criteria.

2.2.2) Matrix Duplicate Samples

A matrix duplicate sample is more commonly called a "laboratory duplicate sample". A matrix duplicate is defined as *"an intralaboratory 'split sample' which is used to document the precision of a method in a given sample matrix. 'Split samples' are aliquots of sample taken from the same container and analyzed independently"* [US EPA, 1992].

Matrix duplicate samples are analyzed to determine if the precision of the test method (ie: in this case, the repeatability of the test method) during the analysis of a particular batch of samples. Poor precision (ie: high RPD values) can be an indication of problems with the test method (either the instrumentation or the sample preparation steps). It can also indicate that the sample matrix contained in the sample container is very heterogeneous (this is usually only a problem with soil matrices, not water matrices).

In practice, two separate subsamples (these are referred to as "aliquots") are removed from the same sample container arriving from the field. Each aliquot is treated identically throughout a laboratory analytical procedure and each is carried through the entire laboratory analytical method as applied to all other samples analyzed with the same method. Thus, for organic analyses of soil samples, each aliquot is extracted and the extract analyzed for the analytes of interest. For metals analyses of soils, each aliquot is acid digested and the digestate analyzed for the analytes of interest.

Note that both aliquots of the matrix duplicate sample must be subjected to the entire analytical procedure, including the sample preparation steps. Simply taking duplicate aliquots from a single sample extract or digestate and analyzing them does not constitute a proper matrix duplicate sample, since this only provides an estimate of the precision of the instrumentation and not the precision of the entire test method.

Once the two aliquots have been analyzed, the RPD (relative percent difference) between the two results is calculated using the following equation:

$$\text{Matrix Duplicate RPD (\%)} = \frac{(C1 - C2)}{(C1 + C2)/2} \text{ x } 100\%$$

where: RPD = relative percent difference
C1 = larger of the two observed values from the aliquot analysis
C2 = smaller of the two observed values from the aliquot analysis

In order for a valid Matrix Duplicate RPD to be calculated, both results must be >5X MDL. If one or both of the analytical results for the matrix duplicate samples are <5X MDL for an analyte, then it is not possible to calculate a valid Matrix Duplicate RPD.

Samples to be analyzed as matrix duplicates should be chosen at random by the Contract Laboratory, before starting the analysis of a sample batch. This will result in some matrix duplicate samples having both sample results >5X MDL, so a valid Matrix Duplicate RPD can be calculated; some matrix duplicate samples will have one or both

results <5X MDL, so a valid Matrix Duplicate RPD cannot be calculated. In the past, some laboratories have used biased sampling to choose only matrix duplicates that will have one or both results <5X MDL, so that a valid Matrix Duplicate RPD can never be calculated. This ensures that the lab always meets its Matrix Duplicate RPD criteria (ie: if no valid RPD's can be calculated, this makes it impossible for the laboratory to ever fail its internal acceptance criteria for Matrix Duplicate RPD's). Laboratories that engage in such dubious practices do not meet Imperial Oil DIAF expectations and laboratories under contract to Imperial Oil are not allowed to engage in this practice.

Analysis of matrix duplicates provides a measure of the analytical precision. At a minimum, the matrix duplicate RPD result must meet the specified acceptance criteria presented in Tables 2.1 - 2.10.

Matrix duplicate criteria vary with matrix and analyte. For example, in the case of antimony in water (Table 2.8), the calculated result for a matrix duplicate relative percent difference (RPD) for the two individual aliquots should be <25% in order for the result to meet acceptance criteria.

Matrix duplicates may in some cases exceed the acceptance criteria established for the particular parameter and matrix. Such results are to be considered suspect and the laboratory must issue a DQW request in such cases. For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed simultaneously. If the valid matrix duplicate result for any single analyte is outside the acceptance criteria, the results for all samples in the analytical batch for this particular analyte should be considered suspect and the laboratory must issue a DQW request. Results for other analytes that met the acceptance criteria are not considered suspect.

With soil samples, failure to meet the matrix duplicate RPD acceptance criteria often occurs due to sample inhomogeneity. If the aliquots involved are known to be from a sample that is suspected to be heterogeneous, the fact that the acceptance criteria were not met usually should not be a significant concern. However, if the sample from which the two aliquots were obtained was observed to be homogeneous, the observance of a matrix duplicate sample that fails the RPD acceptance criteria may be cause for concern.

Due to the inhomogeneity of soil matrices, it is not unusual to observe matrix duplicate soil samples that fail to meet the applicable acceptance criteria. However, exceedances of the acceptance criteria are observed less often in water samples (due to the high degree of homogeneity in such samples). Typically, exceedances of Matrix Duplicate RPD acceptance criteria for water samples are only noted when a significant amount of another material (eg: sediment) is present in the sample bottle.

For the analysis of volatiles samples in water (eg: BTEX, purgeables), duplicate analyses in the laboratory must be performed on separate 43 ml VOA vials, to avoid headspace issues. Thus, the reported matrix duplicate results for these parameters are essentially field duplicates, so poor reproducibility may be observed. A DQW request will be issued by the laboratory, but the consultants should consider that the samples are really field duplicates, when assessing whether to grant the DQW request.

2.2.3) Matrix Spike Samples

A matrix spike sample is defined as *"an aliquot of sample spiked with a known concentration of target analyte(s). The spiking occurs prior to sample preparation and analysis. A matrix spike is used to document the bias of a method in a given sample matrix"* [US EPA, 1992].

Matrix spike samples are analyzed to determine if sample matrix effects are causing a significant bias (either positive or negative) in the data generated by the test method during the analysis of a particular batch of samples. High or low matrix spike recoveries indicate that some component of the samples is interfering with the accuracy of the data being reported by the test method for the analytes of interest. For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. The matrix spike added to the native sample will typically contain all analytes contained in the analytical suite.

In practice, two separate subsamples (these are referred to as "aliquots") are removed from the same sample container arriving from the field. One aliquot is left "as is" and is commonly referred to as an aliquot of the "native" material. The second aliquot has a known amount of the analytes of interest spiked into the aliquot. Both aliquots are identically treated throughout the laboratory analytical procedure and each is carried through the entire laboratory analytical method applied to all other samples analyzed with the same method. Thus, for organic analyses of soil samples, each aliquot is extracted and the extract analyzed for the analytes of interest. For metals analyses of soils, each aliquot is digested and the digestate analyzed for the analytes of interest.

The percentage recovery of the analyte(s) for the matrix spike is determined by subtraction of the native concentration of the analyte (ie: the result obtained from analysis of the aliquot of the original sample that was not spiked) from the spiked sample result and comparison of this result to the known spike level. This is done using the following equation:

$$\text{Matrix Spike Recovery (\%)} = \frac{SSR - SR}{SA} \times 100\%$$

where: SSR = measured concentration of analyte in spiked aliquot
SR = measured concentration of analyte in unspiked aliquot (commonly referred to as the "native" concentration)
SA = actual concentration of analyte spike added to spiked aliquot

Which samples are to be analyzed as matrix spikes should be chosen at random by the Contract Laboratory, before the start of the analysis of a sample batch. This will avoid the practice that some laboratories engage in, where biased sampling is used by the laboratory to choose only soil samples with sandy matrices for matrix spike analysis. This avoids issues with clay matrices, where obtaining matrix spike recoveries that are within acceptance criteria is more problematic. Laboratories that engage in such dubious

practices do not meet Imperial Oil DIAF requirements and laboratories under contract to Imperial Oil are not allowed to engage in this practice.

Matrix spike recoveries may be impacted by high levels of native analytes. Consider an example of a metal analyte in water, where the native concentration is 100 µg/L, the spike level is 10 µg/L and the result for the matrix spike sample is 105 µg/L. This result for the matrix spike sample is well within the analytical precision of the method. However, it would yield a 50% matrix spike recovery, which are outside acceptance criteria. For this reason, matrix spike recoveries are only reported when the spike concentration is greater than the native concentration by a certain factor. The magnitude of this factor varies between test methods and analytes. For example, in metals analysis the spike concentration must be at least twice the native concentration in order for a matrix spike recovery to be reported by the laboratory.

Analysis of sample matrix spikes gives an indication of the accuracy of results generated in the given matrix analyzed. At a minimum, the matrix spike recovery result must meet the specified acceptance criteria presented Tables 2.1 - 2.10. In some cases, laboratories may use acceptance criteria (usually statistically derived using performance data from that laboratory) for matrix spike samples that are tighter (ie: have a narrower range of magnitude) than those presented in Tables 2.1 - 2.10. While the use of acceptance criteria tighter than those presented in Tables 2.1 - 2.10 is acceptable, the use of acceptance criteria looser than these by the laboratory is not.

Acceptance criteria for matrix spikes vary depending on the parameter and matrix. Once the matrix spike recovery is determined for a particular sample, it should fall in the acceptance criteria range given for that particular parameter and matrix. Results reported for samples outside the acceptance criteria range are to be considered suspect and the laboratory must issue a DQW request. For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. If the matrix spike result for any single analyte is outside the acceptance criteria, the results for all samples in the analytical batch for this particular analyte should be considered suspect and the laboratory must issue a DQW request. Results for other analytes that met the acceptance criteria should not be considered suspect.

For instance, in the case of BTEX by purge and trap in water (Table 2.6), the calculated matrix spike recovery should fall between 70%-130%. This means that the concentration of *each* BTEX compound determined to originate from the spiking of the analytes into the sample must be at least 70% of the expected concentration and not greater than 130% of the expected concentration. If matrix spike recoveries fall outside the acceptance criteria for even one of the analytes, the laboratory must issue a DQW request for that analyte.

Data from sample batches where the matrix spike recovery is outside of acceptance criteria should be considered suspect. A low result may be due to inefficient extraction of the analyte(s) from the matrix or instrumental issues. A low result for the extraction surrogate and/or instrument surrogates associated with this analysis (if applicable) would aid in problem solving. A high matrix spike recovery suggests that the sample results

may be biased high due to instrumental issues or because of lab contamination of the samples.

Experience has shown that results for matrix spike QC samples do not often fall outside the acceptance criteria.

2.2.4) Laboratory Control Samples (LCS)

A laboratory control sample (LCS) is commonly referred to as a "spiked blank sample". A laboratory control sample is defined as *"a known matrix spiked with compound(s) representative of the target analyte(s). This is used to document laboratory performance"* [US EPA, 1992].

LCS recoveries are used to estimate the overall analytical method accuracy, independent of sample matrix effects. They are also used to demonstrate routine method performance. Often, the results for LCS samples are control charted over a period of time. Comparison of the results obtained for the LCS with statistically derived control limits allow the determination if the test method was in statistical control when the batch of samples associated with a particular LCS sample was analyzed.

To prepare a LCS, a "clean" analyte-free matrix sample (eg: ultrapure water for water matrices; acid-washed silica sand, glass beads or magnesium sulfate for soil matrices) is spiked with known concentrations of target analytes (usually, at the time of analysis). These samples are carried through the entire sample preparation and analysis procedure used for all other samples. LCS spiking stocks are normally prepared from standard materials of known, certified quality. They are either purchased from a reliable source, or prepared in-house. In either case, Certificates of Analysis documenting the purity of the spiking reagents used to prepare the LCS must be kept on file by the Contract Laboratory. Note that the reagents used to prepare the LCS must be obtained from a separate, independent source from the source used to prepare the calibration standards for the test method. In some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. For these test methods, the LCS will typically contain all of the analytes of interest. For some test methods (eg: metals in water), interferences or precipitation problems can occur if the LCS contains all analytes in the analytical suite. In such cases, the laboratory will run two or more separate LCS samples, in order to cover the entire range of analytes contained in the analytical suite.

The percentage recovery of the analyte(s) is determined by comparison of the result obtained for the sample containing the analyte(s) spiked into the analyte-free matrix, versus the expected results of the spiked "clean" matrix using the following equation:

$$\text{LCS Recovery (\%)} = \frac{SSR}{SA} \text{ x } 100\%$$

where : SSR = observed concentration of LCS analytes from sample analysis

SA = expected concentration of LCS analytes, based on amount of analytes spiked into sample

Analysis of LCS samples gives an indication of the accuracy of results generated from an interference-free sample matrix, for the entire analytical process. The LCS recovery result must meet the specified acceptance criteria presented in Tables 2.1 - 2.10. In some cases, laboratories may use acceptance criteria (usually statistically derived using performance data from that laboratory) for LCS samples that are tighter (ie: have a narrower range of magnitude) than those presented in Tables 2.1 - 2.10. While the use of acceptance criteria tighter than those presented in Tables 2.1 - 2.10 is acceptable, the use of acceptance criteria looser than these by the laboratory is not.

Acceptance criteria for LCS samples vary depending on the parameter and matrix. Once the LCS recovery is determined for a particular sample, it should fall in the acceptance criteria range given for that particular parameter and matrix. Results reported for LCS samples outside of acceptance criteria are to be considered suspect and the laboratory must issue a DQW request. For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. If the LCS result for any single analyte is outside the acceptance criteria, the results for all samples in the analytical batch for this particular analyte should be considered suspect and the laboratory must issue a DQW request. Results for other analytes that met the LCS acceptance criteria should not be considered suspect.

Acceptance criteria for laboratory control samples also vary depending on the parameter and matrix, but the acceptance criteria for matrix spike samples and LCS are often equivalent. Low values for LCS percent recoveries suggest that extraction of the sample may have been inefficient and the sample results may be biased low. A low result for the extraction surrogate or instrument surrogates associated with this analysis (if applicable) would support the possibility that the data may be biased low. A high LCS recovery suggests that the sample results may be biased high due to instrumental issues or because of lab contamination of the samples. If a LCS recovery is reported outside an acceptance criterion, the laboratory must issue a DQW request.

Since LCS are prepared from "clean" matrices, recoveries for LCS QC samples outside the acceptance criteria are rarely observed.

In addition to spiked blank LCS samples, for some test methods, some laboratories also analyze samples of Standard Reference Materials (SRM's) or Certified Reference Materials (CRM's) with every batch of samples. These SRM and CRM materials can also be considered another type of Laboratory Control Sample. Analysis of SRM or CRM samples is often performed with metals analysis. The laboratory's SOP often has internal criteria for these SRM or CRM materials to determine whether or not the quality of an analytical batch is acceptable. Since results from SRM or CRM samples are not usually reported on the CoA's generated by the Contract Laboratory, review of SRM or CRM results by the Environmental Consultant is not required.

2.3) Field QC Sample Results

Field QC samples are submitted for analysis at the Contract Laboratory by the Environmental Consultant. These samples are submitted in order to ascertain the effect of field sampling and sample shipping methodologies on the accuracy and precision of the analytical results reported for a given analytical test method. The accuracy and precision are monitored by comparing the analytical results obtained for the field QC samples to "alert limits". If exceedance of an alert limit occurs, corrective action (eg: re-analysis of the sample) must be taken. Since field QC samples are under the care and control of the Environmental Consultant, the courier and the laboratory, the quality of the field QC sample results obtained depends on the actions of each of these three parties. Since the laboratory does not have complete care and control of the field QC samples, the alert limits (which are less stringent than acceptance criteria) are used for these QC samples.

Field QC samples are included in every submission of samples sent to Imperial Oil's contract environmental analytical laboratories. The frequency for the submission of field QC samples by the consultant is specified by various Imperial Oil POP's [Blue 2002, Walsh 2002]. The following subsections describe the various field QC samples that are taken by the consultant and analyzed by the environmental analytical laboratory; as well as descriptions of how the samples are prepared and the purpose of analyzing the samples. These definitions are based on United States Environmental Protection Agency documentation [US EPA, 1992]. Note that the terminology used for field QC samples varies, depending on the jurisdiction. Throughout this POP, the US EPA definitions will be used. Text taken verbatim from the cited US EPA documentation in the following subsections is italicized.

All results from the analysis of field QC samples are assessed as to whether they meet the alert limits discussed in the following subsections. Since these samples are not under the complete care and control of the Contract Laboratory, exceedance of an alert limit does not result in the issuance of a DQW request by the laboratory.

2.3.1) Field Blank Samples

A field blank is an aliquot of laboratory-supplied UHP water or acid-washed silica sand. These samples are prepared in the same way as the UHP water and acid-washed silica sand used for method blank samples in the laboratory (see Section 2.2.1). Note that the US EPA does not provide a definition of a field blank sample in its SW-846 documentation [US EPA, 1992].

The field blank sample is prepared by the laboratory and shipped for immediate use in the field, where it is treated as an environmental sample in all aspects in both the field and laboratory. This includes the exposure to field ambient conditions and the addition of all preservatives in the field. In the lab, the field blank samples undergo exactly the same processing and analysis as any other sample submitted for the analytes of interest.

For example, consider samples being submitted for BTEX analysis in water. Purged UHP water is shipped from the lab to the site in a large bottle (typically 500 ml in capacity). At the site, the purged UHP water is poured from the large bottle (at the sampling locations in the field) into 43 ml VOA (Volatile Organic Analysis) vials containing chemical preservatives. These vials are sealed and shipped back to the lab, where they are analyzed using the same methodology as any other BTEX in water sample.

For example, consider samples being submitted for pesticide analysis in soil. Pre-cleaned silica sand is shipped from the lab to the site in a glass jar (typically 50 ml in capacity). At the site, a small aliquot (5-10 grams) of the silica sand is poured from the large bottle (at the sampling locations in the field) into the sample bottles being used in the field (the size of these bottles will vary by jurisdiction). These bottles containing the field blank sample are sealed and shipped back to the lab, where they are analyzed using the same methodology as any other pesticide in soil sample. A note should be made on the Chain of Custody form that there was insufficient sample to fill the entire bottle, in order to avoid a laboratory sample submission deficiency for submitting a sample container with headspace.

Field blank analysis is performed to identify contamination resulting from the combination of field sampling techniques, preservatives, sample shipping and laboratory analytical processes. Field practices that could affect the measured analyte concentration in field blank samples include sampling methodologies, the sampling equipment used, field filtration and/or sample preservation. Exposure to contamination sources during shipping could contribute to the measured analyte concentration in field blank samples. Glassware, reagents and/or instrumentation are laboratory factors that can affect the measured analyte level in field blank samples. Low or non-detectable results in the field blank sample provide assurance that results reported for samples analyzed in the sample submission associated with this field blank sample are not false positives results.

If the analyte is detected in the field blank, the concentration should not exceed alert limits presented in Tables 2.1 - 2.10. Data generated from sample submissions where field blanks exceed the alert limits indicate that contamination of samples contained in the batch may have occurred during the course of field sampling, shipping or analysis in the laboratory.

Field blank alert limits vary with matrix and analyte. For most analytes and matrices, the alert limit is that the field blank must have a result <5X MDL. In some cases, a more stringent criteria may be used (eg: the field blank alert limit is <2X MDL for CCME F1 hydrocarbons and CCME F2-F4 hydrocarbons, in both soil and water matrices). More stringent criteria are used in cases where the regulatory limits are set at very low concentrations and a value of 5X MDL would exceed the regulatory criteria for the analyte. In such cases, an alert limit that is below the regulatory limit is set. Typically, the goal is to set a field blank alert limit that is <50% of the regulatory limit.

Field blank results may in some cases exceed the alert limits established for the particular parameter and matrix. Results reported for these samples analyzed in the same batch as

this field blank are to be considered suspect, since results for all samples in the analytical batch may be biased high.

For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. If the field blank result for any single analyte is outside the alert limit, the results in for all samples in the analytical batch for this particular analyte should be considered suspect. Results for other analytes that met the acceptance criteria should not be considered suspect.

Experience has shown that results for field blank QC samples are rarely observed to exceed the alert limits. Occasionally, levels of common laboratory solvents (eg: toluene, acetone, dichloromethane, etc.) that are detectable (but <5X MDL) are observed in water sample field blanks. These positive results may be associated with common laboratory solvents, marker inks, adhesives or automobile exhausts and are usually not of concern, unless it is potable water samples that are associated with this field blank.

Another type of field blank sample that is sometimes used for water samples is an equipment blank sample, where an aliquot of UHP water is exposed to the sample collection equipment. This type of field QA sample is typically utilized when non-dedicated sampling equipment is being used in the field, to ensure that field decontamination procedures are adequate enough to ensure that cross-contamination does not occur between samples. The use of equipment blank samples is left to the discretion of the Environmental Consultant. However, if this type of sample is used, it should clearly be identified as an equipment blank sample, not a field blank sample, on the Chain of Custody form. This will ensure there is no confusion about the type of field QA sample actually being used.

2.3.2) Trip Blank Samples

A trip blank sample is defined as *"a sample of analyte-free media taken from the laboratory to the sampling site and returned to the laboratory unopened. A trip blank is used to document contamination attributable to shipping and field handling procedures. This type of blank is useful in documenting contamination of volatile organics samples"* [US EPA, 1992]. Note that it can also be an indicator of sample container or sample preservative contamination.

A trip blank is an aliquot of UHP water or pre-cleaned silica sand. These samples are prepared in the same way as the UHP water and acid-washed silica sand used for method blank samples in the laboratory (see Section 2.2.1).

The trip blank sample is supplied by the Contract Laboratory and shipped to the site. The trip blank sample remains unopened at the site. It is then shipped back to the laboratory. From here, the aliquot is treated as any other environmental sample by the laboratory. This includes exactly the same processing and analysis steps as any other sample submitted for the analytes of interest.

For example, consider samples being submitted for BTEX analysis in water. Purged UHP water is shipped from the lab to the site in a 43 ml VOA vial. The vial remains unopened at the site and is then shipped back to the lab, where it is analyzed using the same methodology as any other BTEX in water sample.

Trip blanks provide the necessary verification that the levels of analytes found in the samples are attributable to the samples and that analyte concentrations are not elevated due to container contamination or other sources of transportation-induced contamination. Since the trip blank is not opened in the field, trip blank analysis is performed to identify contamination resulting from sample shipping and laboratory analytical processes. Exposure to contamination sources during shipping could contribute to the measured analyte concentration in trip blank samples. Glassware, reagents and/or instrumentation are laboratory factors that can affect the measured analyte level in trip blank samples. Low or non-detectable results in the trip blank sample provide assurance that results reported for samples analyzed in the sample submission associated with this trip blank sample are not false positives results.

If the analyte is detected in the trip blank, the concentration should not exceed alert limits presented in Tables 2.1 - 2.10. Data generated from sample submissions where trip blanks exceed the alert limits indicate that contamination of samples contained in the batch may have occurred during the course of sample shipping or analysis in the laboratory. This data should be considered suspect. When water trip blanks are prepared, the Contract Laboratory retains an aliquot of the trip blank in the lab. When the lab is notified (by the consultant) of a concentration exceeding an alert limit being reported for a trip blank sample, the lab analyzes the retained portion of the trip blank sample to ascertain whether the contamination originated in the laboratory or in the field.

Trip blank alert limits vary with matrix and analyte. For most analytes and matrices, the alert limit is that the trip blank must have a result <5X MDL. In some cases, a more stringent criteria may be used (eg: the trip blank alert limit is <2X MDL for CCME F1 hydrocarbons and CCME F2-F4 hydrocarbons, in both soil and water matrices). More stringent criteria are used in cases where the regulatory limits are set at very low concentrations and a value of 5X MDL would exceed the regulatory criteria for the analyte. In such cases, an alert limit that is below the regulatory limit is set. Typically, the goal is to set a trip blank alert limit that is <50% of the regulatory limit.

Trip blank results may in some cases exceed the alert limits established for the particular parameter and matrix. Results reported for these samples analyzed in the same batch as this trip blank are to be considered suspect, since results for all samples in the analytical batch may be biased high. For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. If the trip blank result for any single analyte is outside the alert limit, the results in for all samples in the analytical batch for this particular analyte should be considered suspect and the laboratory must issue a DQW request. Results for other analytes that met the acceptance criteria should not be considered suspect.

Experience has shown that results for trip blank QC samples are rarely observed to exceed the alert limits.

2.3.3) Field Duplicate Samples

A field duplicate sample is defined as *"two independent samples that are collected as close as possible to the same point in space and time. They are two separate samples taken from the same source, stored in separate containers, and analyzed independently. These duplicates are useful in documenting the precision of the sampling process."* [US EPA, 1992].

The two samples collected in the field are treated identically throughout the laboratory analytical procedure and each is carried through the entire laboratory analytical method. These samples are submitted "blind" to the laboratory. Since the samples are given unique identifiers, the lab is typically unaware that the samples were taken from the same source.

Once the two field duplicate samples have been analyzed, the RPD (relative percent difference) is calculated using the following equation:

$$\text{Field Duplicate RPD (\%)} = \frac{(C1 - C2)}{(C1 + C2)/2} \text{ x } 100\%$$

where: RPD = relative percent difference
C1 = larger of the two observed values from the field duplicate analysis
C2 = smaller of the two observed values from the field duplicate analysis

In order for a valid Field Duplicate RPD to be calculated, both results must be >5X MDL. If one or both of the analytical results for the matrix duplicate samples are <5X MDL for an analyte, then it is not possible to calculate a valid Field Duplicate RPD.

Which samples are to be analyzed as field duplicates should be chosen in the field, based upon a biased sampling program by the Environmental Consultant. The consultant should submit field duplicates samples that field screening indicates will have detectable levels of the analytes of interest. This should maximize the probability that at least some of the field duplicate samples will have both sample results >5X MDL and ensure that a valid Field Duplicate RPD can be calculated. Note that this does not mean that only the worst case samples should be submitted as field duplicates. Instead, the goal is to obtain field duplicate samples with a range of detectable concentrations for which a valid Field Duplicate RPD can be calculated.

Analysis of field duplicates provides a combined measure of the field sampling and analytical precision during the analysis of a particular submission of samples. Poor precision (ie: high RPD values) can be an indication of problems with the test method (either the instrumentation or the sample preparation steps). It can also indicate that the sample matrix contained in the sample container is very heterogeneous (this is usually a more common occurrence with soil matrices than water matrices). Sample matrix inhomogeneity can either be an inherent property of the matrix or the result of poor field sampling techniques by the Environmental Consultant. The field duplicate RPD result must meet the specified alert limits presented in Tables 2.1 - 2.10.

Field duplicate alert limits vary with matrix and analyte. For example, in the case of antimony in water (Table 2.8), the calculated result for a field duplicate relative percent difference (RPD) for the two individual field duplicate samples should be <50% in order for the result to be considered within alert limits. Field duplicates may in some cases exceed the alert limits established for the particular parameter and matrix. Analytical results for these samples should only be considered suspect if the matrix duplicate samples associated with this batch of samples also exceeds the acceptance criteria. Cases where matrix duplicates meet acceptance criteria, but field duplicates exceed alert limits are indicative of sample inhomogeneity issues.

For some test methods (eg: BTEX, PCB's, VOC scans, PAH's and metals scans), multiple analytes are analyzed for simultaneously. If the valid field duplicate RPD result for any single analyte is outside the alert limits, the same actions should be taken as if the RPD for a test method analyzing for a single analyte falls outside the alert limits.

The laboratory is usually unaware that two individual samples submitted are field duplicate samples. The consultant is responsible for prompt notification of the laboratory that a Field Duplicate RPD alert limit has been exceeded, to allow the laboratory to begin an immediate investigation of the problem. Typically, the laboratory will re-analyze both field duplicate samples (assuming hold times have not been exceeded and/or sufficient sample remains to complete the re-analysis), to confirm that the original results for both samples are indeed correct. If an analytical error has been made and the results now meet the Field Duplicate RPD alert limit, the analytical results will be re-issued. However, if the analytical results are confirmed and the alert limit is still exceeded, the laboratory will make comments about the results in the CoA.

In the case of soil samples, failure to meet the field duplicate RPD alert limits often occurs due to sample inhomogeneity. If the field duplicates involved are known to be from a sample matrix that is suspected to be heterogeneous, the fact that the alert limits were not met should not be a significant concern in most instances. However, if the sample from which the two field duplicates were obtained was observed to be homogeneous, the observance of a field duplicate sample that exceeds the field duplicate RPD alert limits may be cause for concern. For water samples, the observation of field duplicate QC samples that exceed the field duplicate RPD alert limits is less common, due to the higher homogeneity of that matrix. Typically, exceedances of Field Duplicate RPD acceptance criteria for water samples are only noted when a significant amount of another material (eg: sediment) is present in the sample bottle.

Table 2.1

Acceptance Criteria and Alert Limits For Soil Hydrocarbon Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
BTEX	HS GC/MS	60-140%	na	<5X MDL	<50%	60-140%	60-140%	>5X MDL	>5X MDL	>100%
BTEX	P+T GC/MS	60-140%	30-130%	<5X MDL	<50%	60-140%	60-140%	>5X MDL	>5X MDL	>100%
C10-C50 Hydrocarbons (PQ)	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
CCME F1	GC/FID	na	30-130%	<2X MDL	<50%	30-130%	30-130%	>2X MDL	>2X MDL	>100%
CCME F2-F4	GC/FID	na	30-130%	<2X MDL	<50%	30-130%	30-130%	>2X MDL	>2X MDL	>100%
Hydrocarbon Class	Fractionation	na	na	<5X MDL	<50%	na	na	>5X MDL	>5X MDL	>100%
HEPH (BC)	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
LEPH (BC)	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Oil&grease	Gravimetric	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
PAH's	GC/MS	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Total Purgeables	P+T GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Total Purgeables	P+T GC/MS	60-140%	30-130%	<5X MDL	<50%	60-140%	60-140%	>5X MDL	>5X MDL	>100%
TPH (gas/diesel) [Ontario]	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
TPH (heavy oils) [Ontario]	Gravimetric	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
TEH (Atlantic RBCA)	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
TPH Fractionation (Atl PIRI)	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
TPuH Fractionation (Atl PIRI)	GC/MS	60-140%	30-130%	<5X MDL	<50%	60-140%	60-140%	>5X MDL	>5X MDL	>100%
VPH (BC)	GC/FID	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.2

Acceptance Criteria and Alert Limits For Other Soil Organic Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Acid Extractable Herbicides	GC/MS	na	10-130%	<5X MDL	<50%	10-130%	10-130%	>5X MDL	>5X MDL	>100%
Acid Extractables (phenols)	GC/MS	na	10-130%	<5X MDL	<50%	10-130%	10-130%	>5X MDL	>5X MDL	>100%
Amines	HPLC	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Amines	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
BNA's (no acid extractables)	GC/MS	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Diethanolamine (DEA)	HPLC	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Diisopropanolamine (DIPA)	HPLC	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
EOX/TOX	Combustion	na	na	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Glycols	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Hopane (Resolved and Total)	GC/FID	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
MMT	GC/MS	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Ontario MOE 22 and MOE 43	GC/MS	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
PCB's	GC/ECD	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Soil Sterilant Scan	HPLC	na	30-130%	<5X MDL	<50%	30-130%	30-130%	>5X MDL	>5X MDL	>100%
Vinyl Chloride Monomer	GC/MS/SIM	50-150%	na	<5X MDL	<50%	60-140%	60-140%	>5X MDL	>5X MDL	>100%
VOC's Scan (with chlorinates)	P+T GC/MS	60-140%	na	<5X MDL	<50%	60-140%	60-140%	>5X MDL	>5X MDL	>100%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.3

Acceptance Criteria and Alert Limits For Soil Metals Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Antimony	Hydride AA	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Arsenic	AA	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Boron (hot water soluble)	ICP	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Chromium (hexavalent)	Colourimetric	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Lead	AA	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Mercury	CVAA	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Metals Scan	Optical ICP	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Metals Scan	ICP/MS	na	na	na	<35%	75-125%	75-125%	na	na	>100%
Selenium	Hydride AA	na	na	na	<35%	75-125%	75-125%	na	na	>100%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)
"Metals Scan" = aluminum, barium, beryllium, boron, cadmium, cobalt, copper, iron, manganese, molybdenum, nickel, silver, strontium, thallium, uranium, vanadium & zinc

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
Preparation of blank samples (method, field and trip) is not practical for metals in a solid matrices (solid matrices will typically have trace levels of these metals >MDL)
Preparation of LCS (spiked blank) samples is practical in solid matrix (spike level is much higher than trace levels of metals that may be found in the matrix)
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable

Table 2.4

Acceptance Criteria and Alert Limits For Other Inorganic and Organic Soil Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Bromide	IC	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Cyanide (Total)	Colourimetric	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Fluoride (Total)	Electrometric	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Nitrate	IC	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Nitrite	IC	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Nitrogen (Total Kjeldahl)	Colourimetric	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
pH	Electrometric	na	na	na	<35%	na	na	na	na	>100%
Phenols	Colourimetric	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Phosphorus (Total)	Colourimetric	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Specific Conductance	Electrometric	na	na	na	<35%	na	na	na	na	>100%
Sulphur (Elemental)	Colourimetric	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Total Inorganic Carbon	Combustion	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%
Total Organic Carbon	Combustion	na	na	<5X MDL	<35%	75-125%	75-125%	<5X MDL	<5X MDL	>100%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
Trip blank samples are not routinely analyzed for soil inorganic parameters, unless analysis of such field QC samples is a regulatory requirement
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.5

Acceptance Criteria and Alert Limits For Miscellaneous Soil Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Bulk Density	Gravimetric	na	na	na	<35%	na	na	na	na	>100%
Exchangeable Cations	IC	na	na	<5X MDL	<35%	na	na	>5X MDL	na	>100%
Flashpoint	Closed Cup	na	na	na	<35%	na	na	na	na	>100%
Ignitability	Match	na	na	na	<35%	na	na	na	na	>100%
Loss on Ignition	Gravimetric	na	na	na	<35%	na	na	na	na	>100%
Micro-Tox (solid phase)	Micro-tox	na	na	na	<35%	na	na	na	na	>100%
Paint Filter Test	Filter	na	na	na	<35%	na	na	na	na	>100%
Rope Burn Test	As defined	na	na	na	<35%	na	na	na	na	>100%
Sodium Adsorption Ratio	ICP calc	na	na	<5X MDL	<35%	na	na	>5X MDL	na	>100%
Soil Texture	Hydrometer	na	na	na	na	na	na	na	na	na
Spontaneous Combustion	Powder train	na	na	na	<35%	na	na	na	na	>100%
Theoretical Gypsum Req.	ICP calc	na	na	<5X MDL	<35%	na	na	>5X MDL	na	>100%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
Trip blank samples are not routinely analyzed for these miscellaneous soil parameters, unless analysis of such field QC samples is a regulatory requirement
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.6

Acceptance Criteria and Alert Limits For Water Hydrocarbon Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
BTEX	P+T GC/MS	70-130%	na	<5X MDL	<40%	70-130%	70-130%	>5X MDL	>5X MDL	>80%
C10-C50 Hydrocarbons (PQ)	GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
CCME F1	GC/FID	na	na	<2X MDL	<40%	30-130%	30-130%	>2X MDL	>2X MDL	>80%
CCME F2-F4	GC/FID	na	na	<2X MDL	<40%	30-130%	30-130%	>2X MDL	>2X MDL	>80%
HEPH (BC)	GC/FID	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
LEPH (BC)	GC/FID	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Oil&grease	Gravimetric	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
PAH's	GC/MS	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Total Purgeables	P+T GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Total Purgeables	P+T GC/MS	70-130%	na	<5X MDL	<40%	70-130%	70-130%	>5X MDL	>5X MDL	>80%
TPH (gas/diesel) [Ontario]	GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
TPH (heavy oils) [Ontario]	Gravimetric	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
TEH (Atlantic RBCA)	GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
TPH Fractionation (Atl PIRI)	GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
TPuH Fractionation (Atl PIRI)	GC/MS	na	na	<5X MDL	<40%	70-130%	70-130%	>5X MDL	>5X MDL	>80%
VPH (BC)	GC/FID	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For test methods where volatile parameters are directly purged from the water sample into the instrument, only instrument surrogates are used
For test methods where semi-volatile parameters are extracted from the water sample and the extract analyzed by the instrument, only extraction surrogates are used
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.7

Acceptance Criteria and Alert Limits For Other Water Organic Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Acid Extractables (phenols)	GC/MS	na	10-130%	<5X MDL	<40%	10-130%	10-130%	>5X MDL	>5X MDL	>80%
Amines	GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
BNA's (no acid extractables)	GC/MS	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Dibenzo Dioxins and Furans	GC/MS	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Diethanolamine (DEA)	IC	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Diisopropanolamine (DIPA)	IC	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Formaldehyde	Colorimetry	na	na	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Glycols	GC/FID	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
MMT	GC/MS	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
MTBE	P+T GC/MS	70-130%	na	<5X MDL	<40%	70-130%	70-130%	>5X MDL	>5X MDL	>80%
PCB's	GC/ECD	na	30-130%	<5X MDL	<40%	30-130%	30-130%	>5X MDL	>5X MDL	>80%
Vinyl Chloride	GC/MS/SIM	60-140%	na	<5X MDL	<40%	70-130%	70-130%	>5X MDL	>5X MDL	>80%
VOC's Scan (with chlorinates)	P+T GC/MS	70-130%	na	<5X MDL	<40%	70-130%	70-130%	>5X MDL	>5X MDL	>80%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For test methods where volatile parameters are directly purged from the water sample into the instrument, only instrument surrogates are used
For test methods where semi-volatile parameters are extracted from the water sample and the extract analyzed by the instrument, only extraction surrogates are used
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.8

Acceptance Criteria and Alert Limits For Water Metals Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Antimony	Hydride AA	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Arsenic	AA	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Chromium (hexavalent)	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Copper	ICP	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Lead	AA	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Mercury	CVAA	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Metals Scan	Optical ICP	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Metals Scan	ICP/MS	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Selenium	Hydride AA	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Zinc	ICP	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)
"Metals Scan" = aluminum, barium, beryllium, boron, cadmium, cobalt, copper, iron, manganese, molybdenum, nickel, silver, strontium, thallium, uranium, vanadium & zinc

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.9

Acceptance Criteria and Alert Limits For Other Water Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
Ammonia	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Bromide	IC	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Chloride	IC	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Cyanide (Total)	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Fluoride (Total)	Electrometric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Nitrate	IC	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Nitrite	IC	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Nitrogen (Total Kjeldahl)	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
pH	Electrometric	na	na	na	<25%	na	na	na	na	>50%
Phenols	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Phosphorus (Total)	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Specific Conductance	Electrometric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Sulfate	IC	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Sulphur (Elemental)	Colourimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Total Dissolved Solids	Electrometric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Total Dissolved Solids	Gravimetric	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Total Inorganic Carbon	Combustion	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%
Total Organic Carbon	Combustion	na	na	<5X MDL	<25%	80-120%	80-120%	>5X MDL	>5X MDL	>50%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For matrix spike samples, the spike concentration must typically be >2X the native concentration in order to obtain a reportable recovery
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

Table 2.10

Acceptance Criteria and Alert Limits For Soil Gas and Air Hydrocarbon Parameters

Parameter	Method Description	Individual Sample Lab QC Acceptance Criteria		Lab QC Samples for Batches Acceptance Criteria				Field QC Samples Alert Limits		
		Instrument Surrogate Recovery	Extraction Surrogate Recovery	Method Blank	Matrix Duplicate RPD	Matrix Spike Recovery	LCS Recovery	Field Blank	Trip Blank	Field Duplicate RPD
VOC's (excluding BTEX)	GC/MS	60-140%	na	<1X MDL	<25%	na	60-140%	>5X MDL	>5X MDL	>50%
BTEX	GC/MS	60-140%	na	<1X MDL	<25%	na	60-140%	>5X MDL	>5X MDL	>50%
TPH Fractionation	GC/MS	60-140%	na	<1X MDL	<25%	na	60-140%	>5X MDL	>5X MDL	>50%

"na" = this type of QC sample not analyzed for this parameter and test methodology
"LCS" = Laboratory Control Sample (commonly referred to as a "spiked blank" sample)

For both matrix duplicates and field duplicates, both sample results must be >5X MDL in order to calculate a valid RPD
For VOC's analysis, the method blank acceptance criteria is <2X MDL for dichloromethane and <10X MDL for toluene (both are common laboratory solvents)
For all suites containing multiple analytes, the lab QC samples for batches must meet the acceptance criteria for all analytes, or a DQW request will be issued
For matrix spike and LCS samples, the minimum allowable acceptance criteria are presented. The use of tighter (usually statistically derived) acceptance criteria is allowable
Depending on regulatory and/or project-specific QC requirements, all field QC samples presented in this table need not be submitted to the laboratory for analysis

3) DATA REPORTING AND REVIEW

3.1) Data Package Requirements For Environmental Consultants

Third-party environmental analytical laboratories are responsible for the analysis of environmental samples generated at Imperial Oil sites across Canada. All analytical results are to be reported to the Environmental Consultant. The Environmental Consultant then reports the data to Imperial Oil via a data package.

For each sample submission to the laboratory, the data package must be prepared and reported to Imperial Oil by the Environmental Consultant in any draft and final reports generated for the project. The data package must contain the following components, in the following order:

1) the CoA generated by the laboratory. Without exception, the laboratory's CoA must contain all of the data reportables presented in Table 3.1. Note that the Contract Laboratory is contractually forbidden from supplying abbreviated CoA's that do not contain all the information contained in Table 3.1. Each CoA must be signed off by the Contract Laboratory's Project Manager to be considered valid.

2) if any DQW requests were generated that are associated with this lab submission, they must be appended immediately following the CoA. These DQW requests are generated by the Contract Laboratory and must be signed off by the consultant, then returned to the laboratory. DQW request requirements will be discussed in detail in Section 3.2.

3) the completed Chain of Custody (CoC) form associated with the CoA must next be appended to the data package by the Contract Laboratory. The completed CoC will be provided to the Environmental Consultant by the Contract Laboratory.

4) finally, the Data Quality Review Checklist that has been completed by the Environmental Consultant must be appended to the data package.

The standardization of reporting in data packages serves several useful purposes. These include:

1) it ensures that all relevant QA/QC data is provided by the laboratory, so that an independent data review can be performed by the Environmental Consultant and/or Imperial Oil.

Table 3.1

Data Reportables for CoA's Generated on Imperial Oil Projects

Reportable	Description
Time Marker Information	• Date sampled (for each sample) • Date shipped (for each sample shipment) • Date received (for each sample shipment) • Date extracted or digested (for each sample) • Date analyzed (for each sample) • Date reported (for each sample)
Data Reportables	• Analytical data • Detection limits • Units • Data Qualifiers (interference, wet weight, etc.) • Temperature of samples upon receipt • Presence of custody seals and whether intact • GC chromatograms and GC/MS traces, if requested • Hydrocarbon scans (by hydrocarbon number), if requested
QC Reportables	• Matrix Duplicates (including RPD for each parameter) • Method Blank • Trip Blank (where applicable) • Field Blank (where applicable) • Lab Control Samples • Matrix Spike Analyses • Surrogate Recoveries (on certain organic analyses)
Analysis Reportables	• A short description of the method used for each analytical parameter must be included in the CoA • The primary reference method that the test method is based upon • The laboratory SOP number and revision number of this SOP that was in use at the time the samples were analyzed
Remarks and Comments	• Reports of any unusual behaviour noted in any step of the analytical process (such as sample inhomogeneity, headspace in vial when there should have been none, result rechecked, etc.) • The laboratory must certify that the analytical methodologies used to generate data contained in the C of A were in "statistical control" when results for the samples contained in the report were generated. Any analytical methods that were not in control must be flagged • The laboratory must certify that the acceptance criteria for spike recoveries, reference material recoveries, blank sample results and lab duplicate precision were met for all the QC samples in the report. Any QC samples results not meeting these criteria must be flagged • Flagging of samples not analyzed within analytical hold times

2) it reduces the error rate of the laboratory when generating data package components, since only one standard Imperial Oil data package is being produced in each region. This avoids the inevitable higher error rates that occur when various consultants and Imperial Oil personnel request the laboratory to produce customized data packages.

3) attachment of the CoC and the completed DQW request to the data package ensures that these documents will not be lost over time. This can be particularly important in legal cases, where it may be necessary to produce these documents many years after the samples were analyzed.

4) attachment of the Data Quality Review Checklist will provide documented assurance that an independent review of the data generated by the laboratory has been performed, before it has been reported to Imperial Oil.

Note that in certain circumstances, there may be legal or business drivers for CoC's not to be included in the data packages that are presented in the Environmental Consultant's report. Under these circumstances, and at the specific request of the Imperial Oil Project Manager, the CoC may be excluded from the data package. In this case, the Environmental Consultant is to provide copies of the CoC's not included in the data packages to the IOL Project Manager under separate cover letter. These CoC's are to be kept in the IOL project file, for easy access, if there is ever any challenge to the validity of the data associated with these CoC's. Note that Environmental Consultants are not authorized to request the exclusion of CoC's from data packages; only Imperial Oil Project Managers have this authority and this permission must be given on a report by report basis.

3.2) Data Quality Waiver Requests

Data Quality Waiver (DQW) requests are generated by the laboratory when a deficiency has been noted that may adversely affect the integrity of the data reported for the sample. Examples of blank and completed DQW request forms are presented in Appendix A.

Environmental Consultants are contractually obligated to review all DQW request's issued for Imperial Oil projects. The Environmental Consultant has option to grant the DQW request for all samples affected by the request, for some of the samples affected by the request, or for none of the samples affected by the request. In cases where the DQW request is not granted for all affected samples, the consultant is required to document its reasons why the request was denied on the DQW request form issued by the laboratory. If a DQW request is not granted by the consultant personnel who reviews the data for all the affected samples, the laboratory is required to make all reasonable efforts to ensure that data meeting all quality standards will be provided to the consultant. These efforts could include sample re-analysis, or possibly even a re-sampling event. In the event of a dispute between the Environmental Consultant and the Contract Laboratory, the Imperial Oil Project Manager (in consultation with their direct supervisor) will determine what

constitutes a "reasonable effort". The decision of Imperial Oil in all such matters will be considered final.

The Environmental Consultant has 14 calendar days to complete and return (via fax) the completed DQW request form to the Contract Laboratory, indicating whether or not they have agreed to grant the DQW request for the data that has failed to meet all quality objectives. If a response is not received after 14 calendar days, the laboratory is allowed to assume that the Environmental Consultant has agreed to accept the data in its qualified format. The number of unsigned DQW request's (broken down by Environmental Consultant and region) is reported to Imperial Oil on a quarterly basis by the Contract Laboratory. Repeated failure to complete and return the DQW request forms by Environmental Consultants within the specified time will be considered non-compliance with contractual obligations by Imperial Oil. This is considered a serious matter and appropriate corrective actions will be swiftly put in place in order to obtain contractual compliance.

Decisions by the Environmental Consultant regarding whether a DQW request is granted must be made based on the criticality of the QC sample failure and the potential impact on the quality of the associated sample data. This is further discussed in Section 3.3.

There are a number of situations when the Contract Laboratory will issue a DQW request. DQW requests will only be issued for situations that were entirely within the control of the laboratory. If a situation arises where the integrity of the data generated from the samples may be compromised, but the situation was not within control of the lab (eg: samples arriving at the laboratory past their analytical hold times), then a DQW will not be issued. However, this type of data integrity issue (which is discussed in more detail in Section 3.3) will be flagged on the Certificate of Analysis generated by the laboratory.

Situations involving laboratory problems in sample handling that will lead to the issuance of a DQW request include:

1) when samples arrive at the laboratory within their analytical hold times, but are extracted and/or analyzed past their hold times, a DQW request will be issued. Note that if a soil BTEX sample is not methanol extracted (if required by the test methodology being used) within 48 hours of receipt by the laboratory, a DQW request will be issued. Note that samples submitted for full VOC scans are not routinely methanol extracted. If the samples are considered to be "critical", the Contract Laboratory may be held responsible for re-sampling, at their expense.

2) should laboratory refrigeration units fail and the temperature of the samples rise to >10°C before they have been analyzed, a DQW request will be issued. If the samples are considered to be "critical", the Contract Laboratory may be held responsible for re-sampling, at their expense.

Situations involving laboratory problems in sample analysis that will lead to the issuance of a DQW request include:

1) when data has been generated that is outside Imperial Oil acceptance criteria levels for surrogate recoveries (either instrument or extraction), method blank concentrations, matrix duplicate RPD's, Lab Control Sample recoveries and/or matrix spike recoveries, a DQW request will be issued by the laboratory.

2) if data is issued from a sample batch where the instrument's continuing calibration verification (CCV) standard has failed to meet internal acceptance criteria, a DQW request will be issued. If the CCV fails to meet acceptance criteria, the lab is required to re-analyze the entire batch of samples associated with the CCV failure. Issuance of a DQW request only occurs when there is insufficient sample remaining to perform re-analysis, the hold time has been exceeded for the samples, or the lab cannot get the instrument back into calibration.

3) when a test method is not in statistical control (ie: when a control chart data point for the LCS is beyond the 3σ control limits) for a sample batch, a DQW request will be issued. Note that statistical trend testing is also performed on control charts generated in the laboratory. When a statistical trend test has been violated, a DQW request will not be issued. Instead, a comment that a trend test has been violated will be included in the CoA.

4) data for multi-analyte analyses (eg: VOC's scan) may be considered acceptable if data for some of the analytes are above the highest calibration standard, but are still within the linear range of the instrument for that component. This is only acceptable if the reference method that the SOP is based upon allows this practice. Otherwise, data reported from outside the calibration range are to be considered suspect and a DQW request must be issued. For single analyte analyses (eg: mercury in water), reporting of data outside the calibration range is not permissible. It is expected that the sample will be diluted back into calibration range. If single analyte analyses are reported outside the calibration range, a DQW request must be issued.

5) situations encountered during the analysis of samples may initiate special handling of the samples, which can trigger the issuance of a DQW request. Examples of these types of special handling include:

   i) analysis of a non-routine matrix (eg: caustic sludge) may cause issues not captured by batch QC (eg: highly elevated MDL's may be reported, due to the high dilution required by the sample). In these cases, a DQW request will be issued by the lab.

   ii) if results are reported for organic parameters from a non-standard extract (eg: PAH's are analyzed from a TEH extract, at the request of a client), a DQW request will be issued.

6) any other laboratory related event that could potentially impact data quality, will result in the issuance of a DQW request. These will likely be highly unusual, one-time events. It is recommended that the Environmental Consultant discuss the implications of these events with the Contract Laboratory, when deciding whether to grant the DQW request.

For any sample submission where one of these issues is noted, a DQW request will be issued by the Contract Laboratory and faxed to the Environmental Consultant (usually at the same time as the CoA is being faxed to the consultant). The DQW request must specify the deviation, the potential adverse consequences of this deviation (eg: results may be biased high or low) and the samples affected by the quality deviation.

3.3) Data Quality Issues Not Covered by DQW Requests

There are a number of situations where the integrity of the data may come into question, but where the Contract Laboratory will not issue a DQW request. DQW requests are only issued for data quality issues that were entirely within the control of the laboratory. If a situation arises where the integrity of the data generated from the samples may be compromised, but the situation was not entirely within control of the lab, then a DQW will not be issued. However, this type of data integrity issue will be flagged on the Certificate of Analysis generated by the laboratory.

Situations that are noted upon the arrival of the samples of the laboratory that will be flagged as a data quality issue on the Certificate of Analysis include:

1) when samples arrive at the laboratory past their required analytical hold times, this will be flagged as a data quality issue on the Certificate of Analysis. If the samples are considered to be "critical", the Environmental Consultant may be held responsible for re-sampling, at their expense.

2) when samples for the analysis of chemical parameters arrive at the lab at >10°C, this will be flagged as a data quality issue on the Certificate of Analysis. This situation will not be flagged if the samples arrive at the laboratory at >10°C on the same day that the samples were taken in the field. If the samples are considered to be "critical", the Environmental Consultant may be held responsible for re-sampling, at their expense.

3) when samples are provided to the laboratory in improper containers, this will be flagged as a data quality issue on the Certificate of Analysis. For example, when VOC and/or BTEX water samples are submitted in a container other than a VOA vial, this will be flagged as a data quality issue on the Certificate of Analysis. In addition, if VOC and/or BTEX soil samples are submitted in a broken jar that requires transferring of the sample into new jar or taping the jar, this will be flagged as a data quality issue on the Certificate of Analysis. If the samples are considered to be "critical", the Environmental Consultant may be held responsible for re-sampling, at their expense.

4) if samples arrive in cooler with a broken or missing custody seal, this will be flagged as a data quality issue on the Certificate of Analysis.

5) if samples arrive at the lab submerged in water inside the cooler, this will be flagged as a data quality issue on the Certificate of Analysis. The sample bottles should be kept dry, inside ziplock plastic bags in the cooler. When this is not done, melting water from the ice can sometimes get inside the sample bottles (if the lids have not been fastened tightly). This can cause dilution of water samples and possible contamination of soil samples. In either case, the compromising of sample integrity can result in the data generated from these samples being considered suspect. Thus, these situations will be flagged as a data quality issue on the Certificate of Analysis.

6) for volatiles analysis, if the sample container has significant headspace upon receipt by the laboratory, this will be flagged as a data quality issue on the Certificate of Analysis. If the samples are considered to be "critical", the Environmental Consultant may be held responsible for re-sampling, at their expense.

Situations resulting from field and/or laboratory problems that will be flagged as a data quality issue on the Certificate of Analysis include:

1) when an alert limit for a field blank concentration and/or a trip blank concentration has been exceeded, this will be flagged as a data quality issue on the Certificate of Analysis. In order for these actions to occur, the Environmental Consultant must inform the Contract Laboratory of the failure of the field QC samples to meet these alert limits in a timely fashion.

2) when a field duplicate RPD exceeds an alert limit, a DQW request will not be issued by the laboratory. This will be flagged as a data quality issue on the Certificate of Analysis. In order for these actions to occur, the Environmental Consultant must inform the Contract Laboratory of the failure of the field QC samples to meet these alert limits in a timely fashion.

3.4) Data Quality Review By Environmental Consultant

3.4.1) Data Quality Review Checklist

The contract with Environmental Consultants stipulates that they are required to perform an independent review of data generated by Contract Laboratories utilized in Imperial Oil projects. The purpose of this review is to ensure that data being utilized in reports prepared for Imperial Oil is considered to be generally reliable (in the professional opinion of the Environmental Consultant). In cases where there are significant data quality issues, these should be identified; the potential effect of these issues on the conclusions drawn from the data should also be evaluated by the consultant.

In order to simplify and expedite a review of the quality of laboratory data reported in a data package (which includes a Certificate of Analysis), a standardized checklist has been developed. This will provide a means of easily identifying deficiencies regarding sample analyses that might impact data quality. This checklist and examples of a completed checklist are presented in Appendix B.

In some cases, Environmental Consultants may have developed their own checklist to review the quality of laboratory data reported in a data package. With the permission of the regional team leader, consultants can use their own checklist to review the quality of laboratory data, providing that the consultant's checklist meets certain minimum requirements. These minimum requirements are also presented in Appendix B.

Upon receipt of a data package from the laboratory, the checklist should be promptly completed by the Environmental Consultant. This allows for timely identification of potential data quality issues and permits the opportunity for resolution of these issues (eg: by re-analysis of samples or by re-sampling). A Data Quality Review Checklist must be completed by the Environmental Consultant for every data package (ie: every CoA) issued by the Contract Laboratory.

Completed Data Quality Review Checklists should be included as part of the data package prepared for inclusion in reports prepared for Imperial Oil (see Section 3.1).

3.4.2) Interpretation of QC Sample Failures and Data Quality Waiver Requests

Once the checklist presented in Appendix B has been completed, quality issues are easily identified and addressed.

The occurrence of QC sample failures and other deficiencies that result in the issue of a DQW request does not always indicate that the impact on the sample data is critical, nor does it imply that the sample data associated with the DQW request and/or QC sample(s) failures is not useful. It is important to review these events on a case-by-case basis, to determine the impact of the deficiency on the sample data quality and ascertain if the sample data is still useable.

There are three useful rules-of-thumb that the Environmental Consultant should consider when deciding whether or not to grant a DQW request to the Contract Laboratory:

1) the criticality of the data end use is a prime factor in deciding whether a DQW request should be accepted or not. For long term monitoring programs, the data quality is usually not of a critical nature. In long term monitoring programs, the site will be sampled again at a future date, so a data quality issue during a single monitoring event is of little consequence. On the other hand, for remediation programs, sites involved with legal issues and sites with active regulatory interest, the quality of the data provided is much more critical. In these cases, re-analysis and/or re-sampling could be required in some

circumstances. For initial intrusive site assessments, the criticality of the data quality generally falls in between these two extremes. Often, further work will be performed on the site before it is released. However, if results very close to regulatory criteria are reported in the intrusive site assessment, potential data quality issues should be taken into account when deciding the scope of future work at the site (eg: further delineation, remediation or monitoring).

2) if the sample result concentration is either far above or far below the regulatory criteria of the parameter in question, then the quality issues associated with the generation of a DQW request are often not a concern (especially the failure of a laboratory QC sample to meet an acceptance criterion or a field QC samples to meet an alert limit). However, if the sample result(s) is close to the regulatory criteria, the fact that a QC sample failure occurred suggests that the data associated with the QC sample is suspect. In these cases, there is a significant risk that sample results may surpass regulatory criteria, although the data does not indicate this (ie: the data is biased low). Alternatively, sample results may appear to exceed criteria, when in fact they do not (ie: the data is biased high). In these cases, re-analysis of a retained sample may be necessary (if hold times have not been exceeded) or re-sampling may need to be done, depending on the criticality of the data.

3) in some cases, data is not being generated for comparison to regulatory criteria. Instead, the data is being generated to monitor the performance of a remedial system. A classic example of this is the case of soil bioremediation projects. In these projects, fertilizers are added to reach target levels or available nitrogen and phosphorus in the soil, to aid in the aerobic biodegradation process. If the Total Kjeldahl Nitrogen (TKN) target is 200 mg/kg, then it is of operational interest to know that levels are in this range. Potential biases caused by data quality issues (eg: a potential positive bias of 7 mg/kg, due to a field blank sample exceeding its alert limit), may not have a significant effect on the conclusions obtained on the TKN results obtained for operational purposes. If this is the case, the generation of a DQW request is often not a matter of concern and the DQW request should be granted by the consultant.

Illustrative examples of cases involving DQW requests and/or failed QC data are presented in Appendix C. These examples provide guidance on determining if the DQW request should be granted by the Environmental Consultant or if further actions are warranted (eg: repeat analysis or re-sampling).

3.4.3) Investigation of Alert Limit Exceedances For Field Duplicate Samples

The exceedance of a field duplicate alert limit does not result in the issuance of a DQW request by the laboratory. Instead, it results in the data being flagged in the CoA. However, the fact that a DQW request is not issued does not mean that exceedances of field duplicate alert limits should not be investigated by the Environmental Consultant. At a minimum, this investigation should include the following steps:

1) the Environmental Consultant should immediately notify the laboratory that the field duplicate sample has exceeded the alert limits. The consultant should provide the laboratory all pertinent information about the field duplicates samples (ie: what the laboratory's unique sample ID number is for each sample and for which analytes the field duplicate RPD alert limits was exceeded).

2) the laboratory will check the sample integrity records they keep for each sample submission. This will note if there were integrity issues with either of the field duplicate samples (eg: for volatiles samples, if one of the samples had significant headspace, while the other did not).

3) if the samples have not been sent for disposal by the laboratory, they will retrieve both samples from storage and visually examine them. The lab will note if the samples appear to be visually different (eg: one water sample contains sediment, while the other does not). The lab will also note if the samples look the same, but consist of matrices where sample inhomogeneity is common (eg: clay or fractured clay samples).

4) the lab will report the findings back to the consultant. If there are no sample integrity issues, both duplicate samples have the same appearance and the sample is not comprised of a matrix that is typically associated with sample heterogeneity issues, then the consultant may wish to request that the lab re-analyze both field duplicate samples. Note that the cost of any such analysis will be borne by Imperial Oil.

In the case of critical samples, the consultant may wish to augment their investigation of field duplicate alert limit exceedances by using additional steps.

4) REFERENCES

Blue, 2002; "Preferred Operating Practices for Soil Sampling for Field Screening and Laboratory Analysis at Hydrocarbon Impacted Sites (Revision 5)"; D.W. Blue, P.R. Walsh and P.G. Miasek; published by Imperial Oil; July 12/2002.

US EPA, 1992; "United States EPA SW-846 Test Methods for Evaluating Solid Wastes Physical/Chemical Methods (Revision 1)"; Chapter 1, Pages 23-29, July 1992. Available at: http://www.epa.gov/epaoswer/hazwaste/test/main/pdfs/chap1.pdf

Walsh, 2002; "Preferred Operating Practices for Borehole/Monitoring Well Installation and Associated Soil/Groundwater Sampling at Hydrocarbon Impacted Sites (Revision 5)"; P.R. Walsh, D.W. Blue, P.G. Miasek and T.T. Strawn; published by Imperial Oil; May 15/2002.

APPENDIX A

DATA QUALITY WAIVER (DQW) REQUESTS

APPENDIX A

DATA QUALITY WAIVER (DQW) REQUESTS

Whenever there has been a data quality situation (these have been defined in Section 3.2 of the main body of this POP), the Contract Laboratory is contractually obligated to issue a Data Quality Waiver (DQW) request to the Environmental Consultant. The consultant is contractually obligated to review this request, using the practices presented in this POP. The consultant will decide to grant the DQW request for all of the samples it applies to, some of the samples for which it applies to, or none of the samples for which it applies to. In cases where the DQW request has not been granted for all samples, the consultant must provide a reason why the request was not granted.

The Envirnomental Consultant must then sign off the DQW request form and return it to the Contract Laboratory (preferrably by fax), within 14 calendar days of the date that the laboratory has issued the DQW request to the consultant. If the Contract Laboratory does not receive a completed copy of the DQW request form from the Environmental Consultant within 14 calendar days of issuance, the laboratory is allowed to assume that the consultant has taken no exception to the the DQW request and the Contract Laboratory is then allowed to close off the DQW request. Consultants should note that not signing off the DQW request form to signify aceptance of the DQW request is not considered an acceptable practice by Imperial Oil. For every Environmetnal Consultant, the Contract Laboratory will be tracking the total number of DQW requests issued and the number returned signed by the consultant. This data will be reported to Imperial Oil on a quarterly basis and consultants who are not routinely signing off and returning DQW request forms within the required time frame will be held accountable for this breach of their contractual obligations.

An example of the blank Data Quality Waiver request form used by PSC Analytical on a national basis is presented in Figure A1. An example of a completed Data Quality Waiver request is provided in Figure A2.

Figure A1

Example Blank Data Quality Waiver Request Form

PSC ANALYTICAL SERVICES

IMPERIAL OIL LIMITED / EXXONMOBIL CANADA
PSC ANALYTICAL SERVICES CONTRACT

Data Quality Waiver Request #

If this waiver is not returned, or the undersigned PSC Analytical representative not contacted within 14 days of issuance, the laboratory will deem the associated data as acceptable to the recipient, as reported by the laboratory. Please note: If no response has been received within 14 days of issuance, this Data Quality Waiver will be considered incomplete by the laboratory and reported as such to Imperial Oil/ExxonMobil Canada in quarterly stewardship reports.

Client:	Form #:
Project:	# of Samples:
Consultant:	IOL PM:
Consultant PM:	

IOL Site Location:

Customer Samples Affected:

Date of Deviation: Test Affected:

DQW Type:

Reason for Deviation:

Waiver Issued By:	Comments:

Data Quality Waiver Reviewed and Accepted By:

Print Name: Title:

Signature: Date:

Samples DQW Accepted For: All samples ☐

☐ Some samples (#'s/reason): _____

☐ No samples (reason): _____

Monday, July 12, 2004

Figure A2

Example Completed Data Quality Waiver Request Form

PSC ANALYTICAL SERVICES

IMPERIAL OIL LIMITED / EXXONMOBIL CANADA
PSC ANALYTICAL SERVICES CONTRACT

PSC Bedford **Data Quality Waiver Request #** **96**

If this waiver is not returned, or the undersigned PSC Analytical representative not contacted within 14 days of issuance, the laboratory will deem the associated data as acceptable to the recipient, as reported by the laboratory. Please note: If no response has been received within 14 days of issuance, this Data Quality Waiver will be considered incomplete by the laboratory and reported as such to Imperial Oil/ExxonMobil Canada in quarterly stewardship reports.

Client:	Fraser River Consultant	**Form #:**	12345678
Project:	V0-12345G	**# of Samples:**	12
Consultant:	Consultant X	**IOL PM:**	Anne Chum
Consultant PM:	Joe Thomas		

IOL Site Location: Queen Valley Road

Customer Samples Affected: COC # 12345678 - PSC Sample #'s 22111 - 22123

Date of Deviation: 3/10/2003 **Test Affected:** F1- BTEX

DQW Type: 3 - Duplicate RPD's outside of acceptance limits

Reason for Deviation: Field duplicates - RPD for F1-BTEX is 110 %, which exceeds IOL criteria

Waiver Issued By:
Drew Sparks

Comments:
Initial corrective action report and provide detail report of root cause.

Data Quality Waiver Reviewed and Accepted By:

Print Name: Mary Smith **Title:** Brownfield Manager

Signature: Mary Smith **Date:** 4/8/2003

Samples DQW Accepted For: **All samples** ☐

☑ **Some samples (#'s/reason):** Do not accept for samples #'s 22117 & 22121 as they are legal compliance samples

☐ **No samples (reason):**

Monday, July 12, 2004

APPENDIX B

DATA QUALITY REVIEW CHECKLIST

APPENDIX B

DATA QUALITY REVIEW CHECKLIST

A Data Quality Review Checklist must be completed by the Environmental Consultant for each CoA issued by the Contract Laboratory.

The minimum requirements for a Data Quality Review Checklist are outlined in Table B1. If a checklist developed by an Environmental Consultant meets all of these requirements, they may use there own checkilst to review data, provided they have received permission from Imperial Oil's regional team leader to do so.

An example of a blank Data Quality Review Checklist is presented in Figure B1. Examples of completed Data Quality Review Checklists using this example are provided in Figures B2-B4. In the completed checklists, the information entered by the Environmental Consultant is presented in *italics*.

Figure B2 is a completed checklist for a metals in soil analysis. Note that there are no extraction or instrument surrogates, lab method blanks, field blanks or trip blanks associated with these analyses. Thus, the NA (Not Applicable) field is checked off in the checklist for each of these lab and field QC samples.

Figure B3 is a completed checklist for a BTEX in soil analysis. Note that there are no field blanks or trip blanks associated with these analyses. While alert criteria are provided for these field QC samples in Table 2.1, these field QC samples are not typically submitted to the laboratory (they would only be submitted if requested by the Imperial Oil Project Manager, or if their submission was a regulatory requirement). Thus, the NA (Not Applicable) is checked off in the checklist for both of field QC samples. A DQW request was issued for this data, due to the failure of the laboratory matrix spike to meet acceptance criteria. Since the affected BTEX levels were several times greater than the regulatory criteria, the the effect of this failure to meet acceptance criteria was considered minimal and the DQW request was granted.

Figure B4 is a completed checklist for a BTEX in groundwater analysis. Note that all laboratory and field QC samples are typically performed with this analysis. A DQW request was issued for this data, due to the failure of the laboratory matrix spike to meet acceptance criteria. The affected BTEX concentrations were very close to the regulatory criteria, but the samples wre part of a long term monitoring program and the criticality of these results was considered to be low. Thus, the DQW request was granted.

Table B1

Minimum Requirements for Data Quality Review Checklist

Reportable	Minimum Information Requirements
Project Information	• Consulting firm. • Site location. • Sampling date. • Contract laboratory used. • Sample submission number.
Laboratory QC Data Results	• Did instrument surrogates recoveries meet acceptance criteria? • Did extraction surrogate recovery meet acceptance criteria? • Did lab method blank concentration meet acceptance criteria? • Did lab matrix duplicate RPD meet acceptance criteria? • Did lab matrix spike recovery meet acceptance criteria? • Did lab control sample recovery meet acceptance criteria?
Field QC Data Results	• Did field blank concentration meet acceptance criteria? • Did trip blank concentration meet acceptance criteria? • Did field matrix duplicate RPD meet acceptance criteria?
Other Data Reportables	• Was the CoA signed off by the lab? • Was the CoC signed off by both the lab and consultant (signature, date and time for both)? • Did lab warrant all test methods were in statistical control? • Were sample temperatures acceptable when they arrived at the laboratory? • Does the consultant consider the lab data to be reliable? If answer is "no", provide a rationale.
Sign Off	• Name of person reviewing the data for the consultant (typed or printed). • Signature of the person reviewing the data for the consultant. • Date of data review.

Figure B1

Example Blank Data Quality Review Checklist

DATA QUALITY REVIEW CHECKLIST - IMPERIAL OIL PROJECTS

Consultant: _____ Sampling Date: _____

Location: _____ Laboratory : _____

Consultant Project Number: _____ Sample Submission Number: _____

Are All Laboratory QC Samples Within Acceptance Criteria (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Instrument Surrogate Recovery				
Extraction Surrogate Recovery				
Method Blank Concentration				
Matrix Duplicate RPD				
Matrix Spike Recovery				
Lab Control Sample Recovery				

Are All Field QC Samples Within Alert Limits (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Field Blank Concentration				
Trip Blank Concentration				
Field Duplicate RPD				

Has CoA been signed off (Yes/No)?: _____
Has lab warranted all tests were in statistical control in CoA (Yes/No)?: _____
Has lab warranted all tests were analyzed following SOP's in CoA (Yes/No)?: _____
Were all samples analyzed within hold times (Yes/No)?: _____
All volatiles samples methanol extracted (if required) within 48 hours (Yes/No)?: _____
Is Chain of Custody completed and signed (Yes/No)?: _____
Were sample temperatures acceptable when they reached lab (Yes/No)?: _____

Was a Data Quality Waiver (DQW) issued (Yes/No)?: _____

Date Issued: _____ Date of Response: _____

Is data considered to be reliable (Yes/No)?: _____
If answer is "No", describe and provide rationale:

Data Reviewed by (Print): _____ Data Reviewed by (Signature): _____

Date: _____

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Figure B2

Example 1 of Completed Data Quality Review Checklist

DATA QUALITY REVIEW CHECKLIST - IMPERIAL OIL PROJECTS

Consultant: *XYZ Consulting* Sampling Date: *July 12/2004*

Location: *123 Main St, Vancouver* Laboratory : *PSC Burnaby*

Consultant Project Number: *XYZ-1298* Sample Submission Number: *4G0345*

Are All Laboratory QC Samples Within Acceptance Criteria (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Instrument Surrogate Recovery			*X*	*- all lab QC have met acceptance criteria*
Extraction Surrogate Recovery			*X*	
Method Blank Concentration			*X*	
Matrix Duplicate RPD	*X*			
Matrix Spike Recovery	*X*			
Lab Control Sample Recovery	*X*			

Are All Field QC Samples Within Alert Limits (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Field Blank Concentration			*X*	*- all field QC have met acceptance criteria*
Trip Blank Concentration			*X*	
Field Duplicate RPD	*X*			

Has CoA been signed off (Yes/No)?:	*Yes*
Has lab warranted all tests were in statistical control in CoA (Yes/No)?:	*Yes*
Has lab warranted all tests were analyzed following SOP's in CoA (Yes/No)?:	*Yes*
Were all samples analyzed within hold times (Yes/No)?:	*Yes*
All volatiles samples methanol extracted (if required) within 48 hours (Yes/No)?:	*Yes*
Is Chain of Custody completed and signed (Yes/No)?:	*Yes*
Were sample temperatures acceptable when they reached lab (Yes/No)?:	*Yes*

Was a Data Quality Waiver (DQW) issued (Yes/No)?: *No*

Date Issued: *na* Date of Response: *na*

Is data considered to be reliable (Yes/No)?: *Yes*
If answer is "No", describe and provide rationale:

Data Reviewed by (Print): *Joe Smith* Data Reviewed by (Signature): *Joe Smith*

Date: *July 22/2004*

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Figure B3

Example 2 of Completed Data Quality Review Checklist

DATA QUALITY REVIEW CHECKLIST - IMPERIAL OIL PROJECTS

Consultant: *XYZ Consulting* Sampling Date: *July 15/2004*

Location: *123 Main St, Vancouver* Laboratory : *PSC Burnaby*

Consultant Project Number: *XYZ-1298* Sample Submission Number: *4G0444*

Are All Laboratory QC Samples Within Acceptance Criteria (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Instrument Surrogate Recovery	*X*			*- BTEX matrix spike is below acceptance criteria*
Extraction Surrogate Recovery	*X*			*- all other lab QC samples met acceptance criteria*
Method Blank Concentration	*X*			
Matrix Duplicate RPD	*X*			
Matrix Spike Recovery		*X*		
Lab Control Sample Recovery	*X*			

Are All Field QC Samples Within Alert Limits (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Field Blank Concentration			*X*	*- all field QC have met acceptance criteria*
Trip Blank Concentration			*X*	
Field Duplicate RPD	*X*			

Has CoA been signed off (Yes/No)?:	*Yes*
Has lab warranted all tests were in statistical control in CoA (Yes/No)?:	*Yes*
Has lab warranted all tests were analyzed following SOP's in CoA (Yes/No)?:	*Yes*
Were all samples analyzed within hold times (Yes/No)?:	*Yes*
All volatiles samples methanol extracted (if required) within 48 hours (Yes/No)?:	*Yes*
Is Chain of Custody completed and signed (Yes/No)?:	*Yes*
Were sample temperatures acceptable when they reached lab (Yes/No)?:	*Yes*

Was a Data Quality Waiver (DQW) issued (Yes/No)?: *Yes*

Date Issued: *Aug 22/2003* Date of Response: *Aug 26/2003*

Is data considered to be reliable (Yes/No)?: *Yes*
If answer is "No", provide rationale:

BTEX results for samples associated with failed matrix spike were several times regulatory criteria. Effect of failure on reported data quality is minimal. DQW request was granted.

Data Reviewed by (Print): *Joe Smith* Data Reviewed by (Signature): *Joe Smith*

Date: *July 27/2004*

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Figure B4

Example 3 of Completed Data Quality Review Checklist

DATA QUALITY REVIEW CHECKLIST - IMPERIAL OIL PROJECTS

Consultant: *ABC Engineering* Sampling Date: *July 20/2004*

Location: *246 Queen St, Toronto* Laboratory : *PSC Burlington*

Consultant Project Number: *ABC-1456* Sample Submission Number: *4G0512*

Are All Laboratory QC Samples Within Acceptance Criteria (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Instrument Surrogate Recovery	*X*			*- all lab QC have met acceptance criteria*
Extraction Surrogate Recovery	*X*			
Method Blank Concentration	*X*			
Matrix Duplicate RPD	*X*			
Matrix Spike Recovery	*X*			
Lab Control Sample Recovery	*X*			

Are All Field QC Samples Within Alert Limits (Yes, No, Not Applicable)?

	Yes	No	NA	Comments
Field Blank Concentration	*X*			*- all field QC have met acceptance criteria*
Trip Blank Concentration	*X*			
Field Duplicate RPD	*X*			

Has CoA been signed off (Yes/No)?:	*Yes*
Has lab warranted all tests were in statistical control in CoA (Yes/No)?:	*Yes*
Has lab warranted all tests were analyzed following SOP's in CoA (Yes/No)?:	*Yes*
Were all samples analyzed within hold times (Yes/No)?:	*No*
All volatiles samples methanol extracted (if required) within 48 hours (Yes/No)?:	*Not Required*
Is Chain of Custody completed and signed (Yes/No)?:	*Yes*
Were sample temperatures acceptable when they reached lab (Yes/No)?:	*Yes*

Was a Data Quality Waiver (DQW) issued (Yes/No)?: *Yes*

Date Issued: *Aug 27/2003* Date of Response: *Aug 30/2003*

Is data considered to be reliable (Yes/No)?: *No*
If answer is "No", provide rationale:

BTEX in water results were not analyzed within hold times, so results may be biased low. Results were just below regulatory criteria, so failure of reported data quality could be very important. Sample is not of a critical nature (part of long term monitoring program). DQW request was granted.

Data Reviewed by (Print): *Joe Smith* Data Reviewed by (Signature): *Joe Smith*

Date: *July 31/2004*

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APPENDIX C

INTERPRETATION EXAMPLES FOR

QA/QC FAILURES AND DQW REQUESTS

APPENDIX C

INTERPRETATION EXAMPLES FOR QA/QC FAILURES AND DQW REQUESTS

Useful rules-of-thumb for evaluation of the potential impact of failed QC samples and/or other deficiencies resulting in the generation of a DQW request have been discussed in Section 3.2. Specific examples of the application of these rules-of-thumb are presented in this Appendix.

Example 1 - Hold Times Exceeded

Samples were delivered to the laboratory within their analytical hold times, but the hold times were exceeded before the samples were analyzed. The samples were analyzed after the hold time had passed, the data was reported and a DQW request was issued.

Scenario A

One sample was a water sample requiring analysis for BTEX. The hold time of 14 days was exceeded by four days. A second sample was a water sample for mercury analysis. The hold time was also exceeded by four days.

Scenario A Resolution

The fact that the hold time was exceeded is a significant concern in the case of BTEX. Due to the volatility and biodegradability of BTEX compounds, hold times exceedances can result in the data being biased low. In the case of the mercury sample, the hold time exceedance is also a concern, due to the fact that a portion of the mercury in the sample could be in its volatile elemental form. Exceedance of the hold time could bias the sample results low. Both the mercury and BTEX data will be suspect. If the concentration of either the BTEX or the mercury is higher than the regulatory limit, then the potential for volatilization or biodegradation losses biasing the results low is not a concern. If the hold times had not been exceeded, the probable outcome would be that the samples would have just exceeded the regulatory criteria by a wider margin. In this case, the consultant should also grant the DQW request. If the results show either parameter to be below the regulatory criteria, these results should be considered as suspect. The DQW request may be rejected and re-sampling or re-testing may be required, if the results are being used in a critical application (ie: they are being used for site closure purposes or in a litigation file). If the results are not being used in a critical application (eg: they were generated as part of a long term monitoring program), the consultant should grant the DQW request.

Scenario B

The sample was a soil sample requiring analysis for lead. The hold time of 6 months was exceeded by 4 days.

Scenario B Resolution

For metals analysis in soil (with the exception of mercury), hold times are rarely exceeded, due to the fact that most hold times are 6 months. If hold times are exceeded, this is generally not a concern with metals, since they are stable for long periods of time in soils. Thus, exceedance of the hold time should not compromise the data and the consultant should grant the DQW request.

Example 1 - Conclusion

For many inorganic parameters (including metals, fluoride, chloride and sulfate) hold time exceedances in soil and water matrices are not a significant concern. Mercury is an exception, since elemental mercury is volatile. Various nitrogen parameters (eg: ammonia, TKN, nitrate and nitrite) should be analyzed within the required hold times; under the proper conditions, nitrogen-containing compounds can transform from one chemical species to another. Phosphorus parameters (eg: orthophosphate) can also undergo chemical transformations, so these should also be analyzed within the required hold times. In water samples, pH and alkalinity samples must be analyzed within the hold time. Otherwise, the adsorption of carbon dioxide from the atmosphere can cause the formation of carbonic acid in the sample (this is referred to as carbonate error), which can significantly change the pH and alkalinity of the sample. For organic compounds in soil and water matrices, strict adherence to hold time is critical for ensuring data quality. This is especially true for organic parameters that are wholly or partially composed of volatile fractions (eg: BTEX, Total Purgeable Hydrocarbons, Total Extractable Hydrocarbons).

Example 2 - Sample Processing Times Exceeded

Several soil samples to be analyzed for BTEX are received by the laboratory on a Friday afternoon at 4 pm.

Scenario A

The soil samples were methanol extracted at noon of Monday (ie: 68 hours after receipt of the samples at the laboratory). The lab is contractually required to methanol extract all BTEX soil samples within 48 hours of receipt by the laboratory. The only exception to this requirement is in jurisdictions where the analysis of the Canada Wide Standard petroleum hydrocarbon fractions has been adopted. In these jurisdictions, it is necessary to analyze BTEX samples using headspace GC/MS and methanol extraction of the soil sample is not required. The analysis shows that the BTEX results are all less than the regulatory criteria.

Scenario A Resolution

Biodegradation and/or volatilization of the BTEX contained in the soil samples can occur if the soil is not extracted and/or analyzed as soon as possible. The delay in sample processing could result in data that is biased low. In this case, it cannot be determined if the samples actually would have yielded results less than criteria if they had been extracted on time, or if the results less than criteria are

due to losses that occurred while awaiting extraction. The results should be considered suspect. The DQW request may be rejected and re-sampling or re-testing may be required, if the results are being used in a critical application. If the results are not being used in a critical application, the consultant should grant the DQW request.

Scenario B
The soil samples were methanol extracted at noon of Monday (ie: 68 hours after receipt of the samples at the laboratory). The lab is contractually required to methanol extract all BTEX soil samples within 48 hours of receipt by the laboratory. The analysis shows that the benzene and xylenes results are greater than the regulatory criteria.

Scenario B Resolution
Biodegradation and/or volatilization of the BTEX contained in the soil samples can occur if the soil is not extracted and/or analyzed as soon as possible. The delay in sample processing could result in data that is biased low. Since the sample exceeds the regulatory criteria, the potential for volatilization or biodegradation losses biasing the results low is not a concern. If the hold times had not been exceeded, the probable outcome would have been that the samples would have just exceeded the regulatory criteria by a wider margin. In this case, the consultant should also grant the DQW request.

Example 2 - Conclusion
BTEX data from soil samples extracted more than 48 hours after their receipt by the lab (when extraction is necessary) must always be considered suspect. Whether or not to grant the DQW request or insist upon re-sampling will depend on whether or not the samples exceed the regulatory criteria and on the criticality of the samples.

Example 3 - Sample Temperatures Exceed 10°C

Samples arrive at the laboratory, the day after they were sampled in the field. The temperatures of the samples in the cooler averaged 13°C. A DQW request is not issued, since this data quality issue is not under the complete care and control of the Contract Laboratory.

Scenario A
The samples are soil samples to be analyzed for lead.

Scenario A Resolution
For lead in soil, the fact that the temperature exceeded 10°C would not in any likelihood cause significant error in the data, due to the low volatility and long term stability of this metal in soil samples.

Scenario B
The samples are soil samples to be analyzed for BTEX. The soil samples meet the BTEX criteria.

Scenario B Resolution
For BTEX, the fact that the temperature of the samples was not maintained at <10°C during shipping is a concern. These samples will generate suspect data, due to potential volatilization or biodegradation losses that may have occurred during shipment. In this case, it cannot be determined if the samples actually would have yielded results less than criteria if they had arrived at the lab at <10°C, or if the results less than criteria are due to losses that occurred while the samples were at a temperature >10°C. The results should be considered suspect. Re-sampling or re-testing may be required, if the results are being used in a critical application.

Scenario C
The samples are soil samples to be analyzed for BTEX. The soil samples exceed the BTEX criteria.

Scenario C Resolution
For BTEX, the fact that the temperature of the samples was not maintained at <10°C during shipping is a concern. These samples will likely generate suspect data, due to volatilization or biodegradation losses that may have occurred during shipment. Since the sample exceeds the regulatory criteria, the potential for volatilization or biodegradation losses biasing the results low is not a concern. If the storage temperature specification had not been exceeded, the probable outcome would have been that the samples would have just exceeded the regulatory criteria by a wider margin. In this case, re-sampling or re-testing will not be required.

Example 3 - Conclusion
Maintenance of the sample temperature between 0-10°C for samples that contain volatile or semi-volatile fraction (eg: BTEX, Total Purgeable Hydrocarbons, VOC's, lower molecular weight PAH's) is paramount. If samples for volatile or semi-volatile analysis arrive at the laboratory at a temperature greater than this range, there is a high probability that losses (either through volatilization or biodegradation) may have occurred, leading to low bias in the sample results. Data associated with these samples will be suspect and re-sampling or re-testing may be required, depending on the criticality of the data. For non-volatile parameters (eg: most inorganics and organics such as PCB's or dioxins/furans), exceedance of the temperature requirement is not usually a concern, due to the low volatility and biodegradability of these parameters. Thus, the data generated from analysis of these samples for these analytes should generally be considered acceptable, even if the samples arrived at the laboratory at >10°C.

Example 4 - Surrogates Outside of Acceptance Criteria

A soil sample has been submitted to the lab for methanol extraction and BTEX analysis by purge+trap GC/MS. Some or all of the surrogates are outside of the acceptance criteria.

Scenario A

The three instrument surrogates recoveries are all within their acceptance criteria, but the recovery for the *d10*-ethylbenzene extraction surrogate is 25% (outside of the 30-130% acceptance range). The lab has issued a DQW request.

Scenario A Resolution

The fact that the instrument surrogates met acceptance criteria indicates that the problem was likely not due to the instrumental analysis. It is likely that the extraction of the sample was inefficient, which may have led to a low recovery in the extraction surrogate. This result indicates that there may be low bias in the sample result. The other possibilities are that the sample matrix affected the recovery of the surrogate or that the lab made an error in spiking the samples with the extraction surrogate. The DQW request may be rejected and re-sampling or re-testing may be required, if the results are being used in a critical application. If the results are not being used in a critical application, the consultant should grant the DQW request.

Scenario B

The three instrument surrogates have recoveries of 52%, 56% and 64% (acceptance criteria is 60-140%) and the recovery for the *d10*-ethylbenzene extraction surrogate is 25% (versus the 30-130% acceptance range). The lab has issued a DQW request.

Scenario B Resolution

The fact that 2 out of 3 instrument surrogates and the extraction surrogate did not meet acceptance criteria indicates that the problem was likely due to the instrument problems, or possibly due to spiking errors by the analyst. In this case, the lab should have re-analyzed the retained sample, if any remained and it had not exceeded the hold time. This type of data failure will typically only be reported if one of these two re-analysis conditions is not met. The DQW request may be rejected and re-sampling or re-testing may be required, if the results are being used in a critical application. If the results are not being used in a critical application, the consultant should grant the DQW request.

Scenario C

The three instrument surrogates have recoveries of 62%, 56% and 64% (acceptance criteria is 60-140%) and the recovery for the *d10*-ethylbenzene extraction surrogate is 45% (versus the 30-130% acceptance range). No DQW request was issued by the laboratory.

Scenario C Resolution

The fact that 2 out of 3 instrument surrogates and the extraction surrogate met acceptance criteria, indicates that there is no problem with the data. No DQW request should be issued by the laboratory in this situation, since there is no data quality issue with this sample.

Example 4 - Conclusion

For BTEX soil samples, the extraction surrogate recovery must always be within acceptance criteria, or a DQW request must be issued. One of the three instrument surrogate recoveries can be outside the acceptance criteria and the data is still considered acceptable (ie: a DQW request does not need to be issued). If two or more of the instrument surrogate recoveries fail to meet the acceptance criteria, a DQW request must be issued. Acceptance or rejection of the DQW request will depend on the criticality of the data in each situation.

Example 5 - Method Blanks Outside of Acceptance Criteria

A method blank QC sample is reported as having failed acceptance criteria, as the concentration of the analyte in the sample was determined to be seven times the MDL value (versus the acceptance criteria of <5X MDL for all method blanks). A DQW request was issued. There is a potential positive bias in the results reported for samples analyzed in the same batch as this method blank sample.

Scenario A

The parameter of interest is nitrate in water. The nitrate in water MDL is 0.05 mg/L. The reported value of 0.35 mg/L (7X MDL) for the method blank exceeds the acceptance criteria. This suggests that the results for the samples associated with this QC sample may be biased high. The results for the drinking water samples associated with this method blank are in the 1-2 mg/L range. The drinking water criteria for nitrate in this jurisdiction is 10 mg/L.

Scenario A Resolution

All samples are much lower than the drinking water criteria for nitrate, even with a potential of a 0.35 mg/L positive bias in the sample result. In this case, the data quality issue will have no effect on the conclusion that the nitrate meets the drinking water criteria. The consultant should grant the DQW request.

Scenario B

The parameter of interest is nitrate in water. The nitrate in water MDL is 0.05 mg/L. The reported value of 0.35 mg/L (7X MDL) for the method blank exceeds the acceptance criteria. This suggests that the results for the samples associated with this QC sample may be biased high. The results for the drinking water samples associated with this method blank are in the 20-22 mg/L range. The drinking water criteria for nitrate in this jurisdiction is 10 mg/L.

Scenario B Resolution

All samples are much higher than the drinking water criteria for nitrate, even if the potential 0.35 mg/L positive bias were removed from the sample results. In this case, the data quality issue will have no effect on the conclusion that the nitrate exceeds the drinking water criteria. The consultant should grant the DQW request.

Scenario C

The parameter of interest is nitrate in water. The nitrate in water MDL is 0.05 mg/L. The reported value of 0.35 mg/L (7X MDL) for the method blank exceeds the acceptance criteria. This suggests that the results for the samples associated with this QC sample may be biased high. The results for the drinking water samples associated with this method blank are in the 10.0-10.2 mg/L range. The drinking water criteria for nitrate in this jurisdiction is 10 mg/L.

Scenario C Resolution

Some or all of the samples are very close to the 10 mg/L drinking water criteria for nitrate. In this case, the potential 0.35 mg/L positive bias may have pushed samples from meeting criteria to failing the criteria. In this case, the data quality issue could have a large effect on the determination of whether or not the nitrate exceeds the drinking water criteria. Re-sampling or re-testing of the critical samples (ie: those very close to the 10 mg/L criteria) may be required if the results are being used in a critical application, in which case the DQW request should be rejected. If the results are not being used in a critical application, the consultant should grant the DQW request.

Scenario D

The parameter of interest is sulfide in water. The sulfide in water MDL is 8 μg/L. The reported value of 55 μg/L (7X MDL) for the method blank exceeds the acceptance criteria. This suggests that the results for the samples associated with this QC sample may be biased high. The results for all the water samples associated with this method blank are in the 60-70 μg/L range. The regulatory criteria for sulfide in water in this jurisdiction is 100 μg/L.

Scenario D Resolution

In this case, the result of the method blank (55 μg/L) represents a significant proportion (55%) of the regulatory criteria for this parameter. A potential positive bias that is this large a proportion of the regulatory criteria is a serious concern, since it can easily lead to false positive results (ie: exeedences are reported, where they do not exist). The DQW request may be rejected and re-sampling or re-testing may be required, if the results are being used in a critical application (eg: regulatory compliance reporting). If the results are not being used in a critical application, the consultant should accept the DQW request.

Scenario E

The parameter of interest is available ammonia in soil. The analysis is being performed as part of a soil bioremediation program, where the target ammonia addition level in the soil is 200 mg/kg. The available ammonia in soil MDL is 0.5 mg/kg. The reported value of 5 mg/kg (10X MDL) for the method blank exceeds the acceptance criteria. This suggests that the results for the samples associated with this QC sample may be biased high. There is no regulatory criteria for ammonia in soil in this jurisdiction.

Scenario E Resolution

A potential positive bias of 5 mg/kg (ie: 2.5% of the 200 mg/kg target) is insignificant from an operational viewpoint. In this case, the magnitude of the positive bias in the data is not critical and the consultant should grant the DQW request.

Example 5 - Conclusion

The potential for high background levels of the analyte of concern to cause a positive bias in the data (due to laboratory contamination) is an issue that should be thoroughly investigated by the laboratory. If the sample results are in the same ballpark as the regulatory criteria (and the samples are needed for a critical purpose), re-analysis and/or re-sampling may be required. For operational parameters where extremely accurate data is less important, the potential for positive bias in the reported data due to laboratory quality issues (as manifested by the method blank sample exceeding its acceptance criteria) is often of little concern from a practical standpoint.

Example 6 - Various Blank Samples Outside of Acceptance Criteria or Alert Limits

In this example, the effects of high levels of various blank samples (method, field and trip) will be examined. For each of the scenarios considered below, the parameter of interest is benzene in water. The benzene in water MDL is 0.2 μg/L, while the regulatory groundwater criteria for benzene in this jurisdiction is 5 μg/L. The results for some of the groundwater samples associated with the blanks are in the 4-6 μg/L range, while the results for the other samples are >30 μg/L.

Scenario A

For this sample batch, the reported value of 1.6 μg/L (8X MDL) for the method blank exceeds the acceptance criteria. The results for the field blank is 1.9 μg/L and the trip blank is 1.7 μg/L (both exceed the alert limits of >5X MDL). The portion of the trip blank sample retained by the laboratory was re-analyzed and benzene was non-detectable in this sample. A DQW request was issued, due to an exceedance of the acceptance criteria by the method blank.

Scenario A Resolution

Both blanks taken in the field (ie: field and trip blank) exceed the alert limits and have results of the same magnitude as the method blank, suggesting that quality

issue lies in the lab, not the field. The method blank (which is not taken to the field and has been prepared from a different batch of purged, ultrahigh purity water) cannot pick up field contamination. The fact that all three samples have similar concentrations indicates the issue is likely instrumental. For the samples in the 4-6 μg/L range, the data quality issue could have a large effect on the determination of whether or not the reported benzene concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria). The DQW request should be rejected and re-sampling or re-testing may be required, if these results are being used in a critical application. If the results are not being used in a critical application, the consultant should grant the DQW request. For the samples with a concentration of >30 μg/L, the potential positive bias will make no difference. These samples would exceed the 5 μg/L criteria, even if the potential bias 1.5-2.0 μg/L bias were eliminated from these samples. For these samples, the consultant should grant the DQW request.

Scenario B

For this sample batch, the reported value of 0.3 μg/L (1.5X MDL) for the method blank meets the acceptance criteria. The results for field blank is 1.9 μg/L (which exceeds the alert limits of >5X MDL) and the trip blank is 0.3 μg/L (which is within the alert limits). A DQW request was not issued, since the method blank met the acceptance criteria.

Scenario B Resolution

The field blank exceeds the alert limits, while the method blank meets the acceptance criteria and the trip blank is within the alert limits. This suggests that quality issue lies in the field, not the lab. Since both the trip blank (which is not opened during the sampling in the field) and the method blank (which is prepared in the laboratory) show no evidence of contamination, this indicates that the source of contamination was likely during field sampling activities. The trip blank result indicates that contamination observed in the field blank sample was not due to transportation of bottles to and from the field, problematic bottle storage or the manufacturer supplying contaminated bottles. The method blank result indicates that the laboratory was not the source of the contamination either. This process of elimination leaves just field sampling as the contamination source. For the samples in the 4-6 μg/L range, the data quality issue could have a large effect on the determination of whether or not the reported benzene concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria). If the results are being used in a critical application, re-sampling or re-testing may be required. For the samples with a concentration of >30 μg/L, the potential positive bias will make no difference. These samples would exceed the 5 μg/L criteria, even if the potential bias 1.5-2.0 μg/L bias from field sampling issues were eliminated from these samples.

Scenario C

For this sample batch, the reported value of 1.6 μg/L (8X MDL) for the method blank exceeds the acceptance criteria. The results for field blank is 0.4 μg/L and

the trip blank is 0.3 µg/L (both of which are well within the alert limits of >5X MDL). A DQW request was issued, since the method blank exceeded that acceptance criteria.

Scenario C Resolution

The fact that the both blanks that have been to the field are well within the alert limits, while the method blank result exceeds acceptance criteria, suggests that quality issue lies with the lab, not the field. Since the trip blank (which is not opened during the sampling in the field) shows no evidence of contamination, the contamination was not due to transportation of bottles to and from the field, bottle storage or the manufacturer supplying contaminated bottles. Since the field blank sample shows no evidence of contamination, the contaminant source was not field sampling techniques. If the lab problem were instrumental (as in Scenario A), both the field blank and trip blank should also show elevated levels of the analyte. The fact that they both do not, indicates that the problem in this scenario is likely due to contamination of the method blank sample. If the method blank can be demonstrated to be contaminated, this should have no effect on the results reported for samples taken in the field. In this case, the consultant should grant the DQW request for the samples in the 4-6 µg/L concentration range and those with concentrations >30 µg/L.

Scenario D

For this sample batch, the reported value of 0.3 µg/L (1.5X MDL) for the method blank is within the acceptance criteria. The results for field blank is 1.4 µg/L and the trip blank is 1.1 µg/L (both of which exceed the alert limits of >5X MDL). The portion of the trip blank sample retained by the laboratory was re-analyzed and benzene was non-detectable in this sample. A DQW request was not issued, since the method blank met the acceptance criteria.

Scenario D Resolution

The fact that the both blanks that have been to the field exceed the alert limit, while the method blank result is within acceptance criteria, suggests that quality issue lies with the field, not the lab. This was confirmed when the portion of the trip blank sample retained by the laboratory was re-analyzed and benzene was not detected. Since the trip blank (which is not opened during the sampling in the field) shows evidence of contamination, this indicates that the source of contamination may be something that the samples have come into contact with during transportation to and from the field. It could also be an indication that the bottles used for the sampling may be a source of contamination (either from poor environmental conditions where they are stored, or to improper cleaning by the manufacturer). For the samples in the 4-6 µg/L range, the data quality issue could have a large effect on the determination of whether or not the reported benzene concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria. If the results are being used in a critical application re-sampling or re-testing may be required. For the samples with a concentration of >30 µg/L, the potential positive bias will make no

difference. These samples would exceed the 5 µg/L criteria, even if the potential bias 1.5-2.0 µg/L bias were eliminated from these samples.

Example 6 - Conclusion

By examining the results for the blank samples associated with a particular sample batch, a determination can be made as to the probable source of any contamination observed in the blank samples that exceeds acceptance criteria or alert limits. The laboratory will not necessarily be aware that the samples they have been analyzing are field blanks or trip blanks. If an exceedance of an alert limit for a field blank or trip blank sample is reported, the Environmental Consultant is responsible to notify the Contract Laboratory of this fact as soon as possible. The laboratory will re-analyze the sample exceeding the alert limit (assuming that there is sufficient sample remaining for re-analysis and the hold time of the sample has not been exceeded). If the sample still exceeds the alert limits, the Environmental Consultant can ensure that the data quality issue is real and not due to a spurious false positive result.

Example 7 - Matrix Duplicate Samples Outside of Acceptance Criteria

The lab has run two aliquots from the same sample container, in order to obtain matrix duplicate results. The parameter of interest is benzene in soil. The regulatory criteria for benzene in soil is 25 mg/kg, while the MDL for benzene in soil is 0.1 mg/kg.

Scenario A

The first aliquot yielded a result of 35 mg/kg, while the second aliquot yielded a result of 15 mg/kg. Both results are >5X MDL and the RPD is calculated as 80% (versus an acceptance criterion of <50%). A DQW request was issued.

Scenario A Resolution

In this case, the data quality issue could have a large effect on the determination of whether or not the benzene contained in this sample exceeds the soil criteria (since the sample results bracket the regulatory criteria). Re-sampling may be required if the results are being used in a critical application. If the results are not being used in a critical application, the consultant should grant the DQW request.

Scenario B

The first aliquot yielded a result of 0.9 mg/kg (9X MDL), while the second aliquot yielded a result of 0.4 mg/kg (4X MDL).

Scenario B Resolution

Since both results are not >5X MDL, the calculation of a meaningful RPD value is not possible for this matrix duplicate. A DQW request will not be issued by the Contract Laboratory in this case.

Scenario C

The first aliquot yielded a result of 200 mg/kg, while the second aliquot yielded a result of 400 mg/kg. Both results are >5X MDL and the RPD is calculated as 67% (versus an acceptance criterion of <50%). A DQW request was issued.

Scenario C Resolution

In this case, the data quality issue will not likely have a large effect on the determination of whether or not the benzene contained in this sample exceeds the soil criteria, since both results exceed the regulatory criteria by a large margin. In this case, the consultant should grant the DQW request.

Example 7 - Conclusion

Matrix duplicate failures often occur due to sample inhomogeneity, especially with soil samples. The lab should provide comments if they observe that the sample matrix appears to be heterogeneous and the matrix duplicate sample has failed to meet the acceptance criteria. If the sample matrix is heterogeneous, failure of the matrix duplicate sample to meet acceptance criteria is not surprising. However, if the sample matrix appears homogeneous, the result for the one of the matrix duplicate aliquots that failed to meet acceptance criteria might be in error. In this case, it would be wise to have the sample re-analyzed in duplicate, to confirm or refute the initial results. Note that the laboratory knows which samples have been chosen as matrix duplicates and the acceptance criteria. If an exceedance of the acceptance criteria is observed, the lab will automatically re-analyze the matrix duplicates. Typically, a DQW request will only be issued if insufficient sample remains for re-analysis or the sample hold time is exceeded before an RPD result within the acceptance criteria can be obtained.

Example 8 - Laboratory Control Samples (LCS) Outside of Acceptance Criteria

A laboratory control sample result for toluene in groundwater had a recovery of 50%, which lies outside the acceptance criteria of 70-130%. A DQW request was issued. There is the potential that the reported results for samples associated with this LCS could be biased low by as much as a factor of two. The regulatory criteria for toluene in this jurisdiction is 37 mg/L.

Scenario A

The samples in the batch associated with this LCS all have reported concentrations in the 2-5 mg/L range.

Scenario A Resolution

All samples are much lower than the groundwater criteria for toluene, even with a potential of factor of two negative bias in the sample results. In this case, the data quality issue will have no effect on the conclusion that the toluene meets the groundwater criteria. The consultant should grant the DQW request.

Scenario B
The samples in the batch associated with this LCS all have reported concentrations in the 125-200 mg/L range.

Scenario B Resolution
All samples are much higher than the groundwater criteria for toluene, even with a potential of factor of two negative bias in the sample results. In this case, the data quality issue will have no effect on the conclusion that the toluene exceeds the groundwater criteria. The consultant should grant the DQW request.

Scenario C
Some of the samples in the batch associated with this LCS have reported concentrations in the 25-35 mg/L range, while the remainder of the samples have concentrations >150 mg/L.

Scenario C Resolution
Some samples (with concentrations in the 25-35 mg/L range) are very close to the 37 mg/L groundwater criteria for toluene. In this case, the potential factor of two negative bias may have resulted in samples that actually exceed criteria being reported with results that meet the criteria. For the samples in the 25-35 mg/L range, the data quality issue could have a large effect on the determination of whether or not the reported toluene concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria). If the results are being used in a critical application, the DQW request should be rejected and re-sampling or re-testing may be required. If the results are not being used in a critical application, the consultant should grant the DQW request. For the samples with a concentration of >200 mg/L, the potential negative bias will make no difference. These samples would exceed the 37 mg/L criteria, even if the concentration results were lowered by as factor of two. For these samples, the consultant should grant the DQW request.

Example 8 - Conclusion
LCS results should not fail criteria on a regular basis, since matrix effects are not present in these samples. The fact that the LCS fell below acceptance criteria suggests that there was either an instrumentation problem or that the purging of the toluene from the water sample was not efficient. The lab should take action to ascertain the root cause of the problem and take remedial actions.

Example 9 - Matrix Spike Sample Outside of Acceptance Criteria

A matrix spike sample result for toluene in groundwater had a recovery of 50%, which lies outside the acceptance criteria of 70-130%. A DQW request was issued. There is the potential that the reported results for samples associated with this matrix spike sample could be biased low by as much as a factor of two. The regulatory criteria for toluene in this jurisdiction is 37 mg/L.

Scenario A
The samples in the batch associated with this matrix spike sample all have reported concentrations in the 2-5 mg/L range.

Scenario A Resolution
All samples are much lower than the groundwater criteria for toluene, even with a potential of factor of two negative bias in the sample results. In this case, the data quality issue will have no effect on the conclusion that the toluene meets the groundwater criteria. The consultant should grant the DQW request.

Scenario B
The samples in the batch associated with this matrix spike sample all have reported concentrations in the 125-200 mg/L range.

Scenario B Resolution
All samples are much higher than the groundwater criteria for toluene, even with a potential of factor of two negative bias in the sample results. In this case, the data quality issue will have no effect on the conclusion that the toluene exceeds the groundwater criteria. The consultant should grant the DQW request.

Scenario C
The samples in the batch associated with this matrix spike sample have reported concentrations in the 25-35 mg/L range, while the remainder of the samples have concentrations >150 mg/L.

Scenario C Resolution
Some samples (with concentrations in the 25-35 mg/L range) are very close to the 37 mg/L groundwater criteria for toluene. In this case, the potential factor of two negative bias may have resulted in samples that actually exceed criteria being reported with results that meet the criteria. For the samples in the 25-35 mg/L range, the data quality issue could have a large effect on the determination of whether or not the reported toluene concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria). If the results are being used in a critical application, the DQW request should be rejected and re-sampling or re-testing may be required. If the results are not being used in a critical application, the consultant should grant the DQW request. For the samples with a concentration of >200 mg/L, the potential negative bias will make no difference. These samples would exceed the 37 mg/L criteria, even if the results were lowered by a factor of two. For these non-critical samples, the consultant should grant the DQW request.

Example 9 - Conclusion
Matrix spike sample results exceed acceptance criteria on a more frequent basis than LCS samples, since matrix effects are often observed with these samples (matrix effects are very minimal for LCS samples). The fact that the matrix spike sample fell below acceptance criteria suggests that there was either an instrumentation problem, that the

purging of the toluene from the water sample was not efficient or that there was a matrix effect that was interfering with the test methodology in this particular matrix. The lab should take action to ascertain the root cause of the problem and take remedial actions, if the root cause of the issue is determined to be something other than a matrix interference.

Example 10 - Field Duplicate Samples Exceeding Alert Limits

A field duplicate result for lead in soil exceeded the alert limit of 100%. One of the field duplicate samples was found to have a lead concentration of 30 mg/kg, the second a concentration of 100 mg/kg. The calculated RPD is 108% (exceeding the alert limits of >100%). A DQW request was not issued, since the laboratory did not have complete care and control of the field duplicate sample.

Scenario A

The matrix duplicate sample associated with this batch of samples had an RPD of 20% (within the acceptance criteria of <35%). All other lab QC samples (method blank, matrix spike and LCS) were within acceptance criteria.

Scenario A Resolution

Since all the lab QC samples were within acceptance criteria, including the matrix duplicate, the exceedance of the alert limits is not likely due to a laboratory problem. The exceedance of the alert limits by the field duplicate sample is likely due to the inhomogeneity of the soil at the sampling location.

Scenario B

The matrix duplicate sample associated with this batch of samples had an RPD of 60% (which is outside the acceptance criteria of <35%). All other lab QC samples (method blank, matrix spike and LCS) were within acceptance criteria.

Scenario B Resolution

Since the matrix duplicate exceeded the RPD acceptance criteria, the exceedance of the field duplicate RPD alert limits could be due to a laboratory problem. The laboratory should investigate the causes of the poor sample precision and take corrective actions. It could also be due to an extremely heterogeneous matrix that makes it impossible to obtain a homogeneous sample even within a single sample bottle. Finally, it could be due to an heterogeneous sample, caused by poor field sampling techniques used by field personnel.

Example 10 - Conclusion

The exceedance of alert limits by a field duplicate sample is often due to matrix inhomogeneity at the sampling location (especially in soil samples). If the lab QC samples meet acceptance criteria, the data should be accepted "as is" by the consultant. If there are also problems with lab QC data exceeding acceptance criteria, these issues need to be dealt with by the laboratory.

Example 11 - Control Chart Data Point Beyond Statistical Control Limits

A water sample for a metals scan has been analyzed by the lab. A DQW request has been issued by the laboratory, since a data point for the LCS that is control charted for this test method has yielded an analytical result that is outside the three sigma (3σ) control limit.

Scenario A

The LCS results for lead is not in statistical control (ie: it is below or above the three sigma control limits). All other lab QC samples (ie: method blank, LCS recovery, matrix spike recovery and lab duplicate RPD) are within acceptance criteria. Lead is a potential contaminant of concern at the site (ie: there is a regulatory limit for this analyte). The LCS results for all other metals parameters are within statistical control. The lab has issued a DQW request.

Scenario A Resolution

Since all the lab QC samples were within acceptance criteria, the exceedance of the three sigma control limit could be a false positive indication of an issue. The meeting of all acceptance criteria for the lab QC samples gives a high degree of confidence that the lead result reported is reliable. The consultant should grant the DQW request.

Scenario B

The LCS results for lead is not in statistical control (ie: it is below the three sigma lower control limit). All other lab QC samples (ie: method blank, matrix spike recovery and lab duplicate RPD) are within acceptance criteria, with the exception of the LCS sample (which has a recovery below the acceptance criteria range). Lead is a potential contaminant of concern at the site (ie: there is a regulatory limit for this analyte). The LCS results for all other metals parameters are within statistical control. The lab has issued a DQW request.

Scenario B Resolution

The low bias of the LCS sample has lead to both a recovery acceptance criteria exceedance and a control limit exceedance. If sample results are close to the regulatory limit for lead, the data quality issue could have a large effect on the determination of whether or not the reported lead concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria). If the results are being used in a critical application, the DQW request should be rejected and re-sampling and/or re-analysis may be required. If the results are not being used in a critical application, the consultant should grant the DQW request. If the results for lead are either far above or far below the regulatory criteria, the data quality issues will not likely change the conclusions that the groundwater samples either meet or exceed the regulatory criteria. In these cases, the consultant should also grant the DQW request.

Scenario C

The LCS results for iron is not in statistical control (ie: it is beyond the three sigma control limits). All other lab QC samples (ie: method blank, LCS recovery,

matrix spike recovery and lab duplicate RPD) are within acceptance criteria. Iron is not a potential contaminant of concern at the site (ie: there is no regulatory limit for this analyte). The LCS results for all other metals parameters are within statistical control. The lab has issued a DQW request.

Scenario C Resolution

Since iron is not a potential contaminant of concern at the site (it has no regulatory criteria), the fact that the LCS sample is not in statistical control is of little concern. The LCS results are in statistical control for all of the potential contaminants of concern at the site and this is what matters. The consultant should grant the DQW request.

Example 11 - Conclusion

The exceedance of three sigma control limits by LCS samples is a warning that that there may potentially be a problem with the analytical test method. However, if all lab QC samples for the sample batch are within acceptance criteria, confidence should be high that the results from the batch with the out of control LCS data point are still reliable. There is a probability that 1 in 370 times, a test method that is in statistical control will yield a result outside the three sigma control limit, solely due to common cause (ie: random) error. Due to the low probability of this event occurring due to random error, the lab will take action (ie: performing re-analysis of all samples in the batch) if this occurs. In some cases, re-analysis is not possible (eg: there is no sample remaining or the sample hold time has been exceeded). It is only in these situations when a DQW request is usually issued by the laboratory.

Example 12 - Results From Outside Calibration Range Are Reported

For almost all test methods, calibration curves are generated that relate instrument response to analyte concentration. Unless specifically allowed by the test reference method, reporting results from outside the calibration range will generate data that is considered suspect. In cases where the lab generates data from outside the calibration range, the laboratory must take corrective actions before reporting the results. Usually, this will involve dilution of the sample and re-analysis, so that its reported concentration will fall within the calibration range. In some cases, re-analysis is not possible (eg: there is no sample remaining or the sample hold time has been exceeded). It is usually only in these situations when a DQW request is issued by the laboratory for reporting a result from outside the calibration range.

Scenario A

The nitrite in water is reported by the laboratory to be outside its calibration range (ie: results of 20-30 mg/L are reported, while the calibration range is 0-10 mg/L). All reported results are far above the applicable regulatory criteria of 1 mg/L for this parameter. The lab has issued a DQW request.

Scenario A Resolution

Since all sample results are far above the regulatory criteria, a potential bias from reporting data from an extrapolated calibration curve is not likely to change the conclusion that the sample results are above the regulatory criteria. The consultant should grant the DQW request.

Scenario B

The mercury in soil is reported by the laboratory to be outside its calibration range (ie: results of 7-15 mg/kg are reported, while the calibration range is 0-10 mg/kg). All reported results are near the applicable regulatory criteria of 10 mg/kg for this parameter. The lab has issued a DQW request for the results reported that are >10 mg/kg.

Scenario B Resolution

For sample results close to the regulatory limit for mercury, this data quality issue could have a large effect on the determination of whether or not the reported concentrations for the samples exceed the soil criteria. If the results are being used in a critical application, the DQW request should be rejected and re-sampling or re-testing may be required. If the results are not being used in a critical application, the consultant should grant the DQW request.

Example 12 - Conclusion

The reporting of results from above the calibration range may lead to the data generated being considered suspect, since it comes from an extrapolated calibration curve and there is no guarantee that the instrument response will remain linear beyond the calibration range. The lab will take corrective action if this occurs.

Example 13 - CCV Sample Is Outside Internal Acceptance Criteria

For some test methods, calibration curves are not generated on a daily basis. Instead, calibration curves are generated periodically. A Continuing Calibration Verification (CCV) sample is analyzed periodically throughout the daily analytical run - this sample typically has a concentration in the middle of the calibration range. As long as the CCV sample gives a result that is within its internal acceptance criteria (typically, this means a result within 15-25% of the expected value), the existing calibration curve has been verified to remain "valid". If results outside the acceptance range are obtained for a CCV sample, the existing calibration curve cannot be considered valid and the laboratory must take corrective actions before reporting the results. Usually, this will involve fixing the problem and re-analyzing all samples that had been run since the last CCV sample that met the acceptance criteria was analyzed. In some cases, re-analysis is not possible (eg: there is no sample remaining or the sample hold time has been exceeded). It is only in these situations when a DQW request is usually issued by the laboratory for a CCV failure.

Scenario A
The CCV result for a batch of cold extractable petroleum hydrocarbons in water is reported by the laboratory to be outside its acceptance criteria. All reported results are either far above or far below the applicable regulatory criteria for this parameter. The lab has issued a DQW request.

Scenario A Resolution
Since all sample results are far from the regulatory criteria, a potential bias from calibration issues is not likely to change the conclusion whether a sample result is above or below the regulatory criteria. The consultant should grant the DQW request.

Scenario B
The CCV result for a batch of cold extractable petroleum hydrocarbons in water is reported by the laboratory to be outside its acceptance criteria. Some reported results are far above the applicable regulatory criteria for this parameter, while other results are either just above or just below the regulatory criteria. The lab has issued a DQW request.

Scenario B Resolution
If sample results are close to the regulatory limit for cold extractable petroleum hydrocarbons, this data quality issue could have a large effect on the determination of whether or not the reported concentrations for the samples exceed the groundwater criteria (since the reported results are so close to the regulatory criteria). If the results are being used in a critical application. the DQW request should be rejected and re-sampling or re-testing may be required. If the results are not being used in a critical application, the consultant should grant the DQW request. For the sample results for cold extractable petroleum hydrocarbons that are far above the regulatory criteria, this data quality issue will not likely change the conclusions that the groundwater samples exceed the regulatory criteria. For these samples, the consultant should grant the DQW request.

Example 13 - Conclusion
The exceedance of CCV acceptance criteria indicates that there is a calibration problem with the instrument. The lab will take corrective action if this occurs.

Example 14 - Custody Seal Not Intact or Missing Upon Cooler Receipt by Lab

A cooler of samples arrives at the contract laboratory. The custody seal is missing from the cooler.

Scenario A
The samples have been taken at a site where there is legal involvement in environmental issues. Thus, the data generated from the site is considered

"legally sensitive". The lab does not issue a DQW request, but does indicate the existence of this data integrity issue in the Certificate of Analysis.

Scenario A Resolution
Since the data is considered legally sensitive, the data must be considered suspect, under any circumstances. With no custody seal, it is impossible to determine if the samples were tampered with during shipment from the field to the laboratory. Re-sampling and re-analysis will most likely be required.

Scenario B
The samples have been taken at a site where there is not currently any legal involvement in environmental issues. Thus, the data generated from the site is not considered "legally sensitive". The lab does not issue a DQW request, but does indicate the existence of this data integrity issue in the Certificate of Analysis.

Scenario B Resolution
Since the data is not considered legally sensitive, the data must still be considered suspect. If the data being generated from the samples is not being used for legal purposes, the need to prove with 100% certainty that the samples were not tampered with during shipment from the field to the laboratory takes on less importance. Re-sampling and re-analysis will depend on the criticality of the data.

Example 14 - Conclusion
When dealing with legally sensitive samples, it is imperative that the custody seal be intact upon receipt by the laboratory. If the custody seal is not intact, there is no way to prove that the samples were not tampered with in transit to the laboratory and the results generated from such samples may not be considered legally defensible in court. Note that should re-sampling be required, this will be the responsibility of the Environmental Consultant. Imperial Oil will not hold the Contract Laboratory responsible for any costs involved in the re-sampling and/or re-analysis of samples in this scenario.

Example 15 - Sample for Volatiles Analysis Has Significant Headspace

Water samples for BTEX analysis arrive at the Contract Laboratory. The samples are all in the proper containers (ie: 43 ml VOA vials). However, one of the samples contains significant headspace (ie: when the vials are inverted, the air bubble inside covers the entire bottom of the VOA vial). A DQW request was not issued, since the laboratory did not have complete care and control of the volatiles sample.

Scenario A
The sample with the large headspace is analyzed and the BTEX results exceed the regulatory criteria.

Scenario A Resolution
The headspace in the sample should result in a low bias for the BTEX result. Thus, the presence of headspace in the sample will not change the conclusion that

the water sample has exceeded the regulatory criteria for BTEX. With no headspace, the likely result is that the exceedance of the regulatory criteria would have been by a wider margin. For this sample, the effect on the quality of the data produced is not material.

Scenario B
The sample with the large headspace is analyzed and the BTEX results meet the regulatory criteria (by a wide margin).

Scenario B Resolution
The headspace in the sample should result in a low bias for the BTEX result. It is not possible to determine if this bias was large enough to change the conclusion that the samples have met the BTEX regulatory criteria or not. If the results are being used in a critical application, re-sampling or re-testing may be required. If the results are not being used in a critical application, re-sampling or re-testing will not be required.

Example 15 - Conclusion
When dealing with volatile parameters (in both water and soil matrices), the headspace inside the sample container must be minimized. Otherwise, volatile losses to the gas phase could result in a negative bias that could result in a false negative result being reported for the sample (ie: it is reported that the sample meets the regulatory criteria, when it actually exceeds the regulatory criteria).

PREFERRED OPERATING PRACTICE FOR

NO PURGE GROUNDWATER SAMPLING

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1) INTRODUCTION

1.1) Scope of Preferred Operating Practice

This POP should be applied for the routine monitoring and sampling of groundwater at sites managed by the Remediation and Reclamation Services (RRS) group of Imperial Oil's Surplus Property Management Department (SPM). The focus of this POP will be on non-operating upstream and downstream sites. However, this POP can also be applied when performing groundwater sampling program at operating upstream and downstream sites.

This POP will provide a detailed description of the practices that RRS Project Managers (and Environmental Consultants working with them) will use to perform the following tasks:

1) Determining if no purge groundwater sampling is an option for use at a site.

2) In cases where no purge groundwater sampling is an option for use at a site, an ExxonMobil Environmental Services (EMES) global best practice is provided that gives guidance on various no purge sampling techniques and devices that can be used at a site. The choice of the best sampling technique/device will depend on a number of site-specific factors.

3) The EMES global best practice provides guidance on how to collect data to demonstrate that purge and no purge sampling methods provide equivalent groundwater quality results for the contaminants of concern at a site. It also describes approaches to use with regulators to get them to give permission to perform no purge sampling at sites.

The development of this POP will provide a framework to ensure that a consistent approach is being used for no-purge groundwater sampling by all RRS Project Managers.

The POP's presented here are recommended practices and are not prescriptive. In certain jurisdictions, groundwater sampling protocols may be specified by Provincial Regulations and/or Guidelines. In these jurisdictions, the regulation or guidance procedure will supercede procedures included in this POP. In some site-specific instances, deviations from the POP may be used with the RRS Project Manager's approval (preferably in advance of the work being completed).

1.2) Limitations of This POP and Disclaimer

The POPs presented here represent practices that are to be applied in conjunction with the best professional judgment of the Environmental Consultant. Environmental Consultants are contractually required to routinely utilize the practices outlined in this POP. Significant deviation from the practices contained in this POP is only permitted if the Environmental

Consultant has discussed the matter with the RRS Project Manager and gained concurrence on the usage of an alternate approach to performing no-purge groundwater sampling. The contents of this POP are classified as *"For Use On Imperial Oil Projects Only"*.

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2) NO-PURGE GROUNDWATER SAMPLING

2.1) EMES Global Best Practice for No Purge Groundwater Sampling

This POP consists of the EMES global best practice for no purge groundwater sampling. The EMES global best practice is presented in Appendix 1 of this POP. This section of the POP provides a brief introduction on how to utilize the EMES global best practice. Sections 2.2 and 2.3 of this POP provide more specific guidance on when to use no purge groundwater sampling at a site; and how to choose the preferred no purge sampling technique/device at a site (taking into account site specific conditions).

The 2-page Executive Summary and 5-page main section of the EMES global best practice provide a brief (but informative) outline on the rationale for no purge sampling, the advantages of this technique and objectives of the global best practice. In developing a scope of work, most of the information the user will need is contained in the following figures, tables and appendices of the EMES global best practice.

Figure 1 of the EMES global best practice contains two decision trees, helping the user determine if no purge sampling is applicable at a given site and what no purge technique/device is preferred for the scope of work.

Table 1 of the EMES global best practice provides details on five preferred no purge methods, and five "specialty" techniques/devices. Included in the table is a list of applicable analytes for each no purge technique/device; advantages and disadvantages for each no purge technique/device; and other information.

Table 2 of the EMES global best practice provides an example cost comparison between the various groundwater sampling methods and no purge devices, for different time frames. Actual costs will (of course) vary from site to site. What is important is that the relative cost differences between the methods and tools contained in this table are expected to exhibit similar directional trends for most projects.

Appendix A of the EMES global best practice contains a detailed description of each of the no purge sampling devices included in the POP.

Appendix B of the EMES global best practice contains spreadsheets detailing cost comparisons between purge and different no purge sampling techniques/devices for a number of different scenarios.

Appendix C of the EMES global best practice describes procedures, data evaluation methods and costs associated with a site specific field demonstration to compare no purge to traditional sampling techniques.

Appendix D of the EMES global best practice contains detailed operating procedures for each of the no purge sampling devices described in the POP.

Appendix E of the EMES global best practice describes various statistical approaches that can be used to prove that purge and no purge sampling techniques/devices provide data that is not statistically significantly different at a site. This data can prove useful in convincing a regulator that no purge sampling can be used to replace purge sampling techniques at a site (or group of sites).

Appendix F of the EMES global best practice contains a letter template, which can be used to assist in gaining regulatory acceptance of no purge groundwater sampling techniques/devices at a site (or group of sites).

2.2) When To Use No Purge Groundwater Sampling

In jurisdictions where the local regulator accepts the use of no purge groundwater sampling, it should be utilized for all project scopes. This would include initial assessment, routine groundwater monitoring and site closure.

In jurisdictions where the local regulator does not approve of using no purge groundwater sampling for site assessment or site closure (or where acceptance of no purge sampling by the regulator is uncertain) the preferred practice will be the following:

1) Well purging sampling techniques (eg: the traditional purging of three well volumes; or low flow sampling) should be used for groundwater sampling during the initial site assessment and during site closure sampling.

2) No purge groundwater sampling should be used for all routine site monitoring activities, which take place between the groundwater sampling during the initial site assessment and the groundwater sampling used for site closure.

If a permit or a plan previously submitted to the local regulator specifies a certain sampling method or device, then that method or device shall continue to be used until a revised permit or plan has been approved by the regulator.

Regardless of whether or not a permit or approval has been issued, unless there is sound scientific justification to not use no purge sampling at a site, it is expected that the RRS Project Manager will endeavor to have the no purge sampling technique approved for that site – or for a group of sites in that regulatory jurisdiction. Site specific comparative analyses may be required. A letter template to assist in gaining regulatory acceptance of no purge groundwater sampling is provided in Appendix F of the EMES global best practice.

A decision tree to help the RRS Project Manager and Environmental Consultant to decide if no purge sampling is applicable at a given site is presented in Figure 2-1 (this is also Part 1 of Figure 1 in the EMES global best practice).

2.3) What No Purge Groundwater Sampling Technique/Device To Use At A Site

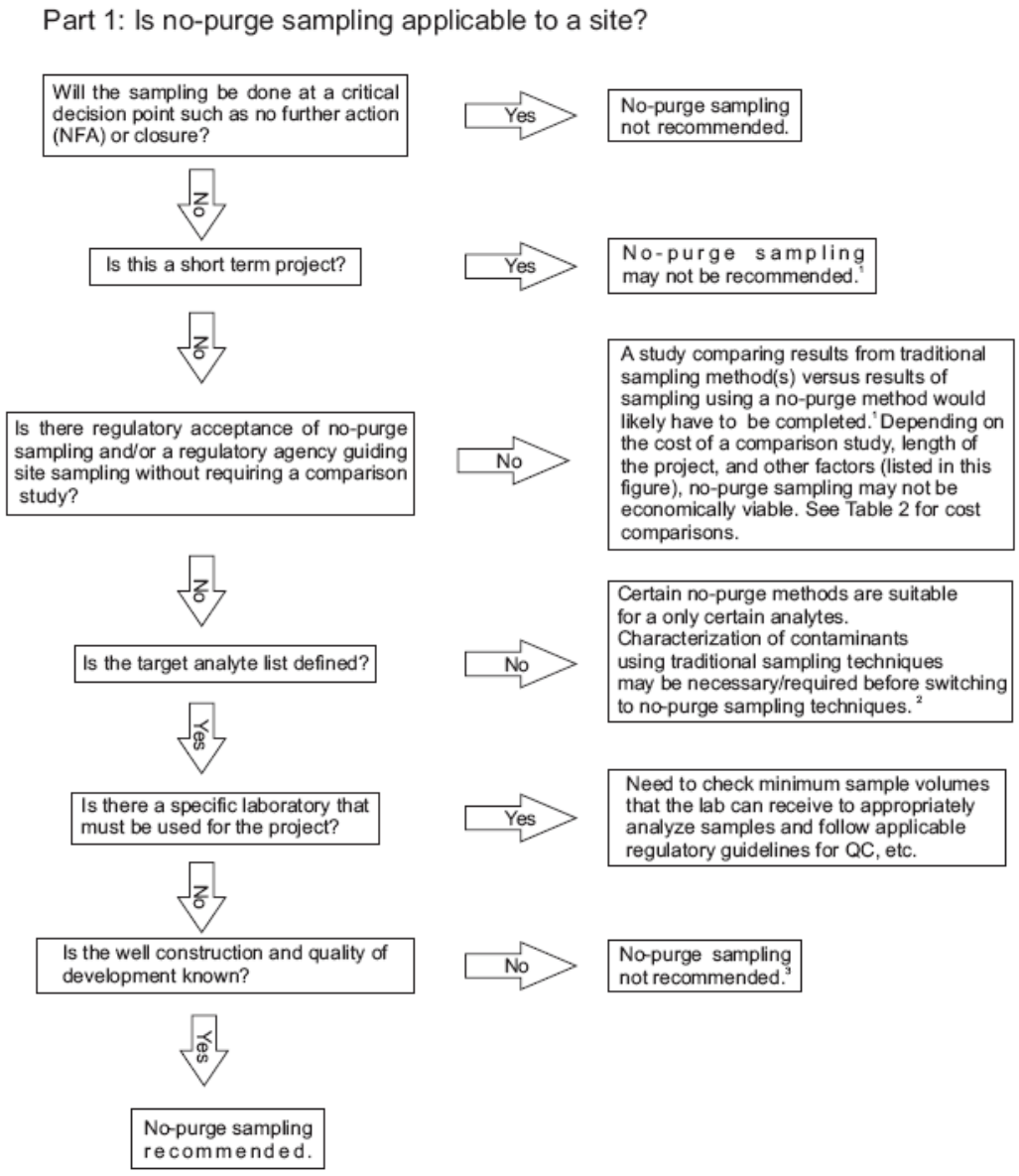
There are a large number of different no purge sampling devices and techniques to choose from. Once it has been determined that no purge sampling can be used at a site, the next step is to decide what the optimal no purge sampling technique/device is to use at the site, for the scope of work that has been developed.

For most applications a standard bailer is the preferred sampling device. In certain situations (eg. high sediments, discreet interval sampling), the bailer may not be an appropriate no purge sampling device.

A decision tree to help the RRS Project Manager and Environmental Consultant determine the preferred no purge sampling technique/device for a given site is presented in Figure 2-2 (this is also Part 2 of Figure 1 in the EMES global best practice).

Figure 2-1

Decision Tree To Determine If No Purge Sampling Is Applicable At A Site



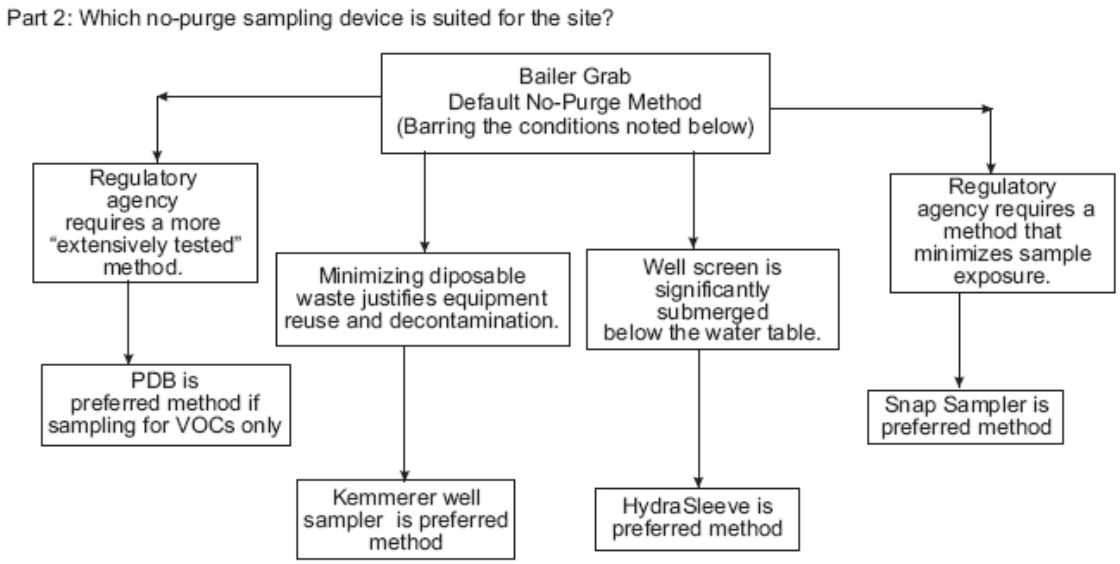
Notes:

1 - See Table 2 (insert hyperlink) for cost comparisons.
2 - See Table 1 (insert hyperlink) for detailed information on suitability of no-purge method to given analytes.
3 - To obtain representative results most no-purge methods depend on locating the sampler in the center of the saturated screened interval.

Figure 2-2

Decision Tree To Determine Preferred No Purge Sampling Technique/Device At A Site

B. What No Purge Groundwater Sampling Device Should You Use.



Also, if the monitoring well contains a high amount of sediment, using a hydrasleeve is the preferred sampling technique/device.

As noted above, a bailer is not recommended under some conditions. However, other no purge sampling devices may also be applicable, in addition to the noted preferred method.

For detailed information on the suitability of the various no purge sampling devices to specific analytes, please refer to Table 1 in the EMES global best practice.

APPENDIX 1

EMES GLOBAL BEST PRACTICE FOR NO PURGE GROUNDWATER SAMPLING

ExxonMobil Global Remediation

Best Practice for Selection and Use of No-Purge Groundwater Sampling Methods

July 2007

Limitations of this Best Practice: The practices presented here are recommended and are not prescriptive. In some site-specific instances, deviations may be required, based upon the best professional judgment of the Environmental Consultant. Significant deviations from this guidance should only be implemented after consultation with the ExxonMobil Project Manager. In all cases, this guidance should only be used by personnel who are trained and have sufficient technical knowledge of the subject matter.

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F Regulatory Agency Letter Template

Acronyms and Definitions

ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethyl benzene, and xylene
CO_2	Carbon dioxide
COCs	Chemical of concern
CPR	Cardiopulmonary resuscitation
Cr^{6+}	Hexavalent chromium
ft	feet
GE	General Electric
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response Standard
HDPE	High-density polyethylene
ITRC	Interstate Technology and Regulatory Council
L	Liters
JSA	Job safety analysis
lbs	pounds
LDPE	Low-density polyethylene
LNAPL	Light non-aqueous phase liquid
MEK	Methyl ethyl ketone
mL	Milliliter
MTBE	Methyl tertiary butyl ether
PCBs	Polychlorinated biphenyls
PDBs	Passive diffusion bags
PFA	Perfluoroalkoxy

Acronyms and Definitions

PPE	Personal protective equipment
p-value	Statistical significance
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
r^2	Coefficient of determination
RPD	Relative percent difference
RPPS	Rigid porous polyethylene samplers
SOP(s)	Standard Operating Procedures
SVOCs	Semivolatile organic compounds
TCE	Trichloroethene
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
VOA	Volatile organic analysis
VOCs	Volatile organic compounds
WRS	Wilcoxon Rank Sum
WSR	Wilcoxon Signed Ranks

Best Practice for Selection and Use of No-Purge Groundwater Sampling Methods

July 2007

Executive Summary

This Best Practice document has been prepared to support ExxonMobil Global Remediation project managers who are involved in groundwater monitoring. No-purge sampling methods offer many advantages over purging-based well sampling methods, including cost savings, and technical and logistical benefits. Although no-purge sampling methods have gained substantial credibility within the past several years, it is still common for regulatory agencies to require a site-specific demonstration of a no-purge method before allowing its routine use for groundwater monitoring at a given site.

No-purge sampling methods offer many advantages over purging-based methods, including cost savings, and technical and logistical benefits.

Factors that influence the decision to use no-purge based sampling include the target analyte list and corresponding laboratory sample volumes, sampling purpose (routine monitoring or site closure), the length of the sampling program, and knowledge of existing well construction and development. However the advantages of no-purge sampling include reduced sampling costs, minimization of waste handling, minimization of site interference, potential for increased safety, and other technical advantages.

This document discusses the basis of no-purge groundwater sampling, describes no-purge sampling techniques, compares costs among these methods and two purging-based sampling methods, and provides decision-making tools to aid in choosing a no-purge sampling method. The appendices of this document present detailed descriptions of the no-purge sampling devices, the basis for the cost calculations presented in Table 2, the process by which the effectiveness of no-purge sampling may be demonstrated at a given site, and detailed field procedures for the no-purge methods estimated to be the most economical.

Although no-purge sampling methods have gained substantial credibility within the past several years, it is still common for regulatory agencies to require a site-specific demonstration of a no-purge method before allowing its routine use for groundwater monitoring.

This document presents:

- Key points called out in the right margin of the document.
- The basis for no-purge sampling
- Figure 1 which assists in deciding whether no-purge sampling may be applicable for a specific site or well, and choosing proper no-purge sampling device(s) for a sampling program.
- Table 1 which provides details regarding the 5 preferred no-purge devices (most relevant to typical ExxonMobil sites) and 5 additional “specialty” methods, including sampler volume, advantages, disadvantages, applicable analytes, and supplier information.

- Table 2, which presents a cost comparison among the methods over varying time frames.
- Appendix A, which presents a description of all of the no-purge sampling devices evaluated in this best practice.
- Appendix B, which presents cost details
- Appendix C, which describes procedures, data evaluation and costs associated with a site specific field demonstration of no-purge versus purging-based sampling
- Appendix D, which includes selected detailed operating procedures
- Appendix E, which summarizes selected statistical methods
- Appendix F, which presents a letter template to propose no-purge groundwater sampling and a site specific field demonstration, if required, to a regulatory agency
- A CD with cost details and calculation worksheets and key referenced documents.

In most circumstances, it will be necessary to compare no-purge sampling with a standard sampling method on a site-specific basis to confirm that no-purge sample results are consistent with those obtained via the standard method.

Objective

This Best Practice document has been prepared to support ExxonMobil Global Remediation project managers who are involved in groundwater monitoring, and it is intended to aid in the selection of appropriate groundwater sampling methods that can reduce long-term monitoring costs. This document is designed to acquaint project managers with no-purge groundwater sampling methods, which have gained significant attention recently as an alternative to groundwater sampling methods that require pumping.

No-purge groundwater sampling depends on a well-developed screened interval so that the open interval is constantly flushed and water quality is representative of the formation around the screen.

Background: Basis for No-Purge Groundwater Sampling

With no-purge groundwater sampling, it is assumed that the water inside the open interval of a monitoring well represents ambient groundwater. This assumption is based on the fact that wellbore hydraulic conductivity is higher than that of the surrounding formation in almost all geologic settings. Thus, upgradient groundwater flow lines converge toward the well and constantly flush the open interval of the well (Graw et al., 2000). This natural "purging" effect has been demonstrated by laboratory tests and computer simulations (Raymond, 1955) and in field studies (Powell and Puls, 1993). In fact, the low-flow purging and sampling procedure, which is a standard groundwater sampling method, is based on the observations of many researchers that water moving through the formation also moves through the well screen. Thus, the water quality in the well screen is representative of the formation surrounding the well screen (American Society for Testing and Materials [ASTM], 2002).

Studies have demonstrated that no-purge sampling methods can produce groundwater analytical data comparable to the data obtained using more conventional (e.g., low-flow and traditional [three-volume purge]) groundwater sampling methods for a wide variety of organics and inorganics.

Preferential flushing of the well by ambient groundwater flow can, therefore, produce representative water quality within the open interval without well purging (e.g., Robin and Gillham, 1987; Powell and Puls, 1993). As early as 1988, studies indicated that no-purge sampling methods produce sampling results similar to those produced by purging methods for organics (Imbrigiotta et al., 1988). Several subsequent studies (listed at the end of this document) have demonstrated that no-purge sampling methods can produce groundwater analytical data comparable to the data obtained using more conventional (e.g., low-flow and traditional [three-volume purge]) groundwater sampling methods for a wide variety of organics and inorganics.

During no-purge sampling, a sampling device is deployed into the screened interval of a well, where ambient groundwater flow occurs. A sample is obtained by mechanically activating the sampler to allow entry and collection of ambient water from the selected depth or depth interval, or by allowing molecular diffusion to occur for a period sufficient for the water inside the sampler to achieve equilibrium with the surrounding water. As in standard low-flow purging and sampling protocols (e.g., United States Environmental Protection Agency [USEPA] 1998), the no-purge sample is commonly collected at the approximate midpoint of the saturated screened interval. In many cases, water quality

may be similar throughout the entire screen length of the well due to mixing within the well (Britt, 2005). Mixing may occur due to diffusion, currents that develop as a result of differential flow velocities through the well screen, or vertical hydraulic gradient components.

No-purge sampling is normally conducted for routine sampling of a plume to identify changes over time and to assess the progress of plume remediation or attenuation. Standard sampling, such as low-flow and traditional (three-volume purge), is commonly conducted for initial plume characterization or site closure confirmation. In most circumstances, it will be necessary to compare no-purge sampling with a standard sampling method on a site-specific basis to confirm that no-purge sample results are consistent with those obtained via the standard method. If the results do not compare favorably, as may occur in monitoring wells with long screens in fractured bedrock settings or in wells that are poorly developed, it may be appropriate to re-develop the well and/or characterize the vertical distribution of target analytes by no-purge sampling at multiple depths before implementing routine no-purge sampling of the well. Data presented by Imbrigiotta et al. (1988) suggest that well development can improve the performance of no-purge sampling methods relative to standard sampling methods in some situations.

To initially, accurately characterize contaminant distribution in wells with long well screens (≥ 10 ft) and/or a fractured rock setting, multiple samplers may need to be stacked to obtain a vertical profile of the contaminant distribution.

In many cases, no-purge sampling is applicable and is capable of providing useful, representative groundwater quality data. No-purge sampling offers several logistical and cost advantages over other groundwater sampling methods.

Advantages:

- well purging is eliminated
- waste handling and disposal are minimized
- sampling time and associated site interference are reduced
- field equipment needs are reduced
- sampling method implementation is simple
- overall sampling cost is reduced
- due to the simplicity of the field procedure, sampling repeatability is increased
- due to simplicity of the field procedure, potential for increased safety

In addition, no-purge sampling can offer a number of technical advantages, including the ability to easily and simultaneously sample at multiple vertical locations in the same well, or to obtain a composite grab sample from the screened interval.

Overview of No-Purge Sampling Methods

This section provides information on selected no-purge sampling methods that are likely to be applicable to most ExxonMobil sites, including a description of the equipment, how each device is used, which general types of analytes it is applicable for, how the actual sample is obtained from the sampler, and whether decontamination is required. The no-purge sampling methods reviewed in this document have undergone field and laboratory testing; nevertheless, these devices continue to be tested in the field and laboratory and modifications continue to be made to the existing devices by the manufacturer. As tests continue, the analyte list for which a given device is suited also develops. Table 1 provides additional details regarding each of these methods and additional "specialty" methods, including sampler volume, advantages, disadvantages, more details on applicable analytes, and supplier information. In addition, a decision tree is included on Figure 1 to assist in deciding whether no-purge sampling may be applicable for a specific site or well.

A decision tree is included on Figure 1 to assist in deciding whether no-purge sampling may be applicable for a specific site or well.

No purge sampling techniques fall into either of two categories:

- diffusion-based sampling, e.g., passive diffusion bag sampler, dialysis sampler, and rigid porous polyethylene sampler

- grab or "thief" sampling, e.g., HydraSleeve®, bailer grab sample, Snap Sampler™, discrete interval sampler, Pneumo-Bailer™, Kabis sampler, Kemmerer well sampler

Diffusion-based samplers require an equilibration period to achieve representative concentrations within the sampler; the required equilibration period, and ability to achieve representative concentrations, is analyte-specific. In contrast, grab or "thief" sampling methods do not rely on diffusion, but remove a sample of the water from the well. Thus, in principle, grab or "thief" methods should be applicable to any analyte and some are applicable to field parameters. See Table 1 for more information.

Detailed descriptions of No-Purge Sampling methods are provided in Appendix A. Selected detailed operating procedures are presented in Appendix D.

Cost Comparison

This section compares the estimated costs of no-purge sampling with the costs of low-flow and traditional (three-volume purge) sampling methods, based on a hypothetical site. The site is assumed to have fifteen 2-inch-diameter monitoring wells with total depths of 20 ft and saturated screened intervals of 10 ft (the water table is assumed to be 10 ft below grade). The assumed sampling depth is 15 ft below grade. Two scenarios are considered and summarized on Table 2 (excluding analytical and reporting costs). It is important to note that factors that could cause these cost estimates to change are summarized in Table 1 and Figure 1 and the costs calculated are based on the assumptions listed above. Descriptions of the two scenarios and details as to how these costs were calculated are provided in Appendix B. The estimated costs to complete a comparison study of no purge versus purge-based sampling are presented in Appendix C.

Bailer Grab, HydraSleeve®, Snap Sampler™, Kemmerer Well Sampler and PDBs were consistently estimated as the most cost effective no-purge sampling methods.

In the cost comparison presented in Table 2, the following methods were consistently estimated as the most cost-effective and would, therefore, be the most cost-effective for long-term groundwater monitoring at the hypothetical site.

- Bailer Grab
- HydraSleeve®
- Snap Sampler™
- Kemmerer Well Sampler
- Passive Diffusion Bags (PDBs)

The Snap Sampler™ costs were evaluated assuming that the sampler may be employed with either of two methods to obtain samples for VOC analysis. One method, which is more economical, was to obtain the sample using one 125-milliliter (mL) bottle and decant the sample to fill 40-mL vials supplied by the laboratory. The other was using two 40-mL vials supplied by ProHydro, which costs more but prevents the sample from being exposed to the atmosphere. Additional details regarding the cost calculations are provided in Appendix B. It is also important to note that the two purging-based sampling methods (traditional three-volume purge and low-flow) were estimated to be among the most expensive in terms of long-term cost under both scenarios. This suggests that no-purge groundwater sampling methods, in general, are more cost-effective than purge-based sampling methods.

The two purging-based sampling methods (traditional three-volume purge and low-flow) were estimated to be among the most expensive in terms of long-term cost.

Detailed Procedures for Selected No-Purge Sampling Methods

Additional details regarding the actual field application of the five no-purge methods estimated to be the most cost-effective over the long term (i.e., Bailer Grab,

HydraSleeve®, Snap Sampler™, Kemmerer Well Sampler and PDB) are included in Appendix D.

The detailed procedure for Bailer Grab Sampling was prepared by an outside consultant. Detailed procedures for use of the HydraSleeve®, Snap Sampler™, and Kemmerer Well Sampler were prepared by their manufacturers (GeoInsight, ProHydro, and Wildco, respectively). The detailed procedure for PDBs was prepared by Vroblesky (2001).

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Table 1 No-Purge Sampler Summary

Sampler	Parameters	Sampler Volume[2]	Costs Per Well (U.S. Dollars)[3]		Advantages[4]	Disadvantages[4]	Remarks[5]
Preferred No-Purge Sampling Devices in Top Portion of Table							
Bailer Grab Sample	BTEX, chlorinated VOCs, chloroform, dichlorobenzenes, naphthalene, MTBE, potassium, manganese, sulfate, magnesium, Freon 113	Typically 1 – 1.2 L, but larger and smaller sizes also available	VOCs & SVOCs or Metals Initial Sampling Event: $218	VOCs & SVOCs or Metals Subsequent Sampling Events: $218	- lowest cost - no sampler decontamination - minimizes potential for increased turbidity & mobilization of colloids - disposable - quick and easy to use - can be used in small diameter wells	- may not be applicable to wells with submerged screens - may underestimate VOC concentrations in low permeability formations - susceptible to inconsistencies in field staff techniques	The Ben Meadows Company www.benmeadows.com Voss Technologies, Inc. www.vosstech.com/default.htm Solinst Canada Ltd www.solinst.com (point source bailer, Model 429) Detailed Description Bailer Grab SOPs
Snap Sampler™	VOCs, SVOCs, Anions, MTBE, field parameters, metals, 1,4-Dioxane, PCBs, explosive compounds, pesticides, perchlorate, 2-butanone, MEK, & Cr^{6+}	Up to 4 samplers (containing sample vials) can be stacked in any combination sample vials available in 40 mL and 125 mL, maximum total volume = 500 mL	VOCs & SVOCs or Metals Initial Sampling Event: (3 x 125 mL) $1,036 (2 x 125 mL & 2 x 40mL) $1,199	VOCs & SVOCs or Metals Subsequent Sampling Events: (3 x 125 mL) $239 (2 x 125 mL & 2 x 40mL) $275	- eliminates non-sample water - potential exposure to air is minimized - commercially available - costs for follow up sampling lower than initial cost - no sampler decontamination	- may be more expensive than other no-purge methods, particularly during initial event or if sampling for more than VOCs only - more complicated field procedure - relatively small sample volume - need at least 2- inch diameter wells - manufacturer recommends deployment period of 72 hours	ProHydro, Inc. www.snapsampler.com Triggers are well-specific. Need well construction information to select trigger lengths. One bottle per Snap Sampler™, up to 4 connected in a series ≤ 10 ft long screen. Detailed Description Snap Sampler™ SOPs
HydraSleeve®	VOCs, SVOCs, major cations & anions, metals, dissolved trace metals, dissolved sulfide, dissolved gases (methane/ethene/CO_2), total dissolved solids, dissolved organic carbon, dissolved silica, explosive compounds, perchlorate, 1,4-Dioxane & Cr^{6+}	500 mL (1.75-inch diameter x 28-inches long) 650 mL (1.75-inch diameter x 30-inches long) 1000 mL (composite sampler, 1.75-inch diameter x 36-inches long) - can be customized	VOCs & SVOCs or Metals Initial Sampling Event: $322	VOCs & SVOCs or Metals Subsequent Sampling Events: $301	- large sample volumes possible - wide variety of analytes - commercially available - quick & easy to use - relatively low cost - disposable - no sampler decontamination - can stack end-to-end for vertical profiling - can be used in short or long screens - for long term monitoring, can be left in well between sampling events	- need at least 2- inch diameter wells - may need to equilibrate in well for at least 24 hours prior to retrieval (shorter equilibration periods may be tested for feasibility)	GeoInsight www.geoinsightonline.com Or EON Products, Inc. www.eonpro.com/ Detailed Description HydraSleeve® SOPs Custom tether set ups , to lock bags in well between events, available through EON

Table 1 No-Purge Sampler Summary (Cont'd)

Sampler	Parameters	Sampler Volume[2]	Costs Per Well (U.S. Dollars)[3]		Advantages[4]	Disadvantages[4]	Remarks[5]
Kemmerer Well Sampler	Major and trace elements, organic compounds, field parameters (list assumes use of Teflon endcaps)	0.6 L	VOCs & SVOCs or Metals Initial Sampling Event: $349	VOCs & SVOCs or Metals Subsequent Sampling Events: $319	- reusable - can target a specific depth with well sampler - well sampler can be manufactured to user specifications	- decontamination required - need at least 2- inch diameter wells	Wildlife Supply Company www.wildco.com Detailed Description Kemmerer Well Sampler SOPs
Passive Diffusion Bag (PDB)	Many VOCs[1], some SVOCs	200 – 350 mL (other sizes can be fabricated as needed)	VOCs & SVOCs or Metals Initial Sampling Event: $380	VOCs & SVOCs or Metals Subsequent Sampling Events: $355	- widely accepted for many VOCs - can be adapted to smaller wells - technical guidance available - well purging eliminated - commercially available - quick & easy to use - no sampler decontamination - can stack for vertical profiling - reduced cost - disposable - turbidity, alkalinity & permanganate excluded	- not suitable for all VOCs (such as MTBE, some ketones, ethers & alcohols) - patent held by USGS & GE, but samplers can be purchased from listed suppliers without infringement (see right) - equilibration required, 2 weeks equilibration time adequate for most investigations	EON Products, Inc. www.eonpro.com/ Or Columbia Analytical Services, Inc. www.caslab.com/ Detailed Description PDB SOPs
Specialty Devices (from this point forward in the table)							
Discrete Interval Sampler	Explosives, pesticides, VOCs, metals, wide variety of analytes	175 mL to 1,800 mL custom diameters and lengths can be made	VOCs & SVOCs or Metals Initial Sampling Event: $453	VOCs & SVOCs or Metals Subsequent Sampling Events: $399	- can fit in a well greater than 1- inch diameter - wide variety of analytes	- needs to be pressurized with a hand pump - relatively complicated to use - few published studies - longer time to deploy and obtain sample than other devices - decontamination required	Solinst Canada Ltd. www.solinst.com Model 425 (stainless steel) Detailed Description
Pneumo-Bailer™	Explosives, pesticides, VOCs, metals, wide variety of analytes	0.5 L (1.0 or 1.5 —inch diameter), 1 L (1.75-inch diameter) or 2 L (3.5-inch diameter) (can be custom-made)	VOCs & SVOCs or Metals Initial Sampling Event: $551	VOCs & SVOCs or Metals Subsequent Sampling Events: $424	- can be used to sample a variety of analytes - good for deep wells (100 -1,000 ft)	- very heavy, need winch to retrieve samples from deeper wells - difficult to use (28 steps) - needs gas (nitrogen) cylinder to pressurize - longer time to deploy and obtain sample than other devices - relatively high cost - decontamination required	Besst, Inc. http://www.besstinc.com/ Detailed Description

Table 1 No-Purge Sampler Summary (Cont'd)

Sampler	Parameters	Sampler Volume[2]	Costs Per Well (U.S. Dollars)[3]		Advantages[4]	Disadvantages[4]	Remarks[5]
Kabis Sampler	Reportedly suitable for most analytes (USEPA's Environmental Technology Verification Program evaluated VOCs)	Model 1 (1 40 mL vial) Model 2 (3 40 mL vials) Model 3 (1 L bottle) (Sampler can be deployed and retrieved multiple times to obtain sufficient sample volume.)	VOCs & SVOCs or Metals Initial Sampling Event: $612	VOCs & SVOCs or Metals Subsequent Sampling Events: $549	- no transfer of sample - potential exposure to air is minimized - no moving parts	- need at least 2- inch diameter wells for Model 1; Models 2 & 3 need >3- inch diameter well - deploying and retrieving more than once to obtain sufficient sample volume may increase turbidity of samples - preservative must be added after filling the sample container - cannot be used where sampling protocols call for use of pre-preserved sampling vials or Teflon-lined septum caps in vials - should not be used in acidic environment due to the stainless steel construction (according to Einfeld & Koglin, 2000) - relatively high cost - devices are heavy (6 – 16 lbs) stainless steel - tricky to operate during retrieval (1 hr training recommended) - increased turbidity possible - decontamination required	SIBAK Industries Limited, Inc. http://www.sibak.com/ Detailed Description
Rigid Porous Polyethylene Sampler (RPPS)	RPPS appears to perform best for inorganic, nonvolatile parameters, including Cr6+ and less well for organic parameters (i.e., VOCs and 1,4 dioxane), according to ITRC, 2006	175 mL	VOCs & SVOCs or Metals Initial Sampling Event: $388	VOCs & SVOCs or Metals Subsequent Sampling Events: $388	- easy to use - relatively low cost - no limit to depth at which they can be deployed - fairly wide variety of analytes - expected to be manufactured as a disposable device	- need at least 2- inch diameter wells - deployment time ranges from 8 days to 22 days, depending on analyte - limited availability (for purchase) through Columbia Analytical Services - may not be suitable for redox sensitive compounds (iron, etc)	Columbia Analytical Services, Inc. http://www.caslab.com/ patent application being considered by USGS Detailed Description
Dialysis Sampler	VOCs, most metals, major cations and anions, some field parameters, most explosives, MTBE	~47 - 400 mL per bag	VOCs & SVOCs or Metals Initial Sampling Event: $438	VOCs & SVOCs or Metals Subsequent Sampling Events: $438	- low cost - can be used in small diameter wells - can be strung together for vertical profiling - disposable - no sampler decontamination	- ready-made samplers are not available, only components are commercially available - cellulose dialysis samplers can degrade within 1 – 2 weeks - warm water and presence of microbes shorten longevity of regenerated cellulose samplers - deployment time ranges from a few days to 14 days depending on analyte of interest	Membrane Filtration Products, Inc. http://www.membrane-mfpi.com/default.htm Spectrum Laboratories, Inc. http://www.spectrapor.com/ can couple these with a PDB for VOCs for additional volume if sampling for more than VOCs Detailed Description

Table 1 No-Purge Sampler Summary (Cont'd)

Notes:

[1] – Lists of applicable VOCs and SVOCs are published by Vroblesky, D.A., 2001; Vroblesky, D.A., and T. Campbell., 2001; others may be applicable also, pending field testing.

[2] – Approximate minimum required sample volumes, listed below, were provide by: ENCO, Florida; STL, Florida; Jupiter Labs, Florida; and Columbia Analytical Services, Inc., Washington.

Minimum Lab Sample Volumes

VOCs: 20 to 40 mL (2 vials)

SVOCs: 250 - 500 mL

Total Petroleum Hydrocarbons (TPH): 1 L

Metals: 25 – 250 mL

Pesticides/PCBs: 100 – 500 mL

Perchlorate: 10 – 250 mL

* PCBs/Pesticides can be run off the same 500 mL aliquot

Contact site-specific lab to verify sample volume requirements.

[3] – Costs are approximate, based on information provided by vendors (Columbia Analytical Services, Inc.; EON Products, Inc.; GeoInsight; The Ben Meadows Company; Voss Technologies, Inc.; ProHydro, Inc.; Solinst Canada Ltd.; SIBAK Industries Limited, Inc.; BESST, Inc.; Wildlife Supply Company); and data from recent publications (ITRC, 2006, and Parker & Clark, 2002). Contact vendor for the most current pricing information.

[4] – All no-purge sampling methods have similar advantages and disadvantages relative to purging-based sampling methods, as discussed in the text and decision tree.
Advantages and disadvantages are listed here relative to the other no-purge methods.

[5] – Additional suppliers may exist, beyond those noted here.

[6] – Parameters and groups of parameters listed here have been reported as suitable for sampling with the specified sampler. Other parameters may also be appropriate, pending field testing and verification.

References:

Einfeld & Koglin, 2000
ITRC, 2006
MacMillan & Splichal, 2005
Newell et al., 2000
Parker & Clark, 2004
Parker & Clark, 2002
Parsons, 2005
Tan et al., 2005
Houghton & Berger, 1984

Table 2 Cost Comparison Summary[1]

Site: Generic Site
Number of Wells: 15
Average Sampling Depth: 15 feet

VOCS ONLY (MINIMUM OF 2 VOA VIALS, 20 or 40 ML EACH)

Method	First Event Cost	Cost Per Well	Subsequent Cost	Subsequent Cost Per Well	5-Year Total *	20-Year Total*	30-Year Total *
3-Volume Purge	$ 7,225	$ 482	$ 7,225	$ 482	$ 72,250	$ 289,000	$ 433,500
Low Flow	$ 6,825	$ 455	$ 6,825	$ 455	$ 68,250	$ 273,000	$ 409,500
Bailer Grab	$ 3,040	$ 203	$ 3,040	$ 203	$ 30,400	$ 121,600	$ 182,400
Snap Sampler™ - 1 x 125 mL	$ 10,505	$ 700	$ 3,204	$ 214	$ 39,338	$ 135,451	$ 199,526
HydraSleeve®	$ 3,865	$ 258	$ 3,550	$ 237	$ 35,815	$ 142,315	$ 213,315
Kemmerer	$ 5,000	$ 333	$ 4,550	$ 303	$ 45,950	$ 182,450	$ 273,450
Snap Sampler™ - 2 x 40 mL	$ 12,957	$ 864	$ 3,530	$ 235	$ 44,727	$ 150,627	$ 221,227
PDB **	$ 5,540	$ 369	$ 5,165	$ 344	$ 52,025	$ 206,975	$ 310,275
Discrete Interval	$ 6,625	$ 442	$ 5,825	$ 388	$ 59,050	$ 233,800	$ 350,300
Pneumo-Bailer	$ 8,100	$ 540	$ 6,200	$ 413	$ 63,900	$ 249,900	$ 373,900
Kabis - 1 x 40 mL, deploy 2x	$ 6,035	$ 402	$ 5,085	$ 339	$ 51,800	$ 204,350	$ 306,050
RPPS	$ 5,655	$ 377	$ 5,655	$ 377	$ 56,550	$ 226,200	$ 339,300
Dialysis Sampler	$ 6,405	$ 427	$ 6,405	$ 427	$ 64,050	$ 256,200	$ 384,300

VOCS AND SVOCS OR METALS (MINIMUM OF 2 VOA VIALS, 20 or 40 ML EACH, PLUS 250 ML)

Method	First Event Cost	Cost Per Well	Subsequent Cost	Subsequent Cost Per Well	5-Year Total *	20-Year Total*	30-Year Total *
3-Volume Purge	$ 10,380	$ 692	$ 10,380	$ 692	$ 103,800	$ 415,200	$ 622,800
Low Flow	$ 7,055	$ 470	$ 7,055	$ 470	$ 70,550	$ 282,200	$ 423,300
Bailer Grab	$ 3,270	$ 218	$ 3,270	$ 218	$ 32,700	$ 130,800	$ 196,200
Snap Sampler™ - 3 x 125 mL	$ 15,540	$ 1,036	$ 3,586	$ 239	$ 47,816	$ 155,403	$ 227,128
HydraSleeve®	$ 4,825	$ 322	$ 4,510	$ 301	$ 45,415	$ 180,715	$ 270,915
Kemmerer	$ 5,230	$ 349	$ 4,780	$ 319	$ 48,250	$ 191,650	$ 287,250
Snap Sampler™ - 2 x 40mL, 2 x 125 mL	$ 17,992	$ 1,199	$ 4,130	$ 275	$ 55,162	$ 179,062	$ 261,662
PDB **	$ 5,705	$ 380	$ 5,330	$ 355	$ 53,675	$ 213,575	$ 320,175
Discrete Interval	$ 6,790	$ 453	$ 5,990	$ 399	$ 60,700	$ 240,400	$ 360,200
Pneumo-Bailer	$ 8,265	$ 551	$ 6,365	$ 424	$ 65,550	$ 256,500	$ 383,800
Kabis - 1 x 40 mL, deploy 8x	$ 9,180	$ 612	$ 8,230	$ 549	$ 83,250	$ 330,150	$ 494,750
RPPS	$ 5,820	$ 388	$ 5,820	$ 388	$ 58,200	$ 232,800	$ 349,200
Dialysis Sampler	$ 6,570	$ 438	$ 6,570	$ 438	$ 65,700	$ 262,800	$ 394,200

Notes:

1 - Costs do not include laboratory analysis or reporting.

2 - * Assumes 2 sampling events per year, with cost discounting for PDBs, HydraSleeve®, and Snap Sampler™ (discounts for purchase of up to 100 samplers and 600 bottles, greater discounts apply with increased items purchased.

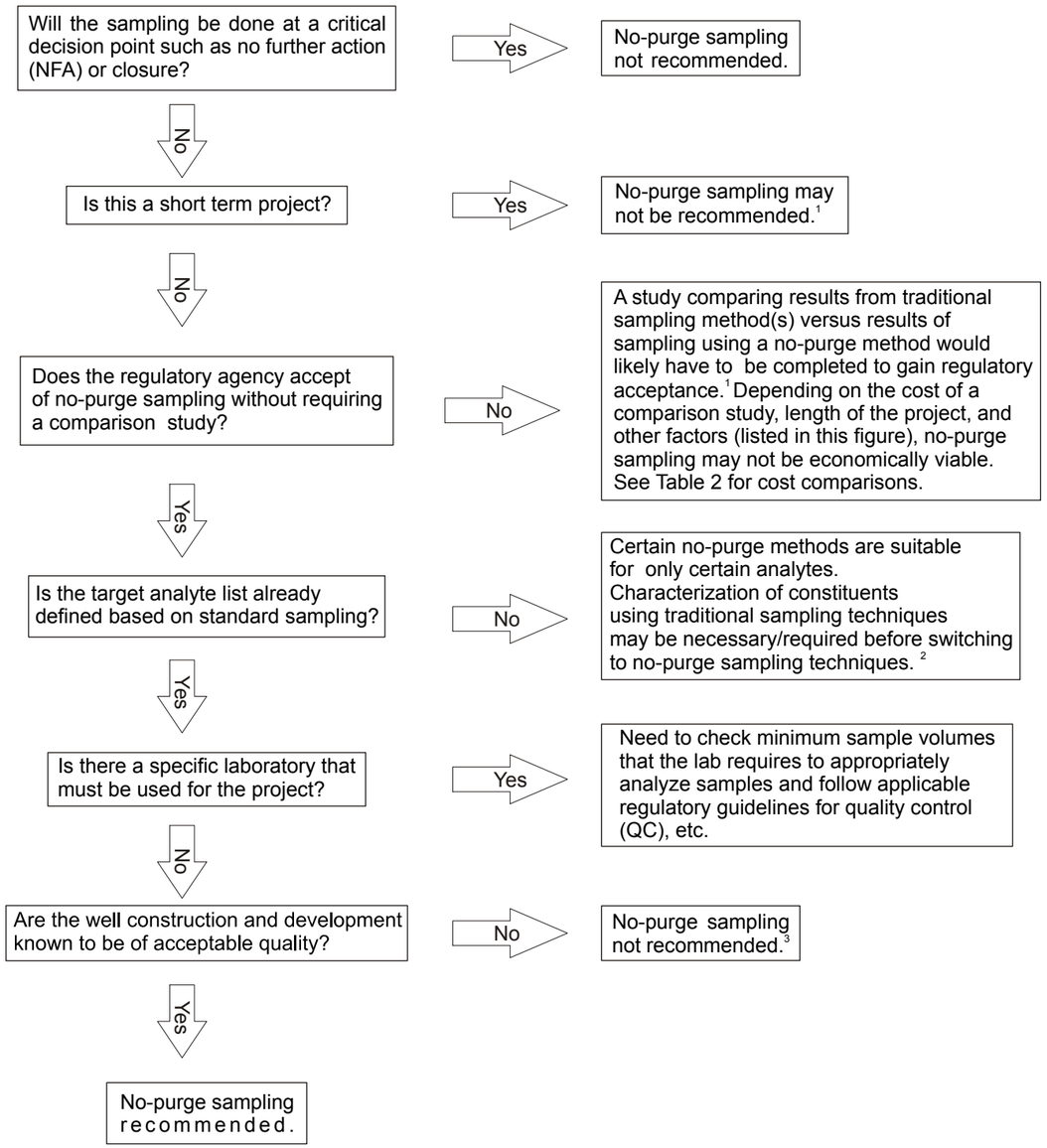
3 - ** PDBs are applicable to most VOCs and a limited number of SVOCs.

4 - Relative cost rank:

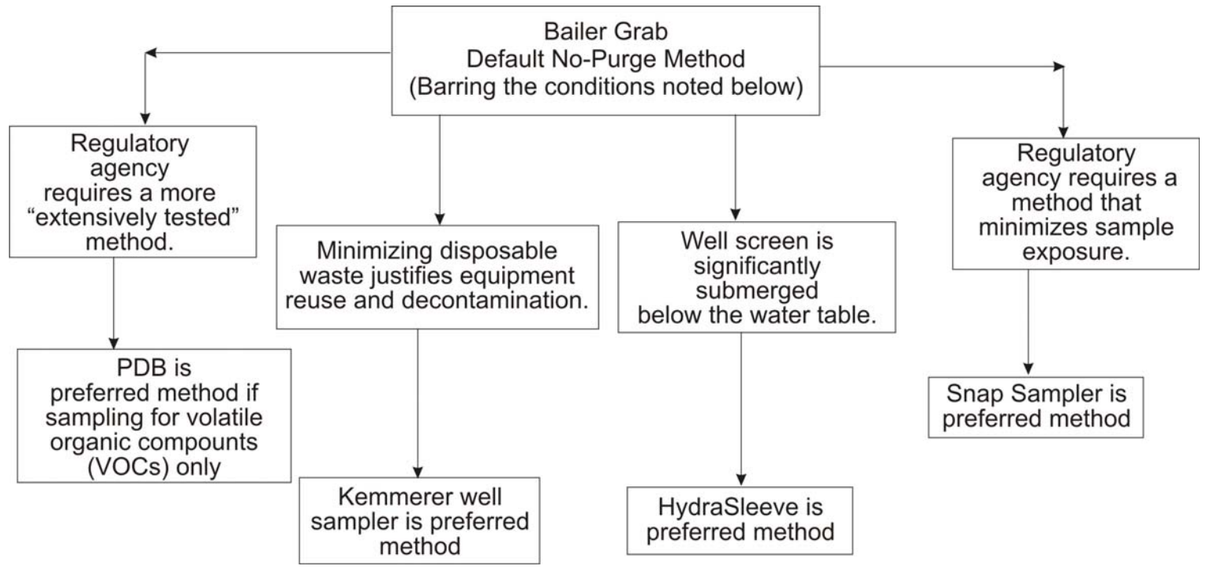
High Cost	Intermediate Cost	Low Cost

Figure 1 No-Purge Sampling Decision Tree

Part 1: Is no-purge sampling applicable to a site?



Part 2: Which no-purge device is suited for the site?



Notes:

1 - See Table 2 for cost comparisons.

2 - See Table 1 for detailed information on suitability of no-purge method to specific analytes.

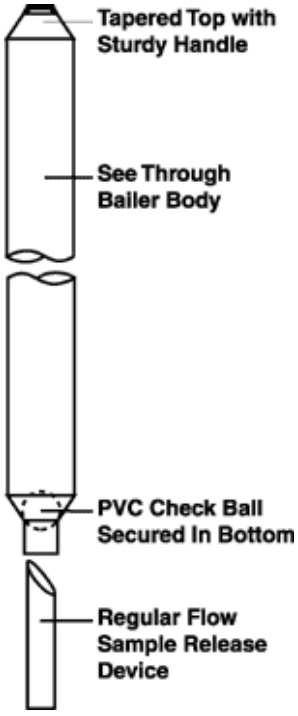
3 - To obtain representative results most no-purge methods depend on locating the sampler in the center of the saturated screened interval. If the well construction details are not available, then a downhole video survey may be performed to identify the screened/open interval so that the midpoint of the screen can be properly located. If the quality of well development is unknown, then the well should be redeveloped prior to sampling.

Appendix A

Description of No-Purge Sampling Methods

Bailer Grab Sample

Above: Point source bailer
Below: Open bailer
(both from Solinst, 2006).



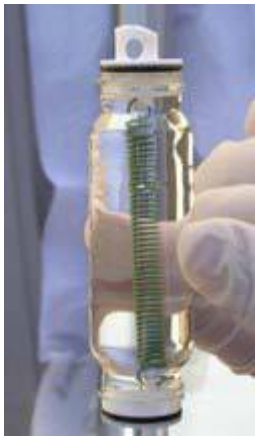
Two types of bailers are available for obtaining grab samples from wells: a point-source bailer and an open bailer. Either type of bailer should be applicable to a wide range of analytes.

A point-source bailer is constructed of stainless steel with ball valves at the top and bottom. A point-source bailer is lowered slowly to the desired sample depth on a support line. As the bailer is being lowered, both ball valves remain open allowing water to flow through the sampler. After reaching the sampling depth, the bailer is raised using the support cable and optional winding reel. The weight of water and upward movement of the bailer keep both ball valves closed. The top ball valve prevents the sample in the bailer from mixing with water at higher levels in the borehole. Once at the surface, the bailer is emptied by opening the top vent and allowing the water to drain slowly through the sample release device into the sample container. The bailer can then be decontaminated before sampling continues.

Open bailer grab samples are not recommended in wells where there is a significant length of water column above the sampling depth.

Open bailers can be constructed of stainless steel, Teflon®, polyvinyl chloride (PVC), or HDPE. Disposable open bailers are typically made of HDPE. An open bailer has one bottom ball valve that allows water to pass through the bailer while it is lowered. After the bailer is lowered to the desired depth, the bailer is retrieved, and the valve closes, retaining the sample in the bailer (Imbrigiotta et al., 1988; Solinst, 2006). However, because the top of the bailer is open, it is possible that the sample could mix, to some degree, with water from the zone above the actual sampling interval. Thus, open bailer grab samples are not recommended in wells where there is a significant length of water column above the sampling depth.

Point source sampling can be used to profile an open borehole or screened well, to collect samples from distinct levels or points of inflow. There is negligible disturbance as can be caused by pumping and purging. Mixing of the sample with water from different levels in the well is minimized (Solinst, 2007).



Snap Sampler 40-mL Vial (from ITRC, 2006).

Snap Sampler™

The Snap Sampler™ is suitable to a wide range of organics and inorganics. It employs standard-sized 40-milliliter (mL) glass VOA vials and/or 125 mL polypropylene bottles with double-end openings. Specialty Teflon® end caps seal water within the Snap Sampler™ vial with an internal closure spring made of perfluoroalkoxy- (PFA Teflon®) coated stainless steel. To deploy the sampling device, the vial is placed inside the Snap Sampler™, and the end closure caps are attached to the sampler's trigger mechanism in an open position. The suspension/trigger cable consists of a 1/32-inch-diameter stainless steel wire rope within ¼-inch high-density polyethylene (HDPE) tubing. Both ends of the vial are open to the well environment during the deployment period (Parsons Engineering Science, Inc. [Parsons], 2005). As many as four Snap Samplers™ can be attached in series to collect as many as four sample bottles with one trigger cable (ITRC, 2006). The trigger cable is secured at the top of the well using a docking station. After an equilibration period (the manufacturer recommends a minimum of 72 hours), the trigger is activated, "snapping" the sample vial(s) closed. The vial(s) are retrieved and remain closed prior to sample analysis. A shorter equilibration period may be used, pending the results of a site-specific demonstration.

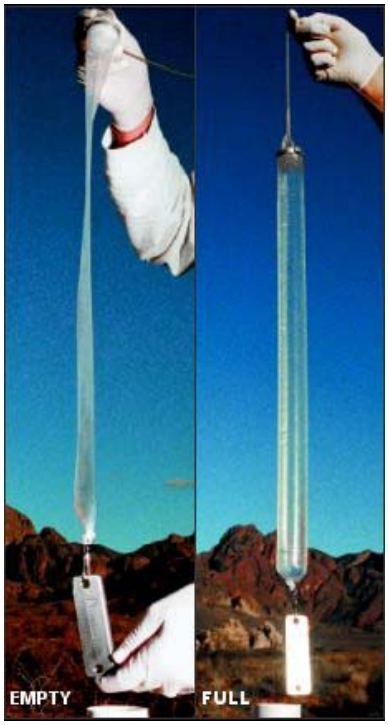
The Snap Sampler™ provides a sample in situ so that the sample is never exposed to air from when it is collected to when it is analyzed. The Snap Sampler is considered more accurate when sampling VOCs because there is no loss due to surface handling and/or tubing during sampling (ITRC, 2007).

HydraSleeve®

The HydraSleeve® groundwater sampler collects a whole water sample from a specified interval and is suitable for a wide range of organics and inorganics. One or more HydraSleeves® are placed within the screened interval of the monitoring well, and a period of time is allocated for the well to re-equilibrate. Hours to months later, the sealed HydraSleeve® is pulled upward, which enables water to enter the check valve into the sample sleeve. The total distance that the check valve must travel to fill the sample sleeve is approximately one to two times the length of the sampler (GeoInsight, 2006). The HydraSleeve® collects a sample with minimal drawdown, agitation and displacement of the water column. HydraSleeve® samplers consist of three basic components: a reusable weight; a long, flexible, lay-flat sample sleeve (usually made of polyethylene); and a self-sealing valve. The valve is located at the top of the lay-flat sample sleeve and includes an attachment point for the suspension line (Interstate Technology and Regulatory Council [ITRC], 2006). Once the sampler is full, the one-way reed valve collapses, preventing the mixing of extraneous, non-representative fluid during recovery (GeoInsight, 2006). The bottom of the flexible tube is sealed and the weight is attached to it. Following retrieval from the well, the sample is opened by using

HydraSleeve® passive ground water sampler is suited for sampling low yield wells. It is suitable for both short and long term groundwater monitoring, and is especially useful in narrow, constricted, or damaged wells. It can also be used to sample discrete intervals from surface water bodies and tanks (GeoInsight, 2007).

the discharge tube provided by the manufacturer. The tube is pushed into the polyethylene sleeve, and the sample is decanted to the glassware for shipment to the analytical laboratory.



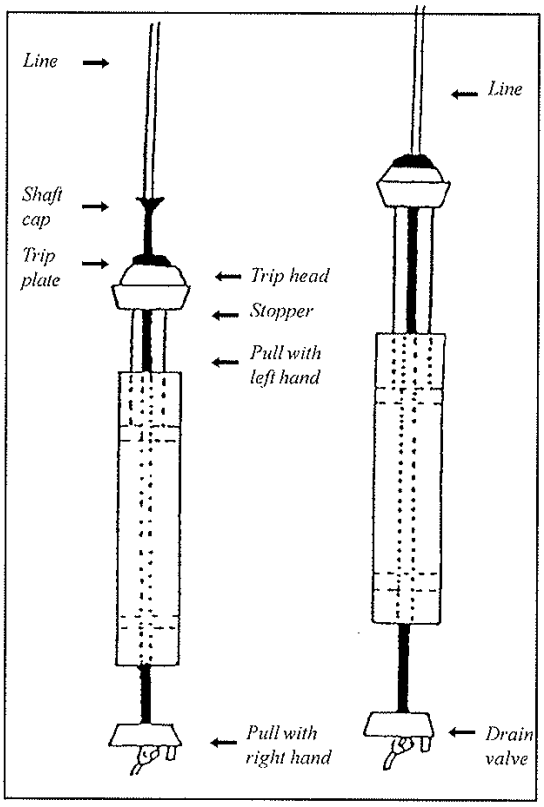
Left and Below:
HydraSleeve®
(from Parsons, 2005 and ITRC, 2006, respectively).

Kemmerer Well Sampler

The Kemmerer Well Sampler is a stainless steel tube with removable stoppers at top and bottom. It is 1⅝ inches in diameter, holds 0.6 liters (L) of sample, and is made with silicone, Teflon® or polyurethane seals. It is suitable for sampling a wide range of organics and inorganics.

Before sampling, the bottom stopper is pulled down until the shaft assembly snaps into the trip head. The stoppers are locked open before the sampler is lowered to the desired depth. A “messenger,” which has been attached to the line either prior to or after the sampler is deployed, is then released from the top of the well, falls down the

Left: Kemmerer Well Sampler and messenger (front of picture) (from Wildco, 2006).



Left: Kemmerer Well Sampler (from Wildco, 2006).

line, and closes both the upper and lower stoppers. (If the depth to water in a well exceeds 50 feet (ft), a shock absorber can be used to provide a cushion between the sampler and the messenger.) The sampler is raised to ground surface, and a drain in the bottom stopper draws off water for collection in sample containers. The sampler can be decontaminated with an appropriate cleaning solution without disassembly. The manufacturer recommends cleaning the sampler before using it, and practicing its use prior to sampling (Wildco, 2006).

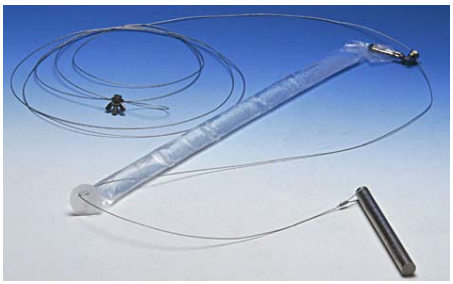
Passive Diffusion Bag Samplers

Above: Typical water-filled PDB samplers used in wells, including: (A) PDB with protective polyethylene mesh, (B) PDB without mesh, and (C) PDB and mesh attached to bailer bottom (from Vroblesky, 2001).

Passive diffusion bag (PDB) samplers are suitable for sampling many volatile organic compounds (VOCs), although some VOCs such as methyl tert-butyl ether (MTBE), ketones, and 1,4-dioxane are not suitable for PDB sampling. A PDB sampler consists of a low-density polyethylene (LDPE) sleeve that contains distilled or deionized water. It is lowered to a target depth within a screened or open interval of a well with a weight (typically stainless steel) that is attached to and suspended below the PDB. Organic analytes diffuse through the LDPE membrane into the chamber that initially contained distilled or deionized water. Analytes diffuse in and out of the device until equilibrium is reached. The time required to reach equilibrium depends on the rate of groundwater exchange within the well, the water temperature, the analyte and the type of membrane. Typically, PDBs are deployed for an equilibration period of 2 weeks (Parker &

The suggested application of this method is for long-term monitoring of VOCs in groundwater wells at well characterized sites (Vroblesky, 2001).

Clark, 2002). A site-specific demonstration may be required to justify a shorter or significantly longer equilibration period. Following equilibration, the PDB is retrieved, the bag is opened by cutting the sleeve (or unscrewing the built-in cap), and the sample is decanted to standard volatile organics analysis (VOA) vials for shipment to the analytical laboratory. The only water discharged from this device is that which is not used for sample collection. That unused water will need to be disposed or containerized and characterized in conjunction with all other waste produced during the field sampling effort.



Left: United States Geologic Survey (USGS) passive diffusion bag sampler with stainless steel weight and stainless steel weighted line (from Parker and Clark, 2002).

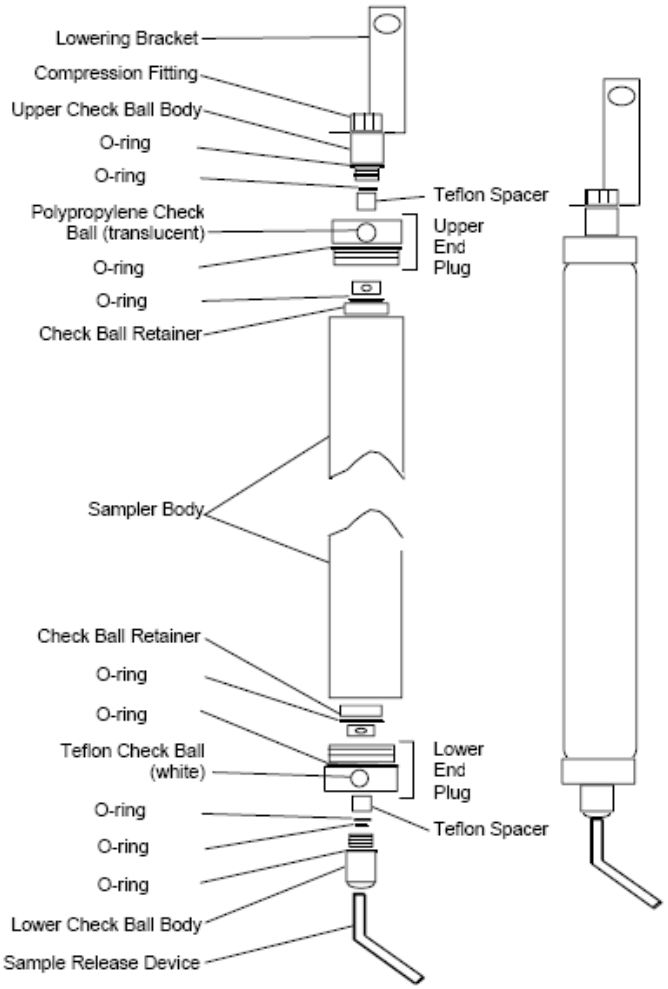
Discrete Interval Sampler

Solinst's Model 425 is a stainless steel discrete interval sampler that is suitable for a wide range of organics and inorganics. Airline tubing (typically LDPE, although Teflon® and Teflon®-lined polyethylene tubing are also available) runs from the surface to the sampler and is mounted on a reel. The system is pressurized with a hand pump that activates a pressure/vent switch. Once the sampler has reached the desired depth, the pressure is released and hydrostatic pressure allows the sampler and tubing to fill with water from the sampling zone. No equilibration period is necessary. The sampler is then repressurized and brought to the surface, and the sample is decanted using a sample release device that, according to the manufacturer, is designed to prevent degassing of the sample (Parker and Clark, 2002). The sampler is disassembled, decontaminated and reassembled (no tools required) prior to sampling at the next well (Solinst, 2006).

Above: Solinst Model 425 Discrete Interval Sampler (from Parker and Clark, 2002).

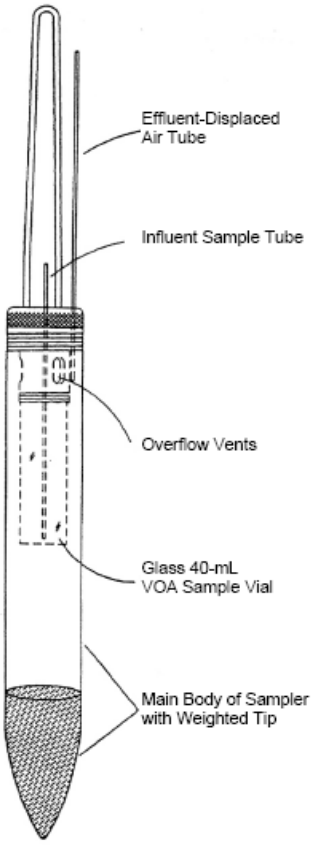
Pneumo-Bailer™

The Pneumo–Bailer™ was designed specifically for recovering samples to be analyzed for dissolved organic and/or inorganic constituents from wells deeper than 100 to 1,000 ft. The sampler has a stainless steel chamber with two O-rings and a polyethylene floating check ball. This device is connected to the surface with an LDPE gas-supply line and utilizes nitrogen gas to pressurize the system during ascent and descent. Available model sizes include 1 L (1.75-inch diameter) and 2 L (3.38-inch diameter). Other sizes can be custom made. Typically, this device is raised and lowered with an automated winch system (Parker and Clark, 2002). No equilibration period is necessary. A drain tube is inserted into a reed valve at the bottom of the device that releases the sample into glassware for shipment to the laboratory. The sampler is then decontaminated prior to sampling at the next well.

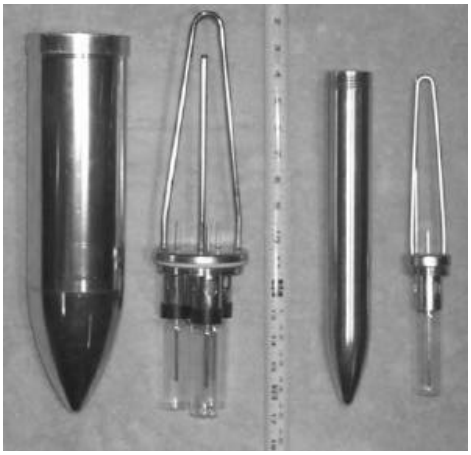


Pneumo-Bailer™ Schematic (from Parker and Clark, 2002).

Kabis Sampler



Above: Kabis Sampler (from Parker and Clark, 2002)



Above: Kabis Sampler Model 2 (left) and Model 1 (right) (from Einfeld and Koglin, 2002)

The Kabis Sampler is designed to collect a sample from a well at a specific depth chosen by the sampler operator. It reportedly can be used to sample most types of analytes (Parker and Clark, 2002).

The Kabis Sampler is a bullet-shaped device made of stainless steel. It has a small collection tube and a longer, larger discharge tube at the top. Depending on the model or size of the sampler, it can hold either one or three VOA vials (Model 1 or 2, respectively) or a 1-L sample bottle (Model 3). The sampler is attached to a fiberglass measuring tape and slowly lowered into the water column. The sampler does not fill until it is held stationary at the desired sample depth, when it begins to fill by hydrostatic pressure. When the sampler is full, it is retrieved, the sampling head is unscrewed from the body of the sampler, and the sample vials are removed from the sample head. No sample transfer is necessary. If sample preservation is required, preservative may be added after sample collection. The samples are then ready for shipment to the analytical laboratory.

The Kabis sampler has no moving parts and requires no maintenance other than routine decontamination. Decontamination consists of a detergent water rinse followed by several distilled water rinses and can be easily carried out in the field (Einfeld and Koglin, 2000). The sampler is then placed in an upright position to air-dry, re-assembled, and made ready for the next well (Kabis, 1998).

Rigid Porous Polyethylene Sampler

Above: RPPS with a mesh cover (from IRTC, 2006)

Rigid porous polyethylene samplers (RPPSs) are rigid polyethylene tubes that are capped at both ends. The material used to construct these devices has a larger pore size (6 to 15 microns) than the material used to construct PDBs. Thus, these devices reportedly can be used to sample for a relatively wide range of analytes, including VOCs, MTBE, chromium, and chloride.

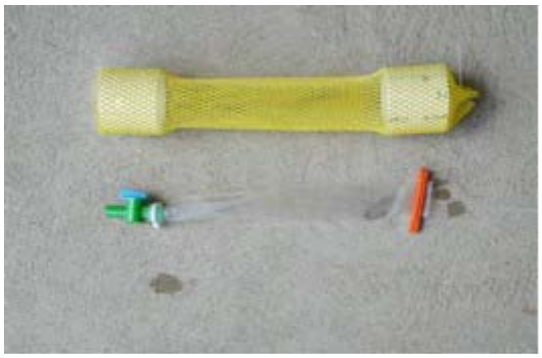
These devices are still undergoing laboratory and field testing (IRTC, 2006; Parsons, 2005).

The RPPS is filled with water free of the target analytes, capped at both ends, and placed inside a mesh liner, which is then attached to a deployment rope using cable-ties and deployed in a well at a target depth. To obtain larger volumes, RPPSs can be attached end-to-end or side-by-side. Chemicals diffuse across the porous polyethylene until equilibrium is achieved. Upon retrieval, the RRPS is inverted, the plug is removed, and the contents of the sampler are transferred to laboratory sample containers via stopcocks. The samplers fit in a 2-inch-diameter well. These devices are still undergoing laboratory and field testing (ITRC, 2006; Parsons, 2005).

Dialysis Sampler

Dialysis samplers are capable of sampling for a wide range of organics and inorganics. Although two types of dialysis sampler were studied, the dialysis sampler described here was developed to sample wells. It consists of a deionized water-filled tube of high-grade, regenerated-cellulose dialysis membrane within an outer protective layer of LDPE mesh. The dialysis sampler may have a PVC pipe external to the dialysis membrane for sampling in low-ionic-strength waters or an internal, perforated PVC pipe to support the membrane in high-ionic-strength waters. The sampler may also have a stopcock at one end to facilitate sample transfer. Each dialysis sampler has an attached weight to overcome its buoyancy and is suspended in the well by means of a dedicated or disposable wire or polyethylene rope. The ITRC recommends that the sampler represent no more than 5 ft of a well's open interval (ITRC, 2006). The materials to construct dialysis sampler are readily available, but each sampler must be constructed for well-specific sampling purposes based a number of variables (e.g., the volume of sample required, the need to delineate possible vertical stratification, the desired level of sampler protection).

A mesh screen or other materials may be used to protect the bags during deployment, to avoid surface contamination during placement in and extraction from the well, and to add weight to the bags (Harter and Talozi, 2004).



Left: Parts of a dialysis sampler before collection of a sample (from IRTC, 2006).

Appendix B

Summary of Cost Estimation Scenarios and Worksheets with Details for Selected Cost Estimate Scenarios

VOCs Only

In the first scenario, the wells are assumed to be sampled twice each year for VOCs only. Thus, relatively low sample volumes are required for analysis. However, it is assumed that a minimum of two VOA vials (20 or 40 mL each) are required per well per sampling event.

In this scenario, the most economical way to use the Snap Sampler™ is to deploy one 125-mL Snap Sampler™ bottle and decant the sample into laboratory supplied VOA vials for shipment to the laboratory. The least economical way to use the Snap Sampler™ but the way to obtain high sample quality is to deploy two 40-mL vials each in two, stacked Snap Samplers™. This technique however, is still competitive versus other no-purge methods and traditional purging based methods. The Kabis sampler model that fits a 2-inch-diameter well accommodates only one 40-mL VOA vial; therefore, it must be deployed twice at each well to obtain two vials with no headspace. It is assumed that standard field parameters would be measured using downhole instruments immediately following sample collection.

The most economical methods over a 5- or 30-year sampling period, in increasing order of estimated cost, are as follows (Table 2):

- Bailer Grab
- Snap Sampler™
- HydraSleeve®
- Kemmerer Well Sampler

The next most economical method is utilizing PDBs. PDBs are more costly than the other methods over a 5- or-30 year period because two mobilizations are necessary for each sampling event for PDB use. The other methods listed above require only one mobilization per sampling event during long-term sampling.

VOCs and SVOCs or Metals

It is recognized that many sites will require sampling for more than VOCs. The second cost comparison scenario is similar to the first, except that the wells are assumed to be sampled twice each year for VOCs, plus *either* semivolatile organic compounds (SVOCs) *or* metals. Thus, it is assumed that two VOA vials (20 or 40 mL each) are required for the VOCs and a minimum of 250 mL is required for the SVOCs or metals. In this scenario, the most economical way to use the Snap Sampler™ is to deploy three 125-mL Snap Sampler™ bottles, decant one of them into laboratory supplied VOA vials for shipment to the laboratory, and submit the other two for analysis of SVOCs or metals. The least economical way to use the Snap Sampler™ but the way to obtain high sample quality is to deploy two 125-mL bottles for SVOCs or metals and two 40-mL vials each in four, stacked Snap Samplers™. This technique however, is

still competitive versus other no-purge methods and traditional purging based methods. The Kabis sampler model that fits a 2-inch-diameter well accommodates only one 40-mL VOA vial; thus, it must be deployed eight times at each well during each event to obtain sufficient sample volume. (Note that this procedure would not be recommended because repeated sampler deployment during an event could increase sample turbidity, which could impact sample quality, particularly for SVOCs or metals.) This scenario is considered only to allow the Kabis sampler to be included in the cost comparison. Similarly, PDBs are included for cost comparison purposes although it is recognized that PDBs are ineffective for metals and many SVOCs. As with the first scenario, it is assumed that standard field parameters would be measured using downhole instruments immediately after sample collection.

The most economical methods over a 5-year sampling period, in increasing order of estimated cost, are as follows (Table 2):

- Bailer Grab
- HydraSleeve®
- Kemmerer Well Sampler
- PDB

The next most economical method over 5 years was Snap Sampler™.

The most economical methods over a 30-year sampling period, in increasing order of cost, are as follows (Table 2):

- Bailer Grab
- HydraSleeve®
- Snap Sampler™
- Kemmerer Well Sampler

The next most economical method over 30 years was PDB.

A detailed breakdown of these cost estimates is provided on the following pages. Note that the calculation worksheets are also provided in electronic format, allowing the user the flexibility to calculate comparative costs on a site-specific basis. Equipment costs, labor estimates and required sample volumes must be verified prior to interpreting calculation results for a given project.

Scenario 1
VOCs Only

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Enter information in shaded cells; **bold cells** are one-time capital costs.
Verify equipment costs, labor estimates, and required sample volumes prior to interpreting calculation results for a given project.
Go to Worksheet No. 2 and fill in number of sampling events per year.
Go to Worksheets No. 3 and 4 for summary of long-term costs.

Site:	Generic Site
Number of Wells:	15
Average Sampling Depth:	15

COST SUMMARY - also see Cost Charts below

Method	1st Event Cost	Cost Per Well	Subsequent Cost	Cost Per Well
3-Volume Purge	$ 7,225	$ 482	$ 7,225	$ 482
Low Flow	$ 6,825	$ 455	$ 6,825	$ 455
Bailer Grab	$ 3,040	$ 203	$ 3,040	$ 203
SNAP™ - 1 x 125 mL	$ 10,505	$ 700	$ 3,204	$ 214
HydraSleeve®	$ 3,865	$ 258	$ 3,550	$ 237
SNAP™ - 2 x 40 mL	$ 12,957	$ 864	$ 3,530	$ 235
Kemmerer	$ 5,000	$ 333	$ 4,550	$ 303
PDB	$ 5,540	$ 369	$ 5,165	$ 344
Dialysis Sampler	$ 6,405	$ 427	$ 6,405	$ 427
Pneumo-Bailer ™	$ 8,100	$ 540	$ 6,200	$ 413
Discrete Interval	$ 6,625	$ 442	$ 5,825	$ 388
Kabis - 1 x 40 mL, deploy 2x	$ 6,035	$ 402	$ 5,085	$ 339
RPPS	$ 5,655	$ 377	$ 5,655	$ 377

Note: costs do not include laboratory analysis or reporting.

COMMON UNIT COSTS

labor cost		
sampling team size	2	persons per team
labor cost	$65	per person-hour
travel time	6	person-hours per mobilization
pump tubing (1/2" x 5/8")	$0.50	per foot
rope	$0.30	per foot
disposable equipment (decon, PPE, etc)	$25	per day per team
perdiem	$150	per day per person
airfare	$500	per mobilization
telephone	$25	per day

expenses	Daily	Weekly	Monthly
pump (for comparative purge-sampling costs)	$175	$400	$900
generator (for comparative purge-sampling costs)	$75	$225	$450
field water quality meter(s)	$135	$325	$925
water level meter	$25	$50	$150
vehicle rental + fuel	$120	$500	$1,000
health and safety monitoring equipment	$100	$300	$900

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

3-Volume Purge					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65.00	person-hour	51	$	3,315.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.33		
purge time		hours/team/well	0.50		
sample collection		hours/team/well	0.20		
decontamination		hours/team/well	0.25		
sampling time per well		hours/team/well	1.3		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	3		
expenses					
pump				$	400.00
generator*				$	225.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
pump tubing (1/2" x 5/8")	$0.50	foot	300	$	150.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$20	well	15	$	300.00
airfare				$	500.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	250.00
totals - initial event					
per event				$	7,225.00
per well				$	481.67
totals - subsequent events					
per event				$	7,225.00
per well				$	481.67

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Low Flow Sampling					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	46	$	2,990.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.33		
purge time		hours/team/well	0.50		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	1.1		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	3		
expenses					
pump				$	400.00
generator*				$	225.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
pump tubing (1/2" x 5/8")	$0.50	foot	300	$	150.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$15	well	15	$	225.00
airfare				$	500.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	250.00
totals - initial event					
per event				$	6,825.00
per well				$	455.00
totals - subsequent events					
per event				$	6,825.00
per well				$	455.00

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

PDBs (assuming 14-day equilibration)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	32	$	2,080.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.20		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.5		
mobilizations		number	2		
travel time		person-hours	12		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
PDBs (pre-filled with deionized water, mesh cover included)	$24	sampler	15	$	360.00
weights	**$25**	**weight**	**15**	**$**	**375.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	100.00
totals - initial event					
per event				$	5,540.00
per well				$	369.33
totals - subsequent events					
per event				$	5,165.00
per well				$	344.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

SNAP™Sampler (1-125 mL bottle)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost - initial event	$65	person-hour	54	$	3,510.00
labor cost - subsequent events	$65	person-hour	26	$	1,690.00
preparation - equipment and lab coordination		person-hours	6		
initial equipment setup		hours/team/well	0.75		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.20		
decontamination		hours/team/well	0.05		
sampling time per well - initial event		hours/team/well	1.2		
sampling and reload time per well - subseq. events		hours/team/well	0.5		
mobilizations - initial event		number	2		
mobilizations - subsequent events		number	1		
travel time - initial event		person-hours	12		
travel time - subsequent events		person-hours	6		
sampling time - intitial event (for rental and perdiem)		days per team	3		
sampling and reload time - subseq. Events		days per team	1		
expenses - initial round only					
SNAP™ - 1x 125 mL	**$149**	**each**	**15**	**$**	**2,235.00**
tool set	**$42**	**each**	**1**	**$**	**42.00**
trigger assembly	**$27**	**each**	**15**	**$**	**405.00**
trigger line	**$1.20**	**each**	**300**	**$**	**360.00**
well docking stations	**$25**	**each**	**15**	**$**	**375.00**
custom sample bottles	$14.50	1-125 mL	15	$	217.50
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	200.00
expenses - subsequent rounds					
custom sample bottles	$7.25	1-125 mL	15	$	108.75
field water quality meter(s)		(re-use bottles 1x each)		$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	100.00
totals - initial event					
per event				$	10,504.50
per well				$	700.30
totals - subsequent events					
per event				$	3,203.75
per well				$	213.58

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

SNAP™Sampler (2-40mL bottles)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost - initial event	$65	person-hour	54	$	3,510.00
labor cost - subsequent events	$65	person-hour	26	$	1,690.00
preparation - equipment and lab coordination		person-hours	6		
initial equipment setup		hours/team/well	0.75		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.20		
decontamination		hours/team/well	0.05		
sampling time per well - initial event		hours/team/well	1.2		
sampling and reload time per well - subseq. events		hours/team/well	0.5		
mobilizations - initial event		number	2		
mobilizations - subsequent events		number	1		
travel time - initial event		person-hours	12		
travel time - subsequent events		person-hours	6		
sampling time - intitial event (for rental and perdiem)		days per team	3		
sampling and reload time - subseq. Events		days per team	1		
expenses - initial round only					
SNAP™ - 2x 40 mL	**$149**	**each**	**30**	**$**	**4,470.00**
tool set	**$42**	**each**	**1**	**$**	**42.00**
trigger assembly	**$27**	**each**	**15**	**$**	**405.00**
trigger line	**$1.20**	**each**	**300**	**$**	**360.00**
well docking stations	**$25**	**each**	**15**	**$**	**375.00**
custom sample bottles	$14.50	1-40 mL	30	$	435.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	200.00
expenses - subsequent rounds					
custom sample bottles	$14.50	1-40 mL	30	$	435.00
field water quality meter(s)				$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	100.00
totals - initial event					
per event				$	12,957.00
per well				$	863.80
totals - subsequent events					
per event				$	3,530.00
per well				$	235.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

HydraSleeve® (assuming deployment and retrieval from a given well in one day or in consecutive days)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	27	$	1,755.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.5		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	1		
expenses					
HydraSleeve - 650 mL size	$20	sampler	15	$	300.00
weights/clips	**$21**	**weight**	**15**	**$**	**315.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	100.00
totals - initial event					
per event				$	3,865.00
per well				$	257.67
totals - subsequent events					
per event				$	3,550.00
per well				$	236.67

Bailer Grab					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	24	$	1,560.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.15		
sample collection		hours/team/well	0.20		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.4		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	1		
expenses					
bailers	$3	sampler	15	$	45.00
rope	$0.10	foot	300	$	30.00
field water quality meter(s)				$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	100.00
totals - initial event					
per event				$	3,040.00
per well				$	202.67
totals - subsequent events					
per event				$	3,040.00
per well				$	202.67

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Dialysis Sampler (assumes 14-day equilibration)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	47	$	3,055.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.50		
sample collection		hours/team/well	0.40		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	1.0		
mobilizations		number	2		
travel time		person-hours	12		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
dialysis samplers	$40	sampler	15	$	600.00
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	125.00
totals - initial event					
per event				$	6,405.00
per well				$	427.00
totals - subsequent events					
per event				$	6,405.00
per well				$	427.00

Pneumo-Bailer™					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	50	$	3,250.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.60		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.40		
sampling time per well		hours/team/well	1.3		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	3		
expenses					
Pneumo-Bailer(tm) (1 L) and air supply line	**$1,900**	**sampler**	**1**	**$**	**1,900.00**
nitrogen gas tank	$50	lump sum	1	$	50.00
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	150.00
totals - initial event					
per event				$	8,100.00
per well				$	540.00
totals - subsequent events					
per event				$	6,200.00
per well				$	413.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Discrete Interval Sampler					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	45	$	2,925.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.50		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.33		
sampling time per well		hours/team/well	1.1		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	3		
expenses					
discrete interval sampler kit (1.1 L)	**$800**	**sampler**	**1**	**$**	**800.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	150.00
totals - initial event					
per event				$	6,625.00
per well				$	441.67
totals - subsequent events					
per event				$	5,825.00
per well				$	388.33

Kabis Sampler					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	44	$	2,860.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.40		
sample collection		hours/team/well	0.50		
decontamination		hours/team/well	0.16		
sampling time per well		hours/team/well	1.1		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
Kabis - 1 x 40 mL	**$950**	**sampler**	**1**	**$**	**950.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	100.00
totals - initial event					
per event				$	6,035.00
per well				$	402.33
totals - subsequent events					
per event				$	5,085.00
per well				$	339.00

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
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Kemmerer Well Sampler					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	35	$	2,275.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.25		
sample collection		hours/team/well	0.33		
decontamination		hours/team/well	0.16		
sampling time per well		hours/team/well	0.7		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
Kemmerer (0.6 L) well sampler	**$450**	**sampler**	**1**	**$**	**450.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	150.00
totals - initial event					
per event				$	5,000.00
per well				$	333.33
totals - subsequent events					
per event				$	4,550.00
per well				$	303.33

RPPS (assuming 14-day equilibration)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	32	$	2,080.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.20		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.5		
mobilizations		number	2		
travel time		person-hours	12		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
RPPS (175 mL) and mesh liners	$55	sampler	15	$	825.00
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	125.00
totals - initial event					
per event				$	5,655.00
per well				$	377.00
totals - subsequent events					
per event				$	5,655.00
per well				$	377.00

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Sampling Events Per Year: 2

Method	1st Event Cost	Cost Per Well	Subsequent Cost	Cost Per Well
3-Volume Purge	$ 7,225	$ 482	$ 7,225	$ 482
Low Flow	$ 6,825	$ 455	$ 6,825	$ 455
Bailer Grab	$ 3,040	$ 203	$ 3,040	$ 203
SNAP™ - 1x 125 mL	$ 10,505	$ 700	$ 3,204	$ 214
HydraSleeve®	$ 3,865	$ 258	$ 3,550	$ 237
SNAP™ - 2 x 40 mL	$ 12,957	$ 864	$ 3,530	$ 235
Kemmerer	$ 5,000	$ 333	$ 4,550	$ 303
PDB	$ 5,540	$ 369	$ 5,165	$ 344
Dialysis Sampler	$ 6,405	$ 427	$ 6,405	$ 427
Pneumo-Bailer™	$ 8,100	$ 540	$ 6,200	$ 413
Discrete Interval	$ 6,625	$ 442	$ 5,825	$ 388
Kabis - 1 x 40 mL	$ 6,035	$ 402	$ 5,085	$ 339
RPPS	$ 5,655	$ 377	$ 5,655	$ 377

Note: costs do not include laboratory analysis or reporting.

3-Volume Purge
Low Flow
Bailer Grab
SNAP™ - 1x 125 mL
HydraSleeve®
SNAP™ - 2 x 40 mL
Kemmerer
PDB
Dialysis Sampler
Pneumo-Bailer™
Discrete Interval
Kabis - 1 x 40 mL
RPPS

PER YEAR COST

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450
$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650
$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080
$ 13,708	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408
$ 7,415	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100
$ 16,487	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060
$ 9,550	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100
$ 10,705	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330
$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810
$ 14,300	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400
$ 12,450	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650
$ 11,120	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170
$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310

CUMULATIVE COST

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
$ 14,450	$ 28,900	$ 43,350	$ 57,800	$ 72,250	$ 86,700
$ 13,650	$ 27,300	$ 40,950	$ 54,600	$ 68,250	$ 81,900
$ 6,080	$ 12,160	$ 18,240	$ 24,320	$ 30,400	$ 36,480
$ 13,708	$ 20,116	$ 26,523	$ 32,931	$ 39,338	$ 45,746
$ 7,415	$ 14,515	$ 21,615	$ 28,715	$ 35,815	$ 42,915
$ 16,487	$ 23,547	$ 30,607	$ 37,667	$ 44,727	$ 51,787
$ 9,550	$ 18,650	$ 27,750	$ 36,850	$ 45,950	$ 55,050
$ 10,705	$ 21,035	$ 31,365	$ 41,695	$ 52,025	$ 62,355
$ 12,810	$ 25,620	$ 38,430	$ 51,240	$ 64,050	$ 76,860
$ 14,300	$ 26,700	$ 39,100	$ 51,500	$ 63,900	$ 76,300
$ 12,450	$ 24,100	$ 35,750	$ 47,400	$ 59,050	$ 70,700
$ 11,120	$ 21,290	$ 31,460	$ 41,630	$ 51,800	$ 61,970
$ 11,310	$ 22,620	$ 33,930	$ 45,240	$ 56,550	$ 67,860

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

PER YEAR COST

Method	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
3-Volume Purge	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450
Low Flow	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650
Bailer Grab	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080
SNAP™ - 1x 125 mL	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408
HydraSleeve®	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100
SNAP™ - 2 x 40 mL	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060
Kemmerer	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100
PDB	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330
Dialysis Sampler	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810
Pneumo-Bailer™	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400
Discrete Interval	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650
Kabis - 1 x 40 mL	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170
RPPS	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310

Note: costs do not include laboratory analysis or reporting.

CUMULATIVE COST

	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
3-Volume Purge	$ 101,150	$ 115,600	$ 130,050	$ 144,500	$ 158,950	$ 173,400	$ 187,850	$ 202,300	$ 216,750	$ 231,200	$ 245,650	$ 260,100	$ 274,550	$ 289,000
Low Flow	$ 95,550	$ 109,200	$ 122,850	$ 136,500	$ 150,150	$ 163,800	$ 177,450	$ 191,100	$ 204,750	$ 218,400	$ 232,050	$ 245,700	$ 259,350	$ 273,000
Bailer Grab	$ 42,560	$ 48,640	$ 54,720	$ 60,800	$ 66,880	$ 72,960	$ 79,040	$ 85,120	$ 91,200	$ 97,280	$ 103,360	$ 109,440	$ 115,520	$ 121,600
SNAP™ - 1x 125 mL	$ 52,153	$ 58,561	$ 64,968	$ 71,376	$ 77,783	$ 84,191	$ 90,598	$ 97,006	$ 103,413	$ 109,821	$ 116,228	$ 122,636	$ 129,043	$ 135,451
HydraSleeve®	$ 50,015	$ 57,115	$ 64,215	$ 71,315	$ 78,415	$ 85,515	$ 92,615	$ 99,715	$ 106,815	$ 113,915	$ 121,015	$ 128,115	$ 135,215	$ 142,315
SNAP™ - 2 x 40 mL	$ 58,847	$ 65,907	$ 72,967	$ 80,027	$ 87,087	$ 94,147	$ 101,207	$ 108,267	$ 115,327	$ 122,387	$ 129,447	$ 136,507	$ 143,567	$ 150,627
Kemmerer	$ 64,150	$ 73,250	$ 82,350	$ 91,450	$ 100,550	$ 109,650	$ 118,750	$ 127,850	$ 136,950	$ 146,050	$ 155,150	$ 164,250	$ 173,350	$ 182,450
PDB	$ 72,685	$ 83,015	$ 93,345	$ 103,675	$ 114,005	$ 124,335	$ 134,665	$ 144,995	$ 155,325	$ 165,655	$ 175,985	$ 186,315	$ 196,645	$ 206,975
Dialysis Sampler	$ 89,670	$ 102,480	$ 115,290	$ 128,100	$ 140,910	$ 153,720	$ 166,530	$ 179,340	$ 192,150	$ 204,960	$ 217,770	$ 230,580	$ 243,390	$ 256,200
Pneumo-Bailer™	$ 88,700	$ 101,100	$ 113,500	$ 125,900	$ 138,300	$ 150,700	$ 163,100	$ 175,500	$ 187,900	$ 200,300	$ 212,700	$ 225,100	$ 237,500	$ 249,900
Discrete Interval	$ 82,350	$ 94,000	$ 105,650	$ 117,300	$ 128,950	$ 140,600	$ 152,250	$ 163,900	$ 175,550	$ 187,200	$ 198,850	$ 210,500	$ 222,150	$ 233,800
Kabis - 1 x 40 mL	$ 72,140	$ 82,310	$ 92,480	$ 102,650	$ 112,820	$ 122,990	$ 133,160	$ 143,330	$ 153,500	$ 163,670	$ 173,840	$ 184,010	$ 194,180	$ 204,350
RPPS	$ 79,170	$ 90,480	$ 101,790	$ 113,100	$ 124,410	$ 135,720	$ 147,030	$ 158,340	$ 169,650	$ 180,960	$ 192,270	$ 203,580	$ 214,890	$ 226,200

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS ONLY
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

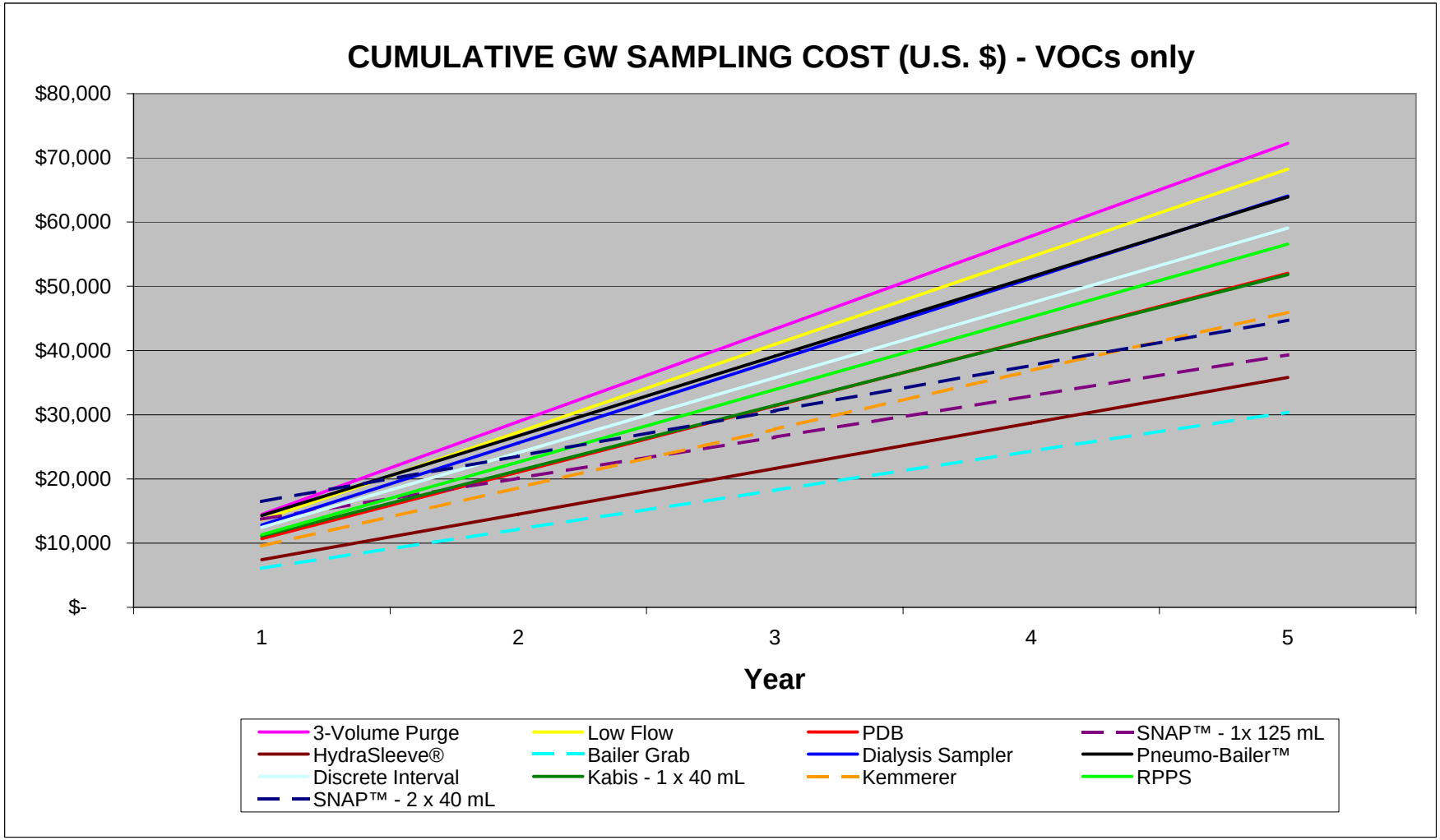
PER YEAR COST

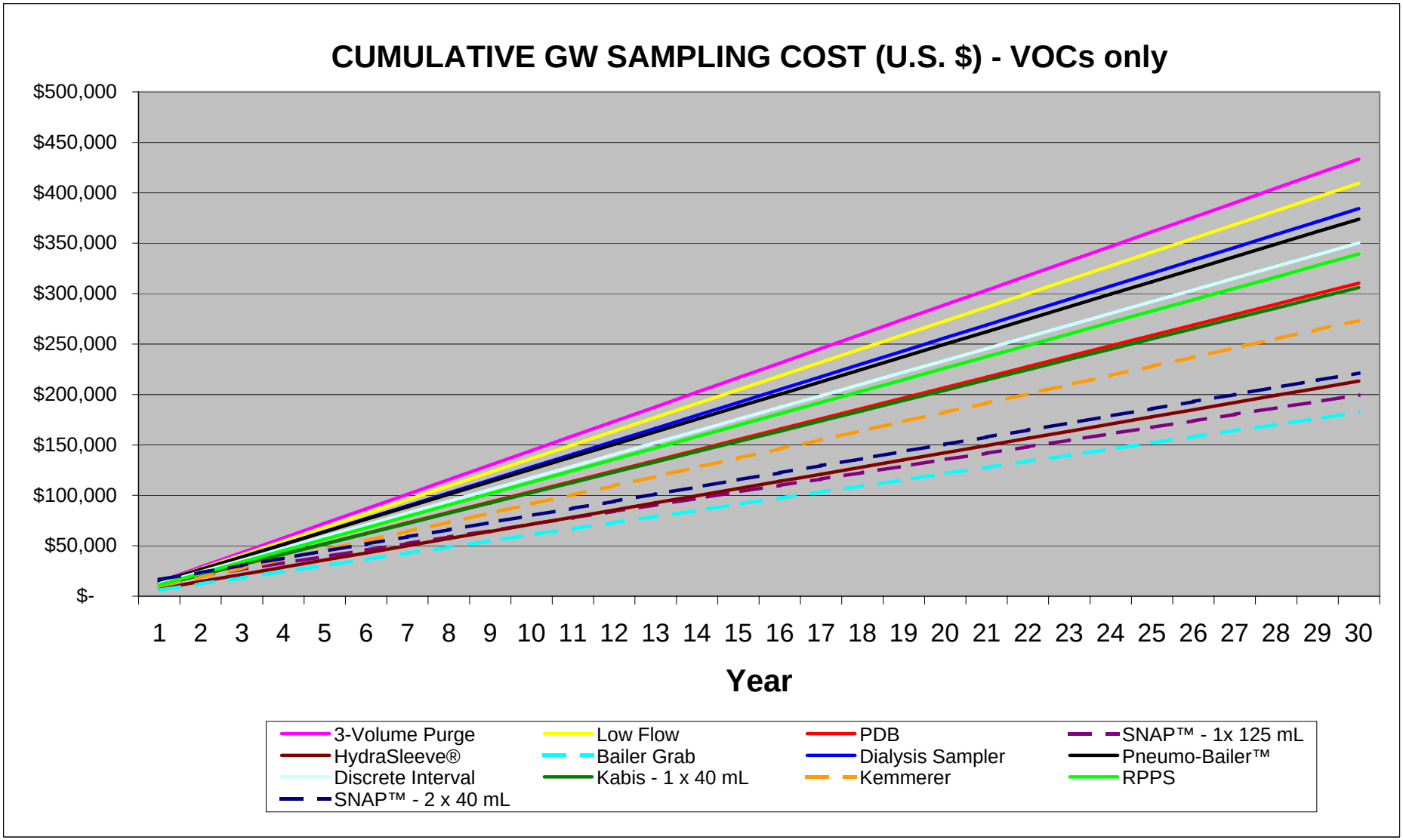
Method	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Total
3-Volume Purge	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 14,450	$ 433,500
Low Flow	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 13,650	$ 409,500
Bailer Grab	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 6,080	$ 182,400
SNAP™ - 1x 125 mL	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 6,408	$ 199,526
HydraSleeve®	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 7,100	$ 213,315
SNAP™ - 2 x 40 mL	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 7,060	$ 221,227
Kemmerer	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 9,100	$ 273,450
PDB	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 10,330	$ 310,275
Dialysis Sampler	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 12,810	$ 384,300
Pneumo-Bailer™	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 12,400	$ 373,900
Discrete Interval	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 11,650	$ 350,300
Kabis - 1 x 40 mL	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 10,170	$ 306,050
RPPS	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 11,310	$ 339,300

Note: costs do not include laboratory analysis or reporting.

CUMULATIVE COST

	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30
3-Volume Purge	$ 303,450	$ 317,900	$ 332,350	$ 346,800	$ 361,250	$ 375,700	$ 390,150	$ 404,600	$ 419,050	$ 433,500
Low Flow	$ 286,650	$ 300,300	$ 313,950	$ 327,600	$ 341,250	$ 354,900	$ 368,550	$ 382,200	$ 395,850	$ 409,500
Bailer Grab	$ 127,680	$ 133,760	$ 139,840	$ 145,920	$ 152,000	$ 158,080	$ 164,160	$ 170,240	$ 176,320	$ 182,400
SNAP™ - 1x 125 mL	$ 141,858	$ 148,266	$ 154,673	$ 161,081	$ 167,488	$ 173,896	$ 180,303	$ 186,711	$ 193,118	$ 199,526
HydraSleeve®	$ 149,415	$ 156,515	$ 163,615	$ 170,715	$ 177,815	$ 184,915	$ 192,015	$ 199,115	$ 206,215	$ 213,315
SNAP™ - 2 x 40 mL	$ 157,687	$ 164,747	$ 171,807	$ 178,867	$ 185,927	$ 192,987	$ 200,047	$ 207,107	$ 214,167	$ 221,227
Kemmerer	$ 191,550	$ 200,650	$ 209,750	$ 218,850	$ 227,950	$ 237,050	$ 246,150	$ 255,250	$ 264,350	$ 273,450
PDB	$ 217,305	$ 227,635	$ 237,965	$ 248,295	$ 258,625	$ 268,955	$ 279,285	$ 289,615	$ 299,945	$ 310,275
Dialysis Sampler	$ 269,010	$ 281,820	$ 294,630	$ 307,440	$ 320,250	$ 333,060	$ 345,870	$ 358,680	$ 371,490	$ 384,300
Pneumo-Bailer™	$ 262,300	$ 274,700	$ 287,100	$ 299,500	$ 311,900	$ 324,300	$ 336,700	$ 349,100	$ 361,500	$ 373,900
Discrete Interval	$ 245,450	$ 257,100	$ 268,750	$ 280,400	$ 292,050	$ 303,700	$ 315,350	$ 327,000	$ 338,650	$ 350,300
Kabis - 1 x 40 mL	$ 214,520	$ 224,690	$ 234,860	$ 245,030	$ 255,200	$ 265,370	$ 275,540	$ 285,710	$ 295,880	$ 306,050
RPPS	$ 237,510	$ 248,820	$ 260,130	$ 271,440	$ 282,750	$ 294,060	$ 305,370	$ 316,680	$ 327,990	$ 339,300


CUMULATIVE GW SAMPLING COST (U.S. $) - VOCs only
$80,000
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$-
1
2
3
4
5
Year
3-Volume Purge
Low Flow
PDB
SNAP™ - 1x 125 mL
HydraSleeve®
Bailer Grab
Dialysis Sampler
Pneumo-Bailer™
Discrete Interval
Kabis - 1 x 40 mL
Kemmerer
RPPS
SNAP™ - 2 x 40 mL


CUMULATIVE GW SAMPLING COST (U.S. $) - VOCs only
$500,000
$450,000
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$-
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Year
3-Volume Purge
Low Flow
PDB
SNAP™ - 1x 125 mL
HydraSleeve®
Bailer Grab
Dialysis Sampler
Pneumo-Bailer™
Discrete Interval
Kabis - 1 x 40 mL
Kemmerer
RPPS
SNAP™ - 2 x 40 mL

Scenario 2
VOCs and SVOCs or Metals

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Enter information in shaded cells; **bold cells** are one-time capital costs.
Verify equipment costs, labor estimates, and required sample volumes prior to interpreting calculation results for a given project.
Go to Worksheet No. 2 and fill in number of sampling events per year.
Go to Worksheets No. 3 and 4 for summary of long-term costs.

Site:	Generic Site
Number of Wells:	15
Average Sampling Depth:	15

COST SUMMARY - also see Cost Charts below

Method	1st Event Cost	Cost Per Well	Subsequent Cost	Cost Per Well
3-Volume Purge	$ 10,380	$ 692	$ 10,380	$ 692
Low Flow	$ 7,055	$ 470	$ 7,055	$ 470
Bailer Grab	$ 3,270	$ 218	$ 3,270	$ 218
SNAP™ - 3 x 125 mL	$ 15,540	$ 1,036	$ 3,586	$ 239
HydraSleeve®	$ 4,825	$ 322	$ 4,510	$ 301
SNAP™ - 2 x 125 mL, 2 x 40 mL	$ 17,992	$ 1,199	$ 4,130	$ 275
Kemmerer	$ 5,230	$ 349	$ 4,780	$ 319
PDB	$ 5,705	$ 380	$ 5,330	$ 355
Dialysis Sampler	$ 6,570	$ 438	$ 6,570	$ 438
Pneumo-Bailer ™	$ 8,265	$ 551	$ 6,365	$ 424
Discrete Interval	$ 6,790	$ 453	$ 5,990	$ 399
Kabis - 1 x 40 mL, deploy 8x	$ 9,180	$ 612	$ 8,230	$ 549
RPPS	$ 5,820	$ 388	$ 5,820	$ 388

Note: costs do not include laboratory analysis or reporting.

COMMON UNIT COSTS

labor cost		
sampling team size	2	persons per team
labor cost	$65	per person-hour
travel time	6	person-hours per mobilization
pump tubing (1/2" x 5/8")	$0.50	per foot
rope	$0.30	per foot
disposable equipment (decon, PPE, etc)	$25	per day per team
perdiem	$150	per day per person
airfare	$500	per mobilization
telephone	$25	per day

expenses	Daily	Weekly	Monthly
pump (for comparative purge-sampling costs)	$175	$400	$900
generator (for comparative purge-sampling costs)	$75	$225	$450
field water quality meter(s)	$135	$325	$925
water level meter	$25	$50	$150
vehicle rental + fuel	$120	$500	$1,000
health and safety monitoring equipment	$100	$300	$900

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

3-Volume Purge					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65.00	person-hour	52	$	3,380.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.33		
purge time		hours/team/well	0.50		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.25		
sampling time per well		hours/team/well	1.3		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	6		
expenses					
pump				$	800.00
generator*				$	450.00
field water quality meter(s)				$	650.00
water level meter				$	100.00
vehicle rental + fuel				$	1,000.00
pump tubing (1/2" x 5/8")	$0.50	foot	300	$	150.00
health and safety monitoring equipment				$	600.00
disposable equipment (decon, PPE, etc)	$25	day	6	$	150.00
waste disposal	$20	well	15	$	300.00
airfare				$	500.00
perdiem	$150	person - day	12	$	1,800.00
telephone	$25	day	6	$	150.00
equipment and sample shipping				$	350.00
totals - initial event					
per event				$	10,380.00
per well				$	692.00
totals - subsequent events					
per event				$	10,380.00
per well				$	692.00

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Low Flow Sampling				
Category	**Unit Cost**	**Unit**	**# Units**	**Total Cost**
labor				
sampling team size		people	2	
labor cost	$65	person-hour	48	$ 3,120.00
preparation - equipment and lab coordination		person-hours	6	
set-up and tear-down		hours/team/well	0.33	
purge time		hours/team/well	0.50	
sample collection		hours/team/well	0.30	
decontamination		hours/team/well	0.05	
sampling time per well		hours/team/well	1.2	
mobilizations		number	1	
travel time		person-hours	6	
sampling time per event (for rental and perdiem)		days per team	3	
expenses				
pump				$ 400.00
generator*				$ 225.00
field water quality meter(s)				$ 325.00
water level meter				$ 50.00
vehicle rental + fuel				$ 360.00
pump tubing (1/2" x 5/8")	$0.50	foot	300	$ 150.00
health and safety monitoring equipment				$ 300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$ 75.00
waste disposal	$15	well	15	$ 225.00
airfare				$ 500.00
perdiem	$150	person - day	6	$ 900.00
telephone	$25	day	3	$ 75.00
equipment and sample shipping				$ 350.00
totals - initial event				
per event				$ 7,055.00
per well				$ 470.33
totals - subsequent events				
per event				$ 7,055.00
per well				$ 470.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

PDBs (assuming 14-day equilibration)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	33	$	2,145.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.5		
mobilizations		number	2		
travel time		person-hours	12		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
PDBs (pre-filled with deionized water, mesh cover included)	$24	sampler	15	$	360.00
weights	**$25**	**weight**	**15**	**$**	**375.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	200.00
totals - initial event					
per event				$	5,705.00
per well				$	380.33
totals - subsequent events					
per event				$	5,330.00
per well				$	355.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

SNAP™ - 3 x 125 mL					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost - initial event	$65	person-hour	56	$	3,640.00
labor cost - subsequent events	$65	person-hour	27	$	1,755.00
preparation - equipment and lab coordination		person-hours	6		
initial equipment setup		hours/team/well	0.75		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well - initial event		hours/team/well	1.3		
sampling and reload time per well - subseq. events		hours/team/well	0.5		
mobilizations - initial event		number	2		
mobilizations - subsequent events		number	1		
travel time - initial event		person-hours	12		
travel time - subsequent events		person-hours	6		
sampling time - intitial event (for rental and perdiem)		days per team	3		
sampling and reload time - subseq. Events		days per team	1		
expenses - initial round only					
SNAP™ - 3 x 125 mL	**$149**	**each**	**45**	**$**	**6,705.00**
tool set	**$42**	**each**	**1**	**$**	**42.00**
trigger assembly	**$27**	**each**	**15**	**$**	**405.00**
trigger line	**$1.20**	**each**	**300**	**$**	**360.00**
well docking stations	**$25**	**each**	**15**	**$**	**375.00**
custom sample bottles	$14.50	125 mL bottle x 3/well	45	$	652.50
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	200.00
expenses - subsequent rounds					
custom sample bottles	$7.25	125 mL bottle x 3/well	45	$	326.25
field water quality meter(s)		(re-use bottles 1x each)		$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	200.00
totals - initial event					
per event				$	15,539.50
per well				$	1,035.97
totals - subsequent events					
per event				$	3,586.25
per well				$	239.08

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

SNAP™ - 2 x 125 mL, 2 x 40 mL					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost - initial event	$65	person-hour	56	$	3,640.00
labor cost - subsequent events	$65	person-hour	27	$	1,755.00
preparation - equipment and lab coordination		person-hours	6		
initial equipment setup		hours/team/well	0.75		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well - initial event		hours/team/well	1.3		
sampling and reload time per well - subseq. events		hours/team/well	0.5		
mobilizations - initial event		number	2		
mobilizations - subsequent events		number	1		
travel time - initial event		person-hours	12		
travel time - subsequent events		person-hours	6		
sampling time - intitial event (for rental and perdiem)		days per team	3		
sampling and reload time - subseq. Events		days per team	1		
expenses - initial round only					
SNAP™ - 2 x 125 mL, 2 x 40 mL	**$149**	**each**	**60**	**$**	**8,940.00**
tool set	**$42**	**each**	**1**	**$**	**42.00**
trigger assembly	**$27**	**each**	**15**	**$**	**405.00**
trigger line	**$1.20**	**each**	**300**	**$**	**360.00**
well docking stations	**$25**	**each**	**15**	**$**	**375.00**
custom sample bottles	$14.50	40 mL or 125mL	60	$	870.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	200.00
expenses - subsequent rounds					
custom sample bottles	$14.50	40 mL or 125mL	60	$	870.00
field water quality meter(s)				$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	200.00
totals - initial event					
per event				$	17,992.00
per well				$	1,199.47
totals - subsequent events					
per event				$	4,130.00
per well				$	275.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

HydraSleeve® (assuming deployment and retrieval from a given well in one day or in consecutive days)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	29	$	1,885.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.30		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.6		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
HydraSleeve - 650 mL size	$20	sampler	15	$	300.00
weights/clips	**$21**	**weight**	**15**	**$**	**315.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	200.00
totals - initial event					
per event				$	4,825.00
per well				$	321.67
totals - subsequent events					
per event				$	4,510.00
per well				$	300.67

Bailer Grab					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	26	$	1,690.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.15		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.5		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	1		
expenses					
bailers	$3	sampler	15	$	45.00
rope	$0.10	foot	300	$	30.00
field water quality meter(s)				$	135.00
water level meter				$	25.00
vehicle rental + fuel				$	120.00
health and safety monitoring equipment				$	100.00
disposable equipment (decon, PPE, etc)	$25	day	1	$	25.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	2	$	300.00
telephone	$25	day	1	$	25.00
equipment and sample shipping				$	200.00
totals - initial event					
per event				$	3,270.00
per well				$	218.00
totals - subsequent events					
per event				$	3,270.00
per well				$	218.00

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Dialysis Sampler (assumes 14-day equilibration)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	48	$	3,120.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.50		
sample collection		hours/team/well	0.45		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	1.0		
mobilizations		number	2		
travel time		person-hours	12		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
dialysis samplers	$40	sampler	15	$	600.00
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	225.00
totals - initial event					
per event				$	6,570.00
per well				$	438.00
totals - subsequent events					
per event				$	6,570.00
per well				$	438.00

Pneumo-Bailer™					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	51	$	3,315.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.60		
sample collection		hours/team/well	0.30		
decontamination		hours/team/well	0.40		
sampling time per well		hours/team/well	1.3		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	3		
expenses					
Pneumo-Bailer(tm) (1 L) and air supply line	**$1,900**	**sampler**	**1**	**$**	**1,900.00**
nitrogen gas tank	$50	lump sum	1	$	50.00
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	250.00
totals - initial event					
per event				$	8,265.00
per well				$	551.00
totals - subsequent events					
per event				$	6,365.00
per well				$	424.33

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Discrete Interval Sampler					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	46	$	2,990.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.50		
sample collection		hours/team/well	0.30		
decontamination		hours/team/well	0.33		
sampling time per well		hours/team/well	1.1		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	3		
expenses					
discrete interval sampler kit (1.1 L)	**$800**	**sampler**	**1**	**$**	**800.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	360.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	3	$	75.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	6	$	900.00
telephone	$25	day	3	$	75.00
equipment and sample shipping				$	250.00
totals - initial event					
per event				$	6,790.00
per well				$	452.67
totals - subsequent events					
per event				$	5,990.00
per well				$	399.33

Kabis Sampler					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	74	$	4,810.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.40		
sample collection		hours/team/well	1.50		
decontamination		hours/team/well	0.16		
sampling time per well		hours/team/well	2.1		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	4		
expenses					
Kabis - 1 x 40 mL, deploy 8x	**$950**	**sampler**	**1**	**$**	**950.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	325.00
water level meter				$	50.00
vehicle rental + fuel				$	480.00
health and safety monitoring equipment				$	300.00
disposable equipment (decon, PPE, etc)	$25	day	4	$	100.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	8	$	1,200.00
telephone	$25	day	4	$	100.00
equipment and sample shipping				$	200.00
totals - initial event					
per event				$	9,180.00
per well				$	612.00
totals - subsequent events					
per event				$	8,230.00
per well				$	548.67

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Kemmerer Well Sampler					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	37	$	2,405.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.25		
sample collection		hours/team/well	0.40		
decontamination		hours/team/well	0.16		
sampling time per well		hours/team/well	0.8		
mobilizations		number	1		
travel time		person-hours	6		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
Kemmerer (0.6 L) well sampler	**$450**	**sampler**	**1**	**$**	**450.00**
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	500.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	250.00
totals - initial event					
per event				$	5,230.00
per well				$	348.67
totals - subsequent events					
per event				$	4,780.00
per well				$	318.67

RPPS (assuming 14-day equilibration)					
Category	**Unit Cost**	**Unit**	**# Units**		**Total Cost**
labor					
sampling team size		people	2		
labor cost	$65	person-hour	33	$	2,145.00
preparation - equipment and lab coordination		person-hours	6		
set-up and tear-down		hours/team/well	0.20		
sample collection		hours/team/well	0.25		
decontamination		hours/team/well	0.05		
sampling time per well		hours/team/well	0.5		
mobilizations		number	2		
travel time		person-hours	12		
sampling time per event (for rental and perdiem)		days per team	2		
expenses					
RPPS (175 mL) and mesh liners	$55	sampler	15	$	825.00
rope	$0.30	foot	300	$	90.00
field water quality meter(s)				$	270.00
water level meter				$	50.00
vehicle rental + fuel				$	240.00
health and safety monitoring equipment				$	200.00
disposable equipment (decon, PPE, etc)	$25	day	2	$	50.00
waste disposal	$5	well	15	$	75.00
airfare				$	1,000.00
perdiem	$150	person - day	4	$	600.00
telephone	$25	day	2	$	50.00
equipment and sample shipping				$	225.00
totals - initial event					
per event				$	5,820.00
per well				$	388.00
totals - subsequent events					
per event				$	5,820.00
per well				$	388.00

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

Sampling Events Per Year: 2

PER YEAR COST

Method	1st Event Cost	Cost Per Well	Subsequent Cost	Cost Per Well	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
3-Volume Purge	$ 10,380	$ 692	$ 10,380	$ 692	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760
Low Flow	$ 7,055	$ 470	$ 7,055	$ 470	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110
Bailer Grab	$ 3,270	$ 218	$ 3,270	$ 218	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540
SNAP™ - 3 x 125 mL	$ 15,540	$ 1,036	$ 3,586	$ 239	$ 19,126	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173
HydraSleeve®	$ 4,825	$ 322	$ 4,510	$ 301	$ 9,335	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020
SNAP™ - 2 x 125 mL, 2 x 40 mL	$ 17,992	$ 1,199	$ 4,130	$ 275	$ 22,122	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260
Kemmerer	$ 5,230	$ 349	$ 4,780	$ 319	$ 10,010	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560
PDB	$ 5,705	$ 380	$ 5,330	$ 355	$ 11,035	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660
Dialysis Sampler	$ 6,570	$ 438	$ 6,570	$ 438	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140
Pneumo-Bailer™	$ 8,265	$ 551	$ 6,365	$ 424	$ 14,630	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730
Discrete Interval	$ 6,790	$ 453	$ 5,990	$ 399	$ 12,780	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980
Kabis - 1 x 40 mL, deploy 8x	$ 9,180	$ 612	$ 8,230	$ 549	$ 17,410	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460
RPPS	$ 5,820	$ 388	$ 5,820	$ 388	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640

Note: costs do not include laboratory analysis or reporting.

3-Volume Purge
Low Flow
Bailer Grab
SNAP™ - 3 x 125 mL
HydraSleeve®
SNAP™ - 2 x 125 mL, 2 x 40 mL
Kemmerer
PDB
Dialysis Sampler
Pneumo-Bailer™
Discrete Interval
Kabis - 1 x 40 mL, deploy 8x
RPPS

CUMULATIVE COST

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
$ 20,760	$ 41,520	$ 62,280	$ 83,040	$ 103,800	$ 124,560
$ 14,110	$ 28,220	$ 42,330	$ 56,440	$ 70,550	$ 84,660
$ 6,540	$ 13,080	$ 19,620	$ 26,160	$ 32,700	$ 39,240
$ 19,126	$ 26,298	$ 33,471	$ 40,643	$ 47,816	$ 54,988
$ 9,335	$ 18,355	$ 27,375	$ 36,395	$ 45,415	$ 54,435
$ 22,122	$ 30,382	$ 38,642	$ 46,902	$ 55,162	$ 63,422
$ 10,010	$ 19,570	$ 29,130	$ 38,690	$ 48,250	$ 57,810
$ 11,035	$ 21,695	$ 32,355	$ 43,015	$ 53,675	$ 64,335
$ 13,140	$ 26,280	$ 39,420	$ 52,560	$ 65,700	$ 78,840
$ 14,630	$ 27,360	$ 40,090	$ 52,820	$ 65,550	$ 78,280
$ 12,780	$ 24,760	$ 36,740	$ 48,720	$ 60,700	$ 72,680
$ 17,410	$ 33,870	$ 50,330	$ 66,790	$ 83,250	$ 99,710
$ 11,640	$ 23,280	$ 34,920	$ 46,560	$ 58,200	$ 69,840

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

PER YEAR COST

Method	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
3-Volume Purge	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760
Low Flow	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110
Bailer Grab	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540
SNAP™ - 3 x 125 mL	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173
HydraSleeve®	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020
SNAP™ - 2 x 125 mL, 2 x 40 mL	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260
Kemmerer	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560
PDB	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660
Dialysis Sampler	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140
Pneumo-Bailer™	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730
Discrete Interval	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980
Kabis - 1 x 40 mL, deploy 8x	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460
RPPS	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640

Note: costs do not include laboratory analysis or reporting.

CUMULATIVE COST

	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
3-Volume Purge	$ 145,320	$ 166,080	$ 186,840	$ 207,600	$ 228,360	$ 249,120	$ 269,880	$ 290,640	$ 311,400	$ 332,160	$ 352,920	$ 373,680	$ 394,440	$ 415,200
Low Flow	$ 98,770	$ 112,880	$ 126,990	$ 141,100	$ 155,210	$ 169,320	$ 183,430	$ 197,540	$ 211,650	$ 225,760	$ 239,870	$ 253,980	$ 268,090	$ 282,200
Bailer Grab	$ 45,780	$ 52,320	$ 58,860	$ 65,400	$ 71,940	$ 78,480	$ 85,020	$ 91,560	$ 98,100	$ 104,640	$ 111,180	$ 117,720	$ 124,260	$ 130,800
SNAP™ - 3 x 125 mL	$ 62,161	$ 69,333	$ 76,506	$ 83,678	$ 90,851	$ 98,023	$ 105,196	$ 112,368	$ 119,541	$ 126,713	$ 133,886	$ 141,058	$ 148,231	$ 155,403
HydraSleeve®	$ 63,455	$ 72,475	$ 81,495	$ 90,515	$ 99,535	$ 108,555	$ 117,575	$ 126,595	$ 135,615	$ 144,635	$ 153,655	$ 162,675	$ 171,695	$ 180,715
SNAP™ - 2 x 125 mL, 2 x 40 mL	$ 71,682	$ 79,942	$ 88,202	$ 96,462	$ 104,722	$ 112,982	$ 121,242	$ 129,502	$ 137,762	$ 146,022	$ 154,282	$ 162,542	$ 170,802	$ 179,062
Kemmerer	$ 67,370	$ 76,930	$ 86,490	$ 96,050	$ 105,610	$ 115,170	$ 124,730	$ 134,290	$ 143,850	$ 153,410	$ 162,970	$ 172,530	$ 182,090	$ 191,650
PDB	$ 74,995	$ 85,655	$ 96,315	$ 106,975	$ 117,635	$ 128,295	$ 138,955	$ 149,615	$ 160,275	$ 170,935	$ 181,595	$ 192,255	$ 202,915	$ 213,575
Dialysis Sampler	$ 91,980	$ 105,120	$ 118,260	$ 131,400	$ 144,540	$ 157,680	$ 170,820	$ 183,960	$ 197,100	$ 210,240	$ 223,380	$ 236,520	$ 249,660	$ 262,800
Pneumo-Bailer™	$ 91,010	$ 103,740	$ 116,470	$ 129,200	$ 141,930	$ 154,660	$ 167,390	$ 180,120	$ 192,850	$ 205,580	$ 218,310	$ 231,040	$ 243,770	$ 256,500
Discrete Interval	$ 84,660	$ 96,640	$ 108,620	$ 120,600	$ 132,580	$ 144,560	$ 156,540	$ 168,520	$ 180,500	$ 192,480	$ 204,460	$ 216,440	$ 228,420	$ 240,400
Kabis - 1 x 40 mL, deploy 8x	$ 116,170	$ 132,630	$ 149,090	$ 165,550	$ 182,010	$ 198,470	$ 214,930	$ 231,390	$ 247,850	$ 264,310	$ 280,770	$ 297,230	$ 313,690	$ 330,150
RPPS	$ 81,480	$ 93,120	$ 104,760	$ 116,400	$ 128,040	$ 139,680	$ 151,320	$ 162,960	$ 174,600	$ 186,240	$ 197,880	$ 209,520	$ 221,160	$ 232,800

NO-PURGE SAMPLING COST ESTIMATION WORKSHEET - VOCS AND SVOCS OR METALS
NO-PURGE GROUNDWATER SAMPLING BEST PRACTICE MANUAL
EXXONMOBIL GLOBAL REMEDIATION

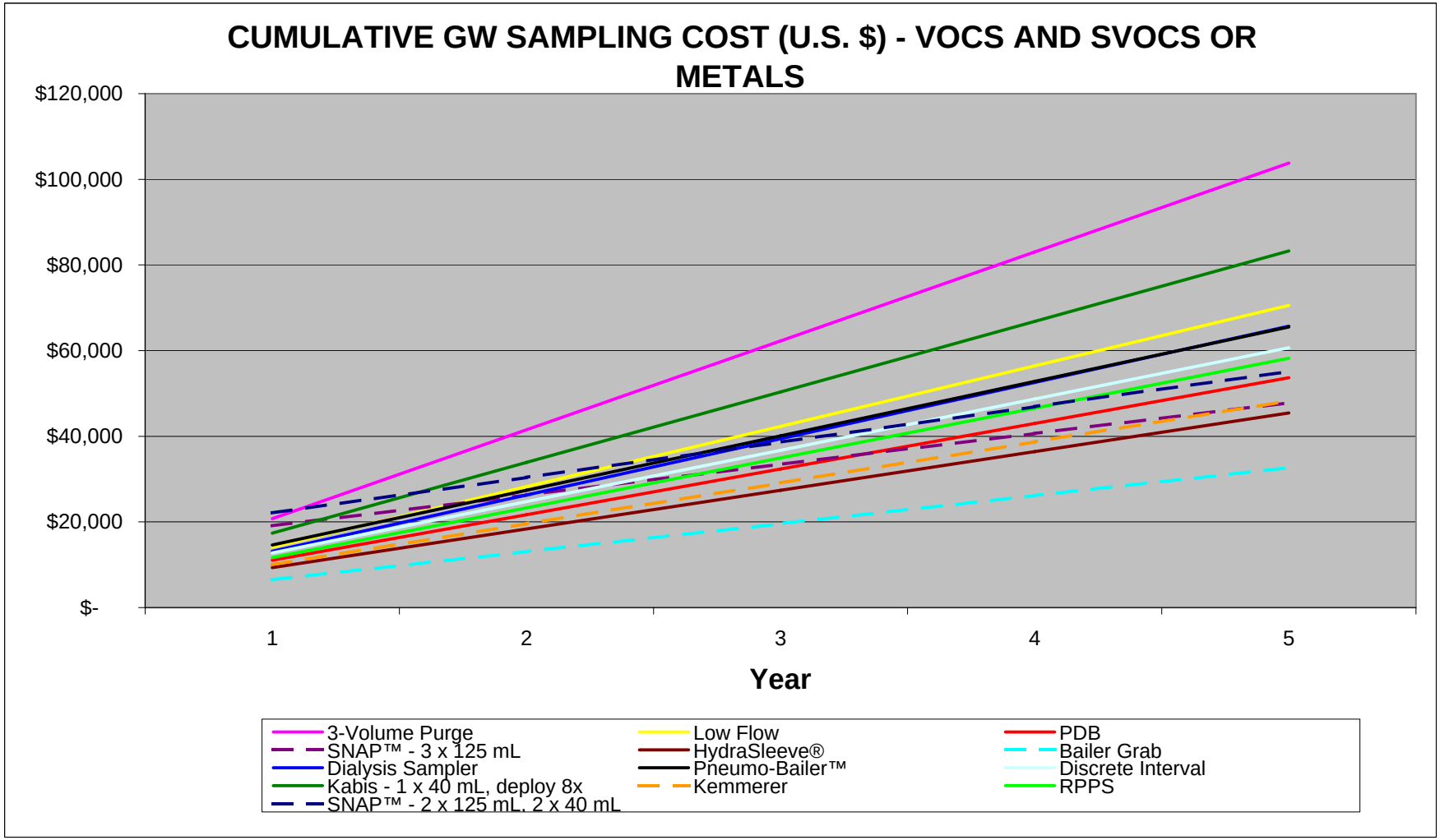
PER YEAR COST

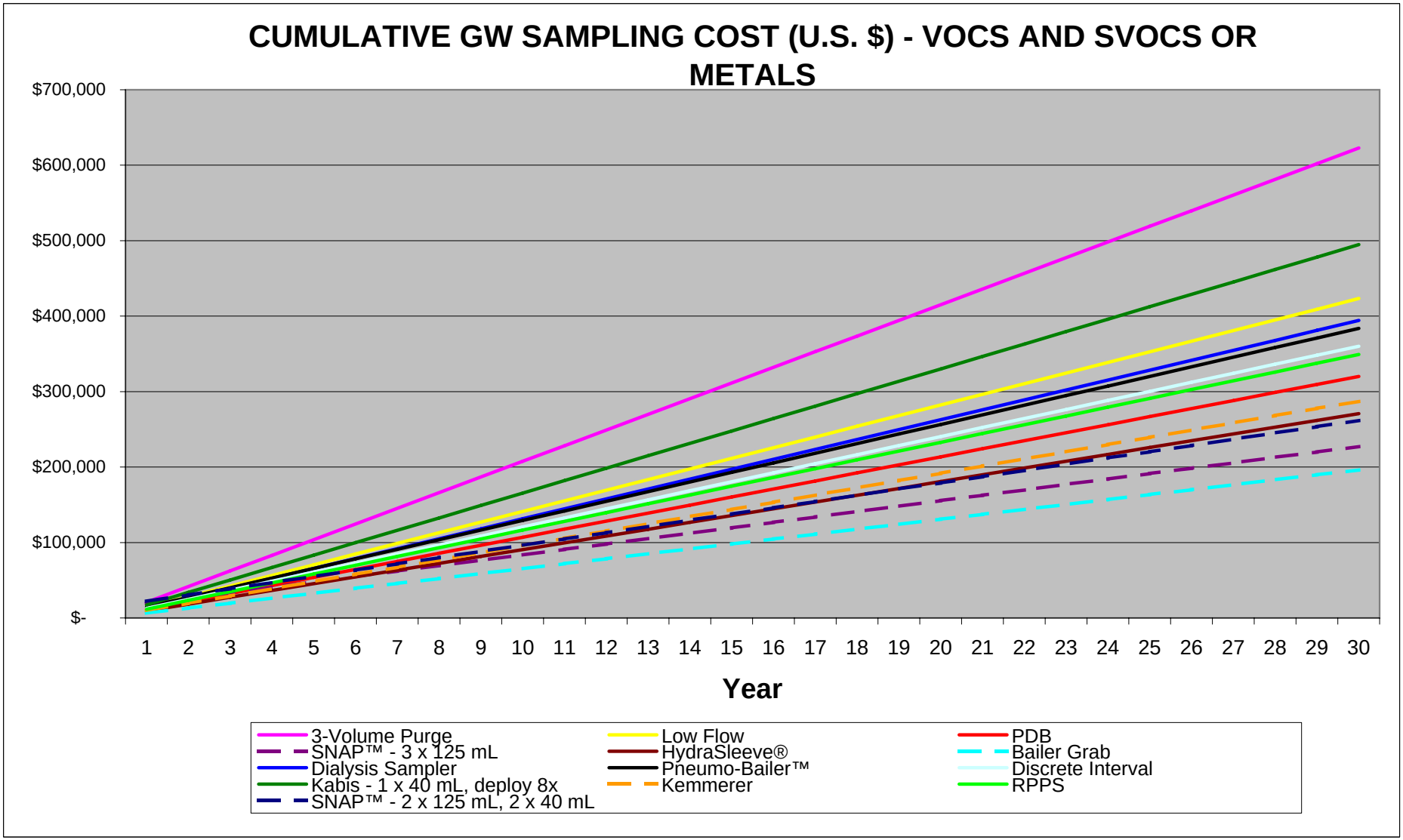
Method	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Total
3-Volume Purge	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 20,760	$ 622,800
Low Flow	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 14,110	$ 423,300
Bailer Grab	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 6,540	$ 196,200
SNAP™ - 3 x 125 mL	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 7,173	$ 227,128
HydraSleeve®	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 9,020	$ 270,915
SNAP™ - 2 x 125 mL, 2 x 40 mL	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 8,260	$ 261,662
Kemmerer	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 9,560	$ 287,250
PDB	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 10,660	$ 320,175
Dialysis Sampler	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 13,140	$ 394,200
Pneumo-Bailer™	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 12,730	$ 383,800
Discrete Interval	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 11,980	$ 360,200
Kabis - 1 x 40 mL, deploy 8x	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 16,460	$ 494,750
RPPS	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 11,640	$ 349,200

Note: costs do not include laboratory analysis or reporting.

CUMULATIVE COST

	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30
3-Volume Purge	$ 435,960	$ 456,720	$ 477,480	$ 498,240	$ 519,000	$ 539,760	$ 560,520	$ 581,280	$ 602,040	$ 622,800
Low Flow	$ 296,310	$ 310,420	$ 324,530	$ 338,640	$ 352,750	$ 366,860	$ 380,970	$ 395,080	$ 409,190	$ 423,300
Bailer Grab	$ 137,340	$ 143,880	$ 150,420	$ 156,960	$ 163,500	$ 170,040	$ 176,580	$ 183,120	$ 189,660	$ 196,200
SNAP™ - 3 x 125 mL	$ 162,576	$ 169,748	$ 176,921	$ 184,093	$ 191,266	$ 198,438	$ 205,611	$ 212,783	$ 219,956	$ 227,128
HydraSleeve®	$ 189,735	$ 198,755	$ 207,775	$ 216,795	$ 225,815	$ 234,835	$ 243,855	$ 252,875	$ 261,895	$ 270,915
SNAP™ - 2 x 125 mL, 2 x 40 mL	$ 187,322	$ 195,582	$ 203,842	$ 212,102	$ 220,362	$ 228,622	$ 236,882	$ 245,142	$ 253,402	$ 261,662
Kemmerer	$ 201,210	$ 210,770	$ 220,330	$ 229,890	$ 239,450	$ 249,010	$ 258,570	$ 268,130	$ 277,690	$ 287,250
PDB	$ 224,235	$ 234,895	$ 245,555	$ 256,215	$ 266,875	$ 277,535	$ 288,195	$ 298,855	$ 309,515	$ 320,175
Dialysis Sampler	$ 275,940	$ 289,080	$ 302,220	$ 315,360	$ 328,500	$ 341,640	$ 354,780	$ 367,920	$ 381,060	$ 394,200
Pneumo-Bailer™	$ 269,230	$ 281,960	$ 294,690	$ 307,420	$ 320,150	$ 332,880	$ 345,610	$ 358,340	$ 371,070	$ 383,800
Discrete Interval	$ 252,380	$ 264,360	$ 276,340	$ 288,320	$ 300,300	$ 312,280	$ 324,260	$ 336,240	$ 348,220	$ 360,200
Kabis - 1 x 40 mL, deploy 8x	$ 346,610	$ 363,070	$ 379,530	$ 395,990	$ 412,450	$ 428,910	$ 445,370	$ 461,830	$ 478,290	$ 494,750
RPPS	$ 244,440	$ 256,080	$ 267,720	$ 279,360	$ 291,000	$ 302,640	$ 314,280	$ 325,920	$ 337,560	$ 349,200


CUMULATIVE GW SAMPLING COST (U.S. $) - VOCS AND SVOCS OR METALS
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$-
1
2
3
4
5
Year
3-Volume Purge
Low Flow
PDB
SNAP™ - 3 x 125 mL
HydraSleeve®
Bailer Grab
Dialysis Sampler
Pneumo-Bailer™
Discrete Interval
Kabis - 1 x 40 mL, deploy 8x
Kemmerer
RPPS
SNAP™ - 2 x 125 mL, 2 x 40 mL


CUMULATIVE GW SAMPLING COST (U.S. $) - VOCS AND SVOCS OR METALS
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$-
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Year
3-Volume Purge
Low Flow
PDB
SNAP™ - 3 x 125 mL
HydraSleeve®
Bailer Grab
Dialysis Sampler
Pneumo-Bailer™
Discrete Interval
Kabis - 1 x 40 mL, deploy 8x
Kemmerer
RPPS
SNAP™ - 2 x 125 mL, 2 x 40 mL

Appendix C

Site-Specific Field Demonstration, Data Evaluation, and Approximate Costs

Site-Specific Demonstration

Although no-purge sampling methods have gained substantial credibility within the past several years, it is still common for regulatory agencies to require a site-specific demonstration of a no-purge method before allowing its routine use for groundwater monitoring. According to the ITRC (2007), if there is specific guidance that requires purge-based sampling, it will be required to obtain exceptions to use passive sampling devices. Additionally most states will require a comparative study if no-purge sampling devices are intended to replace an existing sampling program (ITRC, 2007).

In a site-specific demonstration, no-purge sampling is conducted using one or more no-purge methods at a well or group of wells concurrently with a standard sampling event using the currently accepted sampling method. The analytical results from the standard sampling method and the no-purge sampling method(s) are evaluated to assess the comparability of the data sets.

Field Implementation

Field activities should be conducted in such a manner that the samples are collected in the shortest period of time practicable within a given well, with minimal disturbance to the water column within the well. Samplers that require an equilibration period (e.g., PDB, Snap Sampler™, HydraSleeve®) are deployed in advance of the actual sampling event, and standard sampling is performed at each demonstration well immediately after the no-purge sampler is retrieved from the well and placed into appropriate sample containers.

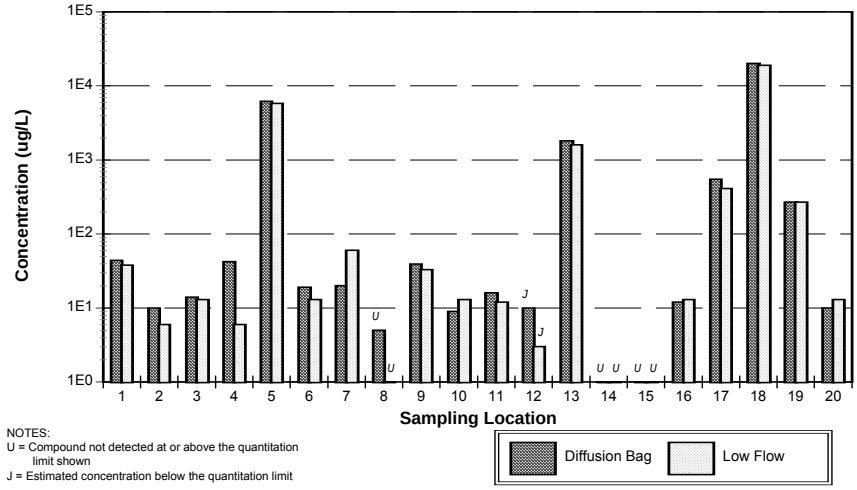
Because standard purge-based sampling causes more perturbation to the water column in the well than no-purge sampling, the no-purge sample(s) should be obtained before the standard sample. The samples obtained by the standard method and the no-purge method(s) from a given well should be packaged as part of the same sample delivery group and included in the same analytical “run” at the analytical laboratory to minimize the potential for analytical differences not related to actual sample characteristics.

Data Comparison Methods

Following receipt of the analytical data for the standard method and the no-purge method(s), the data sets for each detected analyte are graphically or statistically compared. There are many options for comparing the data to determine whether the no-purge results are sufficiently similar to the standard sampling results. Some data comparison approaches are described below. The data comparison approach used at a given site will depend on the quantity and quality of the data, as well as on approval of the data comparison method(s) by the applicable regulatory agency.

Bar Chart

A bar chart provides a simple visual comparison of the analyte concentrations obtained using two or more sampling methods. The bar chart below summarizes actual sampling results for trichloroethene (TCE) at multiple monitoring wells using PDB or low-flow sampling.



(from Gefell et al., 1999)

On a bar chart, results for non-detected analytes can be plotted at one-half the detection limit. Bar charts are useful for illustrating the degree of similarity of sampling results and for evaluating whether one method tends to report higher concentrations than another method.

X-Y Plot with Regression

Results from one sampling method can be plotted against the corresponding results for another sampling method using an X-Y scatter plot. By plotting a best-fit trend line to the data, the equation of the line can be determined. The correlation between the two sets of data can be evaluated by the coefficient of determination (r^2) for each best-fit line. The closer the r^2 value is to 1, the better the fit of the data to the trend line and the lower the degree of scatter. The slope of the best-fit line can also be used to evaluate the data. A slope between 0.90 and 1.10 indicates that the two sets of sampling results may be considered similar. A slope equal to or greater than 1.10 indicates that the sampling method represented on the Y-axis was more likely to return a higher-magnitude result than the sampling method represented on the X-axis. A slope equal to or less than 0.90 indicates the opposite. Analysis of slope is meaningful only if there is not a large degree of scatter about the best-fit trend line. If the r^2 is less than 0.90,

the degree of scatter is such that observations based on slope are less meaningful than those based on an r^2 is greater than or equal to 0.90 (Parsons, 2005).

Relative Percent Difference

The relative percent difference (RPD) is a measure of the error or difference between two values. It is calculated using the following equation:

RPD = [(A-B)/{(A + B)/2}] * 100

Where:
A = result from sampling method A
B = result from sampling method B

A positive RPD indicates that the result from sampling method A is higher than the result from sampling method B, while a negative RPD indicates the opposite. An RPD close to zero generally indicates that the results from both sampling methods were similar.

Additional Statistical Methods

Additional methods that can be used to compare two data sets include the Wilcoxon Rank Sum (WRS) Test, the Wilcoxon Signed Ranks (WSR) Test and the Sign Test. All three of these methods are nonparametric. Thus, it is not required that the data sets be normally distributed.

Parsons (2005) presented results for the WRS and the Sign test, comparing several sampling methods at the McClellan Air Force Base. The WRS, WSR, and Sign tests are more robust for larger data sets and less robust for smaller data sets. In their review of the data, for example, Parsons (2005) noted that the statistical results of data comparisons using 1 to 10 paired data were of very low confidence due to the small number of samples. Thus, as a general guideline and to provide sufficient data to perform these types of statistical methods with confidence, it may be prudent to collect comparative samples from 15 to 20 wells. In some settings, the regulatory agency may require the no-purge method to be demonstrated in every well in which no-purge sampling is to be performed for routine monitoring. If the number of wells is fewer than 15, it may be best to: 1) rely on simpler methods of data comparison; 2) use groups of analytes (e.g., aromatic hydrocarbons, SVOCs, or metals) to provide sufficient pairs of data for comparison; or 3) collect multiple rounds of paired samples.

If the number of wells is fewer than 15, it may be best to: 1) rely on simpler methods of data comparison; 2) use groups of analytes (e.g., aromatic hydrocarbons, SVOCs, or metals) to provide sufficient pairs of data for comparison; or 3) collect multiple rounds of paired

Additional information regarding these tools is included in Appendix E (from USEPA, 2006). The method descriptions presented in Appendix E can be performed by hand or

within a spreadsheet. Another alternative is to obtain a spreadsheet add-on that automatically performs statistical calculations within a spreadsheet. For example, Analyse-it® software (http://www.analyse-it.com/ —— cost $150 U.S.) integrates seamlessly with Microsoft Excel® and allows the user to perform the various statistical tests, directly in Excel® without a separate data importing/exporting step. Lastly, the above-mentioned calculations can be accomplished using more sophisticated statistical software packages (e.g., Systat, SPSS, SAS, Mathematica), although these tools can be relatively expensive.

Wilcoxon Rank Sum Test

The WRS Test can be used to test for a difference between the mean of two populations of data. The WRS Test is nonparametric, but it assumes that the two sets of data have approximately the same shape (variance), with the only difference being a shift in location. This assumption can be qualitatively tested for by plotting and comparing histograms of the data.

Wilcoxon Signed Ranks Test

The WSR Test can be used to determine whether two dependent variables (e.g., analytical results from two different sampling methods) represent two different populations. The WSR Test determines whether the median of the differences between the pairs of data is equal to zero. A significant difference indicates that there is a high likelihood that the two data sets represent different populations. The opposite is also true.

Sign Test

The Sign Test is applicable to situations where the researcher has two measures (e.g., under two conditions) for each subject and wishes to establish whether the two measurements (or conditions) are different. The only assumption required by the Sign Test is that the underlying distribution of the variable of interest be continuous; no assumptions about the nature or shape of the underlying distribution are required. The test simply computes the number of times (across subjects) that the value of the first variable (A) is larger than that of the second variable (B). Under the null hypothesis, which states that the two variables are not different from each other, this is expected to be the case approximately 50 percent of the time. Based on the number of observed cases where A is greater than B, a statistical significance (p-value) and associated confidence level can be calculated for the data set.

Cost of Site Specific Field Demonstration

The cost to complete a site specific field demonstration was estimated based on the assumptions used above to calculate the cost of no-purge and purge-based sampling at the hypothetical site, the labor involved to complete select statistical analyses and produce a report, and laboratory costs.

For the cost comparison, a hypothetical site is assumed to have fifteen 2-inch-diameter monitoring wells with total depths of 20 ft and saturated screened intervals of 10 feet (the water table is assumed to be 10 ft below grade). The assumed sampling depth is 15 ft below grade. Additional assumptions are that there are six major chemicals of concern (COCs) at the site, and that the types data comparison methods study include x-y regression, bar chart, and RPD. Additional and more rigorous statistics would require the purchase of software as mentioned above and additional time to complete the data evaluation. This section compares the estimated costs of two events for one no-purge sampling event and one three-volume purge event. The six COCs are assumed to be quantifiable with EPA Method 8260 for volatile organic compounds. For this cost comparison, the traditional three-purge method is compared to HydraSleeve®. The costs for the sampling methods were obtained from Table 2, ("first event cost"). Therefore the costs of different techniques can be substituted in this table.

The table below presents the assumptions used in estimating these costs along with the estimated costs.

Table C-1. Summary of Costs for Comparison Study

Item	Unit Cost	Number of Units	Total	Remarks
1 sampling event using 3-volume purge method	-	One	$7,225	From cost spreadsheets (VOCs only)
1 sampling event using HydraSleeve®	-	One	$3,865	From cost spreadsheets (VOCs only)
Laboratory Analysis	$100/sample	40, including two sampling methods & QA/QC samples	$4,000	
Data Evaluation	$ 80/hour	40 hours	$3,200	
Reporting	$ 80/hour	40 hours	$3,200	Includes CAD time if needed and report production
Total (rounded)	**-**	**-**	**$21,500**	

Appendix D

Selected Detailed Operating Procedures

Bailer Grab Sampling

Standard Operating Procedure: Bailer Grab Sampling

I. Scope and Application

The objective of this Standard Operating Procedure (SOP) is to describe the procedure to collect groundwater samples using bailers with no purging of the monitoring well, piezometer, etc. This SOP describes the equipment, field procedures, materials, and documentation procedures necessary to collect groundwater samples by "bailer grab" sampling. Relevant JSAs must be followed during sampling.

This SOP (i.e., typically applicable) may be varied or changed, as required, dependent on site conditions, equipment limitations, or limitations imposed by the procedure. The ultimate procedure employed will be documented in the project work plans or reports.

II. Personnel Qualifications

Field sampling personnel will have current health and safety training, including 40-hour Hazardous Waster Operations and Emergency Response Standard (HAZWOPER) training, site supervisor training, site-specific training, first aid, and cardiopulmonary resuscitation (CPR), as needed. In addition, field sampling personnel will be versed in the relevant SOPs and possess the required skills and experience necessary to successfully complete the desired field work. Region-specific field personnel qualifications must also be met.

III. Equipment List

- Electronic water-level or oil-water level indicator;
- Plastic sheeting;
- Masking tape;
- Tape measure;
- Appropriate cleaning materials;
- Well keys;
- Bailer;
- Polyethylene or Nylon Rope;
- Field notebook/logs/forms; and
- Personal protective equipment (PPE), as required by the Health and Safety Plan (HASP).

IV. Cautions

Two types of bailers are available for obtaining grab samples from wells: a point-source bailer; and an open bailer. A point source bailer is constructed of stainless steel and has dual ball valves at the top and bottom which prevent mixing of water with a sample

collected at a discrete interval. Open bailers can be stainless steel, Teflon®, PVC, or HDPE. Disposable open bailers are typically made of HDPE. An open bailer has one bottom ball valve. After the point-source or open bailer is lowered to the desired depth, the bailer is retrieved upward and the valve(s) retain the sample of water in the bailer. Because the top of the open bailer is exposed to the water in the overlying water column, it is possible that the sample could mix, to some degree with the water column above the bailer upon removal from the well. Thus, open bailers should not be used in situations where a substantial water column length exists above the sampling depth. In addition, bailer grab sampling is not recommended in monitoring wells (or piezometers) containing a floating layer of light, non-aqueous phase liquid (LNAPL), also known as separate phase hydrocarbons.

Avoid introduction of surface soils or other materials by staging down-hole equipment on a clean and dry working surface.

V. Health and Safety Considerations

Upon opening monitoring wells, monitor well headspace and breathing zone using equipment specified in the HASP.

VI. Procedure

1. Open the well and obtained a depth to water measurement using a properly decontaminated water level indicator or oil-water level indicator.

2. Based on the depth to water and the total well depth (based on well log, accounting for the “stickup height above grade”), calculate the length of the water column and the depth to the midpoint of the saturated screened or open interval from the top of casing (call this distance Z).

3. Tie an appropriate length of new, disposable polyethylene or nylon rope to a new, disposable or properly decontaminated bailer and, using a tape measure, measure from the midpoint of the bailer up the rope to the distance Z calculated above – mark the rope at this height with a knot or piece of masking tape. Avoid allowing the bailer or the rope to contact the ground surface by placing these on clean plastic sheeting next to the well, if necessary.

4. Slowly lower the bailer into the well; the rate of lowering should be no more than 0.5-ft per second within the water column. When the mark on the rope is at the top of casing, indicating that the midpoint of the bailer is at the midpoint of the saturated screened or open interval, slowly raise and retrieve the bailer from the well.

5. Fill sample vials and bottles as usual. If field filtering of metals samples is *required*, decant the water from the bailer into a sterile container and use a decontaminated peristaltic pump to pump the water through an appropriate disposable filter, collecting the filtered water directly in the appropriate sample containers. If field parameters are needed, measure them in the sterile container using appropriate field probes, or else use a downhole probe. Collect quality assurance/quality control (QA/QC) samples at the appropriate frequency as required under the standard sampling program. If additional sample volume is required at a well, repeat Step 7; however, repeat deployment of the bailer should be avoided if possible because it could increase sample turbidity and compromise sample quality.

6. Cap the well, properly decontaminate the water level meter or interface probe, and dispose of waste materials.

VII. Waste Management

Decontamination water will be disposed of properly. Rinse water, PPE, and other residuals generated during equipment decontamination will be placed in appropriate containers and labeled.

VIII. Data Recording and Management

Water-level measurements and depth calculations will be documented on the groundwater sampling log and/or the field logbook, including the following information:

- Well designation;
- Water-level measurement time;
- Total well depth;
- Depth to water; and
- Depth to midpoint of saturated screened or open interval.

In addition, the following information regarding the groundwater sample will be recorded:

- Type, size, and construction materials of bailer (point source or open);
- Type of rope;
- Time of sample collection;
- Type and volume of glassware filled, for which analytical methods;
- Field observations regarding groundwater sample (color; odor; presence of sheen, film, or particulate (if any); and
- Field parameter measurements.

IX. Quality Assurance

Depending on data quality objectives and data end use, aqueous QA/QC samples may be obtained.

X. References

N/A

Standard Operating Procedure: Field Equipment Cleaning and Decontamination

I. Scope and Application

This standard operating procedure (SOP) outlines the cleaning/decontamination procedure to be used for non-disposable field sampling equipment that may come in contact with environmental samples.

II. Personnel Qualifications

Personnel qualifications are the same as listed in the above SOP for Bailer Grab Sampling.

III. Equipment List

- health and safety equipment, as required in the site Health and Safety Plan (HASP);
- distilled water;
- non-phosphate soap (Alconox or equivalent);
- potable water;
- cleaning solvent, i.e., hexane (for PCBs) and/or isopropanol (for other organics);
- if sampling for inorganics, 0.1M hydrochloric acid (for stainless steel) or nitric acid
- rinse collection plastic containers;
- disposable gloves
- knife;
- brushes;
- garbage bags;
- spray bottles;
- Ziploc-type bags; and
- plastic sheeting.

IV. Cautions

Rinse equipment thoroughly and allow the equipment to dry before re-use or storage to prevent introducing solvent into sample medium.

V. Health and Safety Considerations

Review the material safety data sheets (MSDS) for the solvents to be used in the decontamination. Avoid use of spray bottles to apply solvent on equipment to minimize potential for introducing vapors into breathing zone. Work in a well ventilated area and stand upwind while applying solvent to equipment during the decontamination process. Application of solvent to the equipment will be completed in a manner that minimizes

potential for exposure to workers. Follow health and safety procedures outlined in the HASP.

VI. Procedure

Decontamination Equipment

- All storage containers (spray bottles) will be constructed of proper materials to ensure their integrity. The following are acceptable materials for containing the specified cleaning solutions:

- Detergent must be kept in clean plastic, metal, or glass containers until used. It should be poured directly from the container during use.

- Solvent must be stored in the unopened original containers until used and will be applied using Teflon® or polyethylene squeeze bottles.

- Potable water may be kept in clean tanks, hand-pressure sprayers, squeeze bottles, or applied directly from a hose

- Deionized or distilled water must be stored in clean glass, stainless steel, or plastic containers that can be closed prior to use. It can be applied from plastic squeeze bottles.

- Organic-/analyte-free water must be stored in clean glass, Teflon®, or stainless steel containers prior to use. IT may be applied using Teflon® squeeze bottles.

Sampling Equipment Decontamination

The following steps describe the procedures to be taken to properly decontaminate field sampling equipment:

- Tools, equipment, machinery, and field sampling personnel will be decontaminated in the contamination reduction zone, as outlined in the HASP.

- Locate the designated equipment decontamination area. Equipment decontamination stations will be established in sequence from initiation to completion of the decontamination procedures. All necessary waste management containers will be placed at the appropriate decontamination station.

If organic compounds are a potential constituent of concern, reusable field sampling equipment will be decontaminated as follows:

- Don personal protective equipment (PPE) per the HASP
- Non-phosphate detergent and distilled water wash (removing large particulates with brush);
- Distilled water rinse;
- Solvent rinse, using hexane (for PCBs) and/or isopropanol (for other organics);
- Double-distilled water rinse;
- Solvent rinse
- Triple-distilled water rinse;
- Air dry;
- Storage in a clean container

If inorganic compounds are a potential constituent of concern, reusable field sampling equipment will be decontaminated as follows:

- Don personal protective equipment (PPE) per the HASP
- Non-phosphate detergent and distilled water wash (removing large particulates with brush);
- Distilled water rinse;
- 0.1M hydrochloric acid (for stainless steel) or nitric acid rinse;
- Triple-distilled water rinse;
- Air dry;
- Storage in a clean container

- Cleaning/decontamination will be conducted in labeled plastic containers that will be transported to each sampling location. These containers will have leak-proof covers and will also be used to collect all decontamination rinsate. Plastic sheeting will be placed on the surface beneath the containers.

VII. Waste Management

Decontamination water should be containerized and characterized in conjunction with all other waste produced during the field sampling effort. Waste management procedures should be outlined in the Sampling and Analysis Plan (SAP). Rinse water, PPE, and other residuals generated during equipment decontamination will be placed in approved drums/containers and labeled.

VIII. Data Recording and Management

Equipment cleaning and decontamination will be noted in the field notebook. An inventory of the solvents brought on site and used and removed from the site will be maintained in the files. Containers with decontamination fluids will be labeled.

IX. Quality Assurance

Equipment blanks should be considered in the Field Sampling Plan (FSP) when using this SOP. The need for equipment blanks will depend on the data quality objectives.

X. References

N/A

Notes on Bailer Grab Sampling Use:

Bailer grab sampling has been used successfully at sites with wells completed in unconsolidated materials or bedrock. The results from the sampling indicated that the data were consistent with data from PDB and low-flow sampling methods. At two sites undergoing pilot testing for chemical oxidation in bedrock, the well screens were significantly below water table, but the data were still consistent with expectations based on previous results. The analytes of interest were chlorinated solvents, BTEX, selected inorganics compounds, and field parameters.

Safety: Inspect bailer setup prior to use. Use proper lifting techniques when moving equipment. Lift with legs and arms, not back (bend at knees, minimize twisting). When lifting, keep loads close to body, avoid twisting torso, and use legs, not back, to lift loads. Use two people if necessary; take breaks as needed. Wear safety glasses and gloves. Potential hazards include lifting hazards and muscle strain, and exposure to affected ground water.

HydraSleeve®

HYDRASleeve

Simple by Design

US Patents No. 6,481,300; No. 6,837,120; others pending

Field Manual

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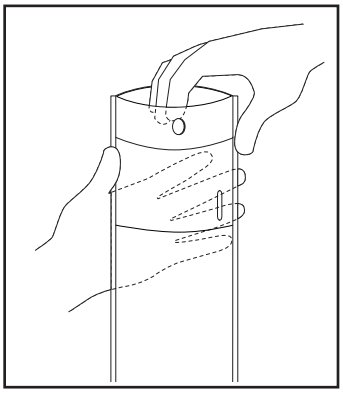
Introduction

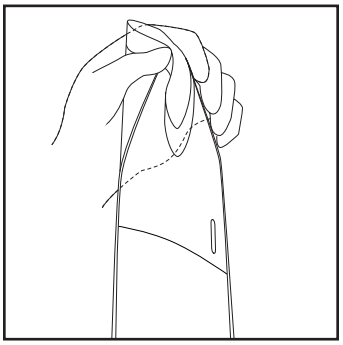
The HydraSleeve groundwater sampler can be used to collect a representative sample for most physical and chemical parameters without purging the well. It collects a whole water sample from a user-defined interval (typically within the well screen), without mixing fluid from other intervals. One or more HydraSleeves are placed within the screened interval of the monitoring well, and a period of time is allocated for the well to re-equilibrate. Hours to months later, the sealed HydraSleeve can be activated for sample collection. When activated, HydraSleeve collects a sample with no drawdown and minimal agitation or displacement of the water column. Once the sampler is full, the one-way reed valve collapses, preventing mixing of extraneous, non-representative fluid during recovery.

Assembly

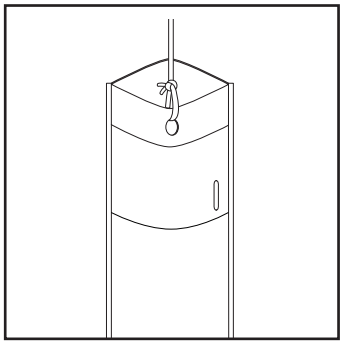
Assembling the HydraSleeve is simple, and can be done by one person in the field, taking only a minute or two.



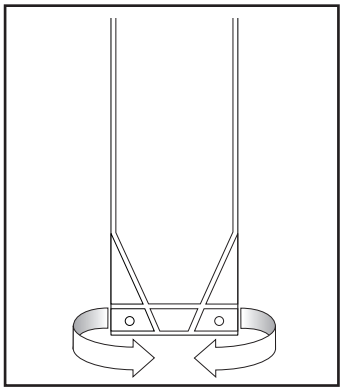
1 Remove HydraSleeve from package and grasp top to "pop" open.



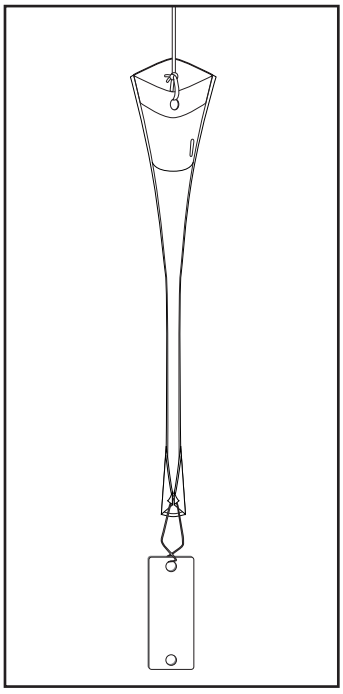
2 Squeeze side fins together at top to bend reinforcing strips outward.



3 Attach line to hole at top of HydraSleeve.



4 Fold the two holes at bottom of HydraSleeve together and attach weight



5 Sampler is ready to insert into the well.

Placing the HydraSleeve(s)

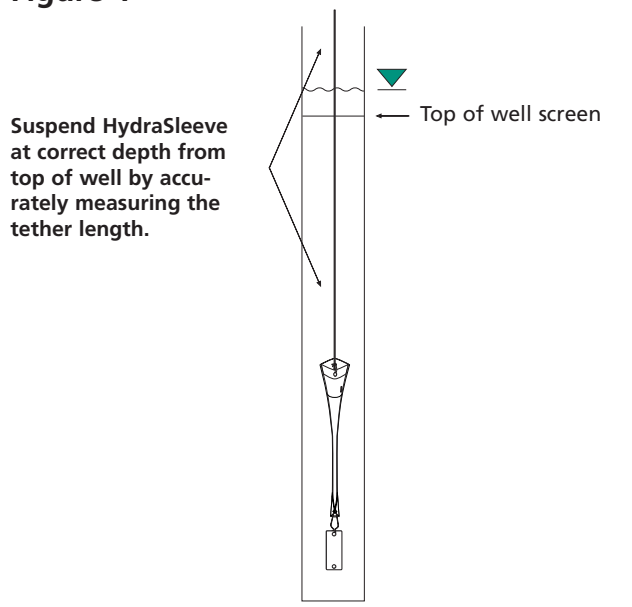
To collect a representative groundwater sample without purging, the well must be allowed time to re-equilibrate after placement of the sampler. When any device is lowered into a well, some mixing of the water column occurs. The diameter of the device and its shape greatly affect the degree of mixing. The flat cross-section of the empty HydraSleeve minimizes the disturbance to the water column as the sampler is lowered into position, reducing the time needed for the well to return to equilibrium.

There are three basic methods for holding a HydraSleeve in position as the well equilibrates.

TOP DOWN DEPLOYMENT (Figure 1)
Measure the correct amount of suspension line needed to "hang" the top of the HydraSleeve(s) at the desired sampling depth (in most cases, this will be at the bottom of the sampling zone). The upper end of the tether can be connected to the well cap to suspend the HydraSleeve at the correct depth until activated for sampling.

Note: For deep settings, it may be difficult to accurately measure long segments of suspension line in the field. Factory prepared, custom suspension line and attachment points can be provided.

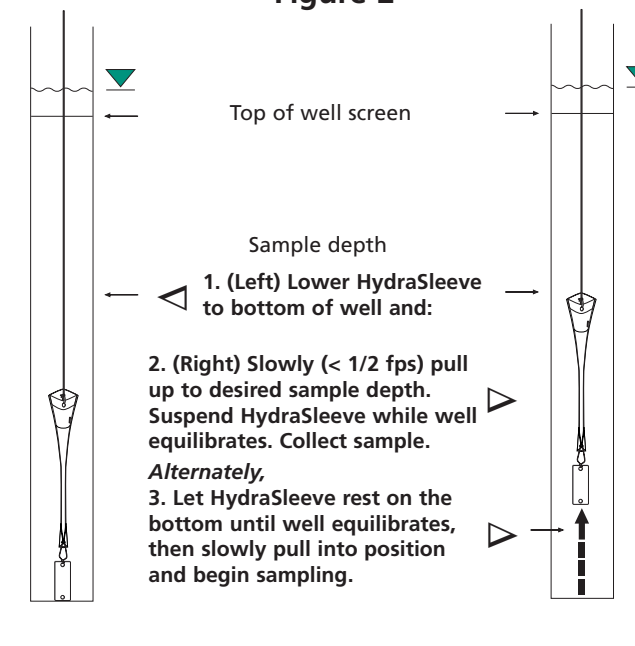
Figure 1



BOTTOM DEPLOYMENT (Figure 2)
Sound the well to determine the exact depth. Lower the weighted HydraSleeve into the well and let it touch the bottom. Very slowly (less than 1/2 foot per second) raise the sampler to the point where the check valve is at the depth the sample is to be collected. Attach the suspension line to the top of the well to suspend it at this depth. (It is often easier to measure a few feet from the bottom of the well up to the sample point, than it is to measure many feet from the top of the well down.)

Alternately, the sampler can be left on the bottom until the well re-equilibrates. For sampling, it can be very slowly pulled (< 1/2 fps) to sampling depth, then activated (see "Sample Collection," p. 6) to collect the sample, and retrieved to the surface.

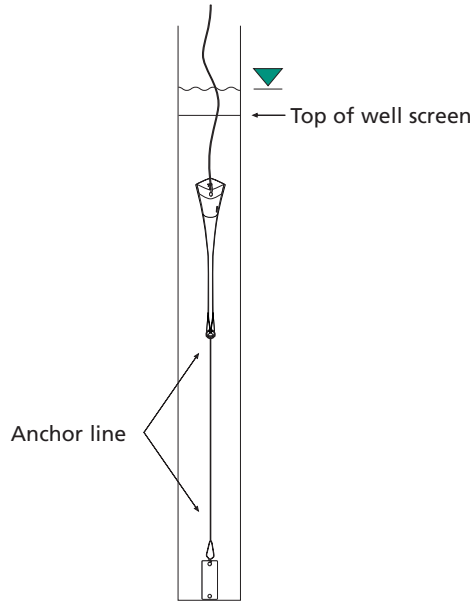
Figure 2



BOTTOM ANCHOR (Figure 3)

Determine the exact depth of the well. Calculate the distance from the bottom of the well to the desired sampling depth. Attach an appropriate length anchor line between the weight and the bottom of the sampler and lower the assembly until the weight rests on the bottom of the well, allowing the top of the sampler to float at the correct sampling depth.

Figure 3



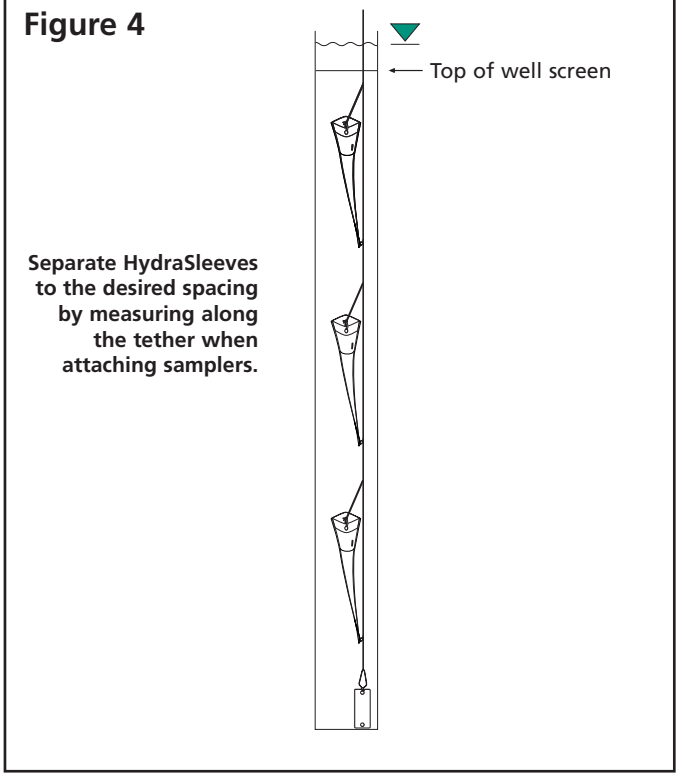
Multiple Interval Deployment

There are two basic methods for placing multiple HydraSleeves in a well to collect samples from different levels simultaneously.

ATTACHED TO A SINGLE TETHER (Figure 4)

To use 3 or more samplers simultaneously, we recommend attaching them all to a tether for support to prevent the sampling string from pulling apart. The weight is attached to a single length of suspension line and allowed to rest on the bottom of the well. The top and bottom of each HydraSleeve are attached to the tether at the desired sample intervals. Cable tie or stainless steel clips (supplied) work well for attaching the HydraSleeves to the line. Simply push one end of the clip between strands of the rope at the desired point before attaching the clip to the HydraSleeve.

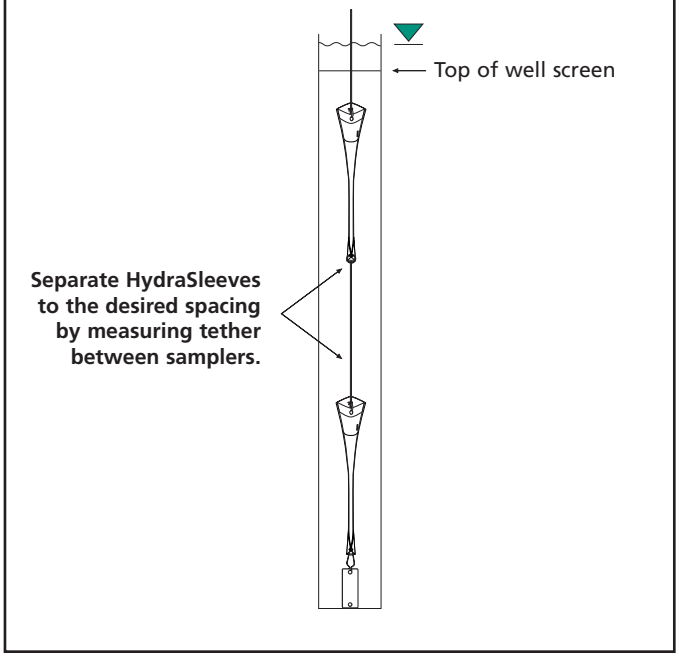
Figure 4



ATTACHED END TO END (Figure 5)

To place 2 or 3 stacked HydraSleeves for vertical profiling, use one of the methods described above to locate the bottom sampler. Attach the bottom of the top sampler to the top of the following HydraSleeve(s) with a carefully measured length of suspension cable. Connect the weight to the bottom sampler. Note: if many HydraSleeves are attached to a tether, more weight may be required than with a single sampler.

Figure 5



Sample Collection

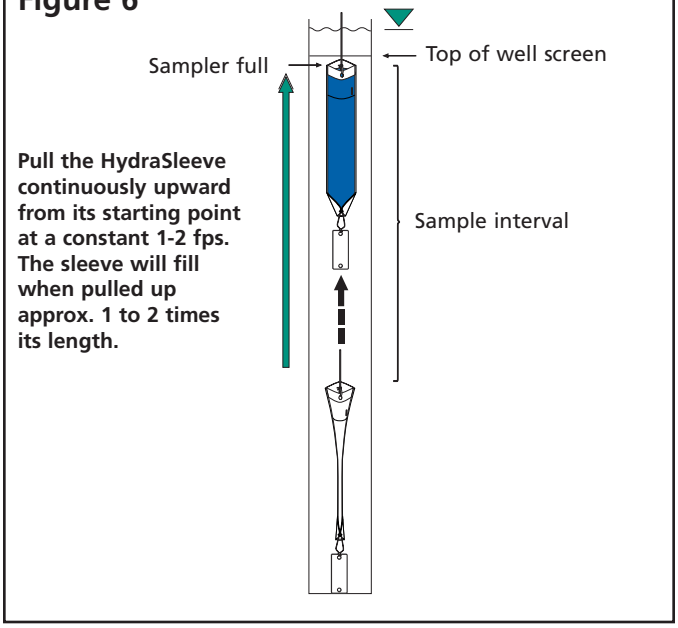
The HydraSleeve must move upward at a rate of one foot per second or faster (about the speed a bailer is usually pulled upward) for water to pass through the check valve into the sample sleeve. The total upward distance the check valve must travel to fill the sample sleeve is about 1 to 2 times the length of the sampler. For example, a 24-inch HydraSleeve needs a total upward movement of 24 to no more than 48 inches to fill. The upward motion can be accomplished using one long continuous pull, several short strokes, or any combination that moves the check valve the required distance in the open position. A special technique is used for sampling low-yield wells.

CONTINUOUS PULL (Figure 6)

Pull the HydraSleeve continuously upward from its starting point at a constant 1 to 2 feet per second until full. This method usually provides the least turbid samples and is analogous to coring the water column from the bottom up.

Note: When using this method, the screen interval should be long enough so the sampler fills before exiting the top of the screen.

Figure 6

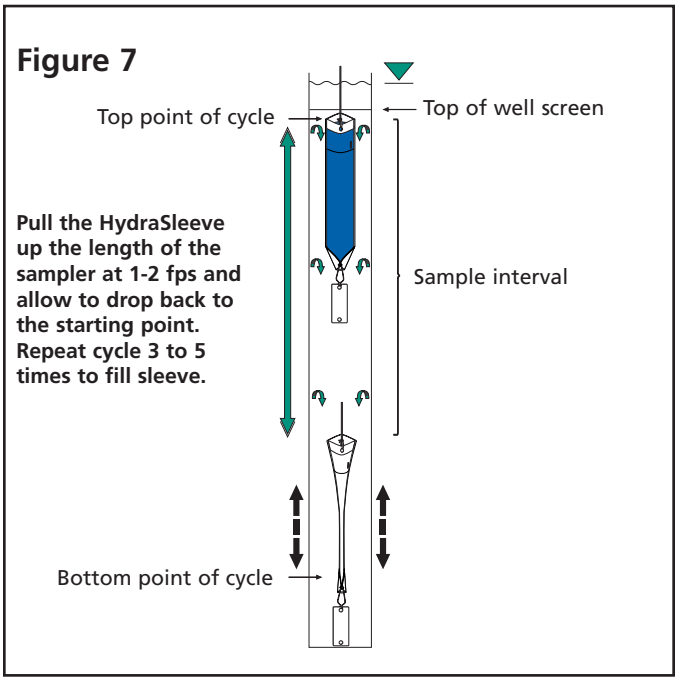


SHORT STROKES (Figure 7)

Pull the sampler upward at about 1 to 2 feet per second for the length of the sampler and let it drop back to the starting point. Repeat the cycle 3 to 5 times.

This method provides a shorter sampling interval than the continuous pull method (above), and usually reduces the turbidity levels of the sample below that of numerous rapid, short cycles (below). The sample comes from between the top of the cycle and the bottom of the sampler at its lowest point.

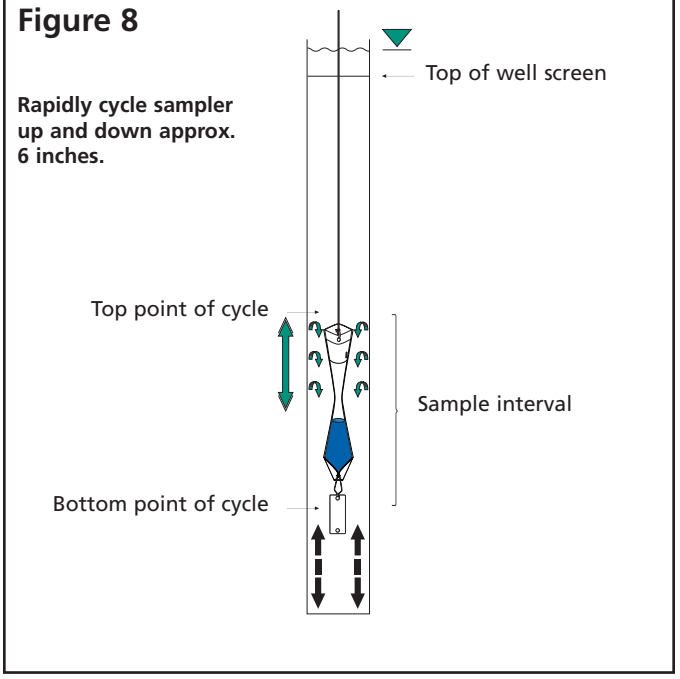
Figure 7



RAPID, SHORT CYCLES (Figure 8)

Cycle the HydraSleeve up and down using rapid, short strokes (6-inch cycle at a minimum of 1 cycle per second) 5 to 8 times. This method provides the shortest sampling interval. Dye studies have shown that when using this method the sample flows into the check valve from along the length of the sampler and immediately above the check valve. The sample interval is from the bottom the sampler at its lowest point in the cycle to the top of the check valve at the peak of the cycle.

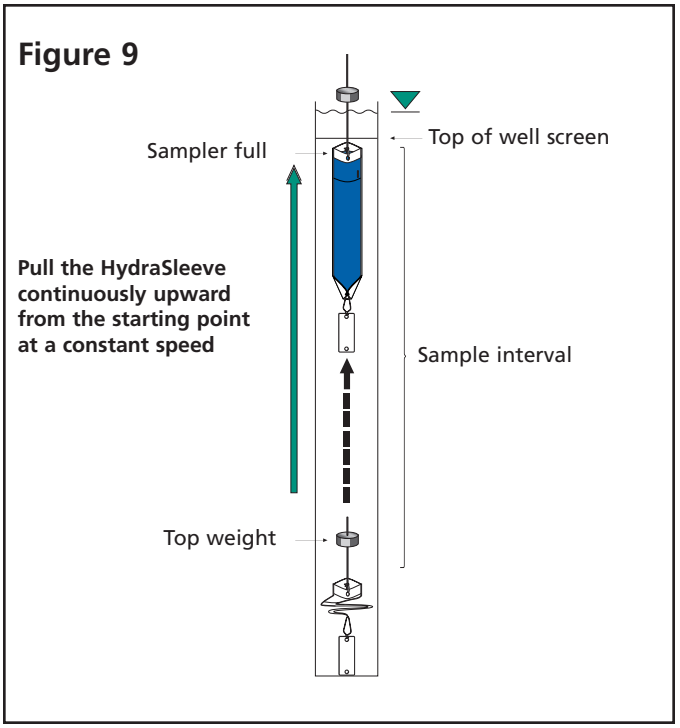
Figure 8



SAMPLING LOW-YIELD WELLS (Figure 9)

HydraSleeve provides the best available technology for sampling low yield wells. When pulled upward after the well re-equilibrates, the HydraSleeve will collect a water core from the top of the sampler to about its own length above that point. The sample is collected with no drawdown in the well and minimal sample agitation. An optional top weight can be attached to compress the sampler in the bottom of the well if needed for an extremely short water column. With a top weight, the check valve is pushed down to within a foot of the bottom of the well.

Figure 9



Sample Discharge

The best way to remove a sample from the HydraSleeve with the least amount of aeration and agitation is with the short plastic discharge tube (included).

First, squeeze the full sampler just below the top to expel water resting above the flexible check valve. (Photo 1, top left)

Then, push the pointed discharge tube through the outer polyethylene sleeve about 3-4 inches below the white reinforcing strips. (Photo 2, middle left)

Discharge the sample into the desired container. (Photo 3, bottom left)

Raising and lowering the bottom of the sampler or pinching the sample sleeve just below the discharge tube will control the flow of the sample. The sample sleeve can also be squeezed, forcing fluid up through the discharge tube, similar to squeezing a tube of toothpaste. With a little practice, and using a flat surface to set the sample containers on, HydraSleeve sampling becomes a one-person operation.

GeoInsight

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Notes on HydraSleeve® Use:

It is recommended to order a few extra HydraSleeves®. During shipping it is possible for sample ports to puncture a bag(s).

GeoInsight recommends polypropylene line. A polypropylene 1/8-inch line to tether the sampler is recommended because when deploying the HydraSleeve® in a deep well, it is easier to feel the bottom of the well with the 1/8-inch polypropylene line.

EON Products, Inc. will manufacture dedicated “tethers” for these samplers that EON Products, Inc. sells. Each tether is made to a specific length for a given well. Polypropylene rope tethers or stainless steel tethers are available.

Safety: Inspect equipment setup prior to use. Lift with legs and arms, not back (bend at knees, minimize twisting). When lifting, keep loads close to body, avoid twisting torso, and use legs, not back, to lift loads. Use two people if necessary; take breaks as needed. Wear safety glasses and gloves. Potential hazards include lifting hazards and exposure to affected ground water. Relevant JSAs must be followed during sampling.

Snap Sampler™

Standard Operating Procedure for the Snap Sampler™ Passive Groundwater Sampling Method (January 2007)

FORWARD

This standard operating procedure (SOP) was adapted from SOPs in USEPA's groundwater guidance for RCRA and Superfund project managers (U.S. Environmental Protection Agency, 2002). Portions of the applicable text are repeated here. With this forward, the authors and USEPA are acknowledged in sincerest appreciation. Edited and supplemental text is included to detail application information and procedures for use and deployment of the Snap Sampler™ passive groundwater sampling device and method.

INTRODUCTION

The goal of groundwater sampling is to collect samples that are "representative" of *in situ* groundwater conditions and to minimize changes in groundwater chemistry during sample collection and handling. Experience has shown that groundwater sample collection and handling procedures can be a source of variability in water quality concentrations due to differences in sampling personnel, sampling procedures, and equipment (U.S. Environmental Protection Agency, 1995).

The collection of "representative" water samples from wells is neither straightforward nor easily accomplished. Groundwater sample collection can be a source of variability through differences in sampling personnel and their individual sampling procedures, the equipment used, and ambient temporal variability in subsurface and environmental conditions. Many site inspections and remedial investigations require the sampling at groundwater monitoring wells within a defined criterion of data confidence or data quality, which necessitates that the personnel collecting the samples are trained and aware of proper sample collection procedures.

The purpose of this SOP is to provide a description of the Snap Sampler™ passive groundwater sampling method. The method and specialized equipment is designed to minimize the impact the sampling process on groundwater chemistry. This is accomplished through deployment and passive re-equilibration of the monitoring well to ambient groundwater flow and/or diffusive contaminant flux within the well/aquifer system. The Snap Sampler™ method eliminates well purging prior to sample collection.

As a passive groundwater sampling device, the Snap Sampler™ is a viable alternative to well purge and low-flow sampling in qualified wells. Historical and recent research shows that many if not most well screen zones exhibit ambient flow-through under natural groundwater gradients (Gillham, 1982; Pankow, et al 1985; Robin and Gillham, 1987; Powell and Puls, 1993; Puls and Barcelona, 1996; Vroblesky, et al, 2001a; ASTM, 2002; ITRC, 2004). The screen sections of these wells are "naturally purged" without pumping. Ongoing research (Britt, 2005; Martin-Hayden and Britt, 2006; Vroblesky, et al 2006), suggests that natural ambient flow can induce mixing within wells, resulting in a flow-weighted averaging effect in the well without purging. Though not all wells are thoroughly mixed, many wells show relatively narrow ranges of vertical concentrations when vertically profiled (Vroblesky et al, 2001b; Parsons, 2003). These studies indicate flow-weighted contaminant concentration averaging within wells may be common. The Snap Sampler™ takes advantage of "naturally purged" wells by capturing natural flow-through in the open VOA vial during sampler deployment.

Wells in poor yielding formations with slow recharge during pumping have always been problematic for pumping methods. The Snap Sampler™ can be deployed in low yield wells to take advantage of the passive technology. Passive sampling of poorly yielding wells has been suggested as a better method than purging to dryness in VOC impacted wells (McAlary and Barker, 1987; Puls and Powell, 1993; Puls and Barcelona, 1996).

The Snap Sampler™ passive groundwater sampling method limits sample collection variables by sealing the sample while it is still in the well. The sample is not poured into sample bottles at the ground surface. Sampling personnel are essentially prevented from introducing error, variability, or bias during the sample collection process. Sample collection is virtually the same for any

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collector because the sample is never exposed to the ambient air from the well to the laboratory.

SCOPE AND APPLICATION

This SOP should be used primarily at monitoring wells that have a screen or an open interval with a length of ten feet or less and can accept a downhole device of 1.7 inches in diameter. Longer screen interval sampling may be conducted, but vertical stratification testing is more likely to be required to identify vertical concentration gradients. Vertical stratification monitoring may be warranted if previous information about aquifer and/or well contaminant stratification is not available. The Snap Sampler™ groundwater sampling method is similar in many respects to the passive diffusion bag (PDB) sampler. Like the PDB, vertical profiling may be recommended depending on site-specific data quality objectives (DQO's) and other site requirements (Vroblesky, 2001a; ITRC, 2004).

The groundwater samples that are collected using this procedure are useable for the analyses of groundwater contaminants that may be found at Superfund and RCRA contamination sites. The analytes may be volatile, semi-volatile organic compounds, pesticides, PCBs, metals, and other inorganic compounds, including perchlorate and other emerging contaminants.

For contaminant plume monitoring, the sampler should be placed within the screened interval of the well. For consistency and comparability of results over time, the sampler should be placed in same location or depth for each subsequent sampling event.. This argues for the use of dedicated sampling devices with dedicated trigger lines whenever possible. If this is not possible, then the placement of the Snap Sampler™ should be positioned using pre-measured trigger tubing placed at the same depth during each sampling event. The Snap Sampler™ should not be placed resting on the bottom of the screened interval to avoid disturbing any sediment at the bottom of the well during deployment or when the sampler is triggered.

The Snap Sampler™ relies on natural flow-through and/or diffusion of contaminants from the aquifer to the well (Powell and Puls, 1993; ASTM, 2002). Well purging is not conducted before sampling and therefore measurement of water-quality-indicator parameters is not a prerequisite to sample collection. Water-quality indicator parameters dp not need to be collected prior to sampling. If parameters are required for certain monitoring programs independent of sampling method (e.g. for monitored natural attenuation), parameters can be collected by utilizing one of the deployed Snap Sampler™ bottles or post-sampling by another method.

Samples collected for metals, semi-volatile organic compounds, pesticides, and other analytes may be impacted by sample turbidity. They also may be subject to transport by colloidal flow in the natural groundwater regime (Kearl, et al, 1992, Puls and Powell, 1992). Deployment and re-equilibrium of the Snap Sampler™ allows natural colloidal flow to be monitored within the well. This is a distinct advantage over sampling methods such as the PDB, where colloidal particles are excluded from the sample; and over purge methods where colloids may be artificially mobilized. Field filtering is not recommended for samples collected with the Snap Sampler™.

Proper well construction, development, and maintenance are essential for any groundwater sampling procedure. Prior to conducting the field work, information on the construction of the well and well development should be obtained and that information factored into the site specific sampling procedure. This SOP is not to be used where non-aqueous phase liquids (NAPL) (immiscible fluids) are present in the monitoring well.

MATERIALS AND EQUIPMENT

- Approved Field Sampling and Quality Assurance Project Plan.
- Site Health and Safety Plan with specifications for personal protective equipment and air monitoring equipment.

- Personal protective equipment in good working order as specified in the site Health and Safety Plan.

- Air monitoring equipment in good working order as specified in the Site Health and Safety Plan.

- Site access/permission documentation for site entry.

- Well keys and map of well locations.

- Tool box - All needed tools for all site equipment used.

- Snap Samplers™ - stainless steel samplers should be used when sampling organic compounds. Acetal or other appropriate plastic sampler material may be used when sampling for metals. When sampling for metals and organics, dedicated plastic samplers are preferred.

- Snap Sampler™ Trigger lines, – Dedicated polyethylene tubing with stainless steel trigger wire is preferred when sampling for organic compounds. Non-metalic trigger wire or stainless steel trigger wire coated with nylon or appropriate fluorocarbon may be used when sampling for metals.

- Snap Sampler™ Well Docking Station – replacement well caps for Snap Sampler™ - deployed wells.

- Sample bottles, sample preservation supplies, sample tags or labels, and chain-of-custody forms.

- Well construction, field, and water quality data from the previous sampling event.

- Field notebook, groundwater sampling logs, and calculator.

- Polyethylene sheeting placed on ground around the well head.

- Depth-to-water measuring device - An electronic water-level indicator or steel tape and chalk, with marked intervals of 0.01 foot. Interface probe for determination of liquid products (NAPL) presence, if needed.

- Steel tape and weight - Used for measuring total depth of well. A lead weight should not be used.

- Multi-parameter meter, if required. The water-quality-indicator parameters that may be monitored under common monitoring programs include pH, ORP/Eh, (ORP) dissolved oxygen (DO), turbidity, specific conductance, and temperature. Turbidity readings, if required, must be collected from a sacrificed Snap Sampler™ bottle because retrieving the sampler may agitate the well, increasing turbidity values not present in the actual samples. Calibration fluids for all instruments should be NIST-traceable and there should be enough for daily calibration throughout the sampling event.

- Decontamination supplies - Including a reliable and documented source of distilled water and any solvents (if used). Pressure sprayers, buckets or decontamination tubes for pumps, brushes and non-phosphate soap will also be needed.

- A suitable container for excess sample and decontamination water, as needed or required.

Construction materials of the sampling equipment (samplers, tubing, and other equipment that comes in contact with the sample) should be limited to stainless steel, Teflon®, glass, and other inert material. This will reduce the chance that sampling materials alter the groundwater where concentrations of the site contaminants are expected to be near the detection limits. The tendency of organics to sorb into and desorb out of plastic materials makes dedicated equipment preferable where possible.

It should be noted that sorbing materials used in the Snap Sampler™ is not usually problematic. Using this method, the sampler is deployed for one to two weeks (or more), allowing materials prone to sorption to achieve equilibrium with groundwater before the sample is collected.

DEPLOYMENT/SAMPLING PROCEDURES

The following describes the deployment and sampling procedures for the Snap Sampler™ passive groundwater sampling method. These procedures describe steps for dedicated and non-dedicated systems.

Pre-Sampling Activities

1. Well location maps, construction information, keys and sampling equipment should be assembled and transported to the site.

2. Water level monitoring and sampling must begin at the monitoring well with the least contamination, generally up-gradient or farthest from the site or suspected source. Then proceed systematically to the monitoring wells with the most contaminated ground water.

3. Check and record the condition of the monitoring well for damage or evidence of tampering. Lay out polyethylene sheeting around the well to minimize the likelihood of contamination of sampling/purging equipment from the soil.

4. Unlock well head. Record location, time, date, and appropriate information in a field logbook or on the groundwater sampling log.

5. Remove inner casing cap.

6. Monitor the headspace of the monitoring well at the rim of the casing for volatile organic compounds (VOC) with a photo-ionization detector (PID) or flame ionization detector (FID) and record in the logbook. If the existing monitoring well currently has or has a history of positive headspace readings, then the sampling must be conducted in accordance with the Health and Safety Plan.

7. Measure the depth to water (water level must be measured to nearest 0.01 feet) relative to a reference measuring point on the well casing with an electronic water level indicator or steel tape and record in logbook or groundwater sampling log. If no reference point is found, measure relative to the top of the inner casing, then mark that reference point and note that location in the field logbook. Record information on depth to ground water in the field logbook or groundwater sampling log. Measure the depth to water a second time to confirm initial measurement; measurement should agree within 0.01 feet or re-measure.

8. Check the available well information or field check for the total depth of the monitoring well.

Deployment Activities

Selection of the deployment depth within the screen interval is dependent on site specific DQO's. If depth-specific monitoring is required, multiple samplers may be deployed at intervals appropriate for the sampling objective. If previous vertical profiling of a well has been conducted, a selected single deployment depth may be chosen based on the sampling objective. For example, previous data show the bottom three feet of a well have historically contained the highest contaminant concentration; deployment at this depth could be selected based on an objective to sample the highest known concentration within stratified wells. Alternatively, if a well is not stratified, a mid-screen deployment may be appropriate.

Sample zones within a well may be isolated using a packer or baffle device to limit in-well mixing (Britt, 2006; Vroblesky et al, 2006). These can be attached to the Snap Sampler™ trigger line or deployed separately. Installation of an upper baffle designed to isolate the unscreened well casing or well headspace is recommended. The upper baffle will limit mixing of "stagnant" casing water with screen-interval water, an/or gas exchange with the headspace air.

1. Remove the Snap Sampler bottle(s) from its package.

2. Turn the translucent (PFA) vial cap on each end of the bottle slightly to release the O-ring (the o-ring may tend to stick on the glass of the vial if the o-ring is not loosened before trying to set the sampler).

3. Insert the bottle into the upper end of the sampler as shown in Figure 1.

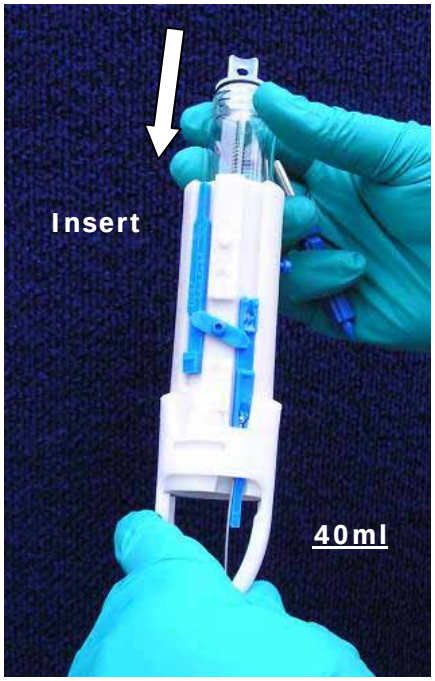

FIGURE 1

4. Place the sampler connector onto each end of the sampler; turn clockwise to align the set pins/screw; then gently tighten the set screw with the Snap Driver Tool (Figure 2).

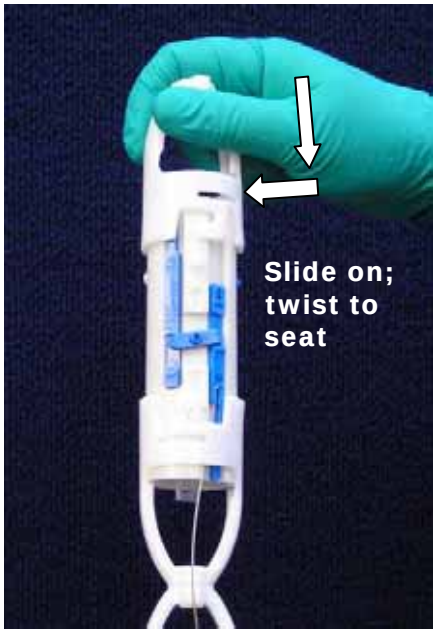

FIGURE 2

5. Pivot the vial cap (Snap Cap) into its seat with the Snap driver. Push up the retainer pin through the lower hole in the vial cap. Repeat for all Snap Caps (Figure 3). If an O-ring should dislodge from its seat during setting, remove the sample bottle and carefully replace it in the o-ring groove; repeat setting procedure.

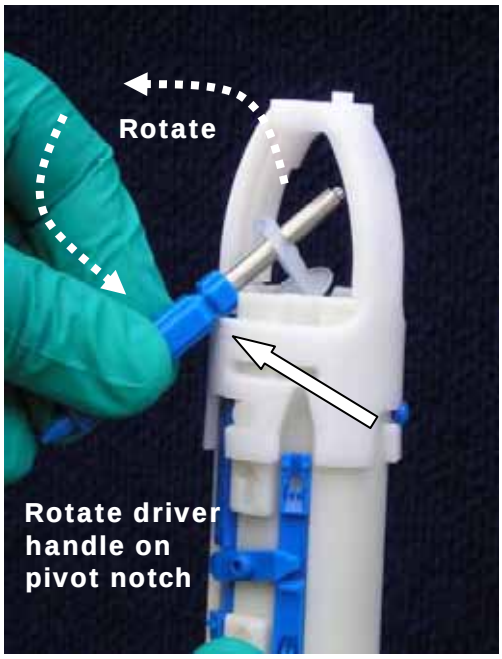

FIGURE 3

6. Feed ball-fitting end of trigger cable through lower release pin groove; click tube fitting into connector (Figure 4).

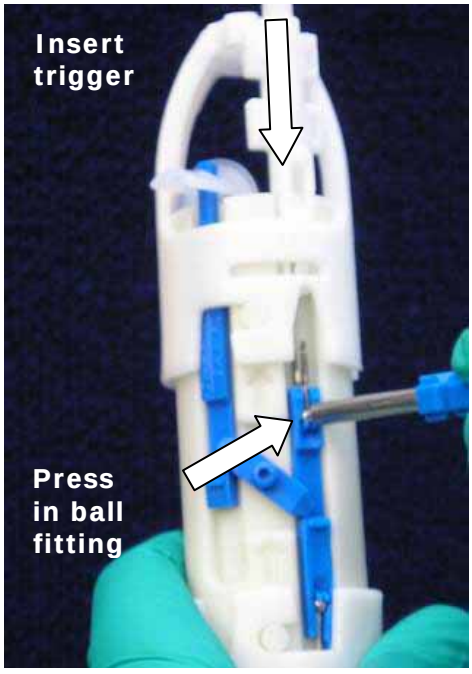

FIGURE 4

7. Press in the ball fitting to attach to lower release pin (Figure 4).

FIGURE 5

8. Deploy to selected depth with trigger cable tubing and attach to well head docking station (Figure 5).

9. Additional Snap Samplers™ can be deployed with separate trigger tubing cables or in series with a single trigger. If separate triggers are used, the ID tags should be marked at the surface for later reference.

10. The recommended deployment period is two weeks. There may be hydrogeologic conditions where a shorter deployment is possible, but two weeks would generally assure a return of the well to its steady-state condition (Vroblesky, 2001a, 2001b).

11. The Snap Sampler™ can also be deployed for more extended periods. It is suggested that quarterly or semi-annual sampling can be done with one mobilization per quarter, with one set of

samplers collected and the following quarter's samplers deployed at the same time.

Sample Collection Activities

When the deployment interval is completed, the sampler should be triggered from the well head without disturbing the sampler position. The trigger cable should be pulled with sufficient force to move the cable up the tubing. Depending on the length of the cable, closure of the samplers usually can be felt through the trigger line when the samplers trip. If more than one triggering line is present, closure should proceed from the deepest to the shallowest sampler position to limit capture of sediment re-suspended by closure of the first sampler.

After the sampler is triggered and retrieved, the upper connector should be removed by loosening the retainer screw and turning the connector.

While the vials should not leak with reasonable handling, they should not be agitated (to check for headspace) until after the screw caps are tightened. Under most circumstances there will be no air in the vials at retrieval. However, some field conditions, including deep groundwater, natural effervescence, or other causes, may allow some small air bubbles to be present in the bottle or on the spring when retrieved. This is not a concern if the air was entrained while deployed. Air adhering to the vial during deployment would be in equilibrium with the sample water upon sampler closure. Therefore it is not "headspace air" into which sample VOCs could volatilize. Deployment air could be attached to the spring or cap, and should not be larger than 1-2 mm upon retrieval. Pankow (1986) showed that small headspace air from these or other causes do not substantially impact results for most common volatiles. If air bubbles are larger than 5 mm before placing the screw cap, or water is clearly leaking from the vial, the sample may not have sealed properly and should be discarded. (A failure rate of less than 1% should be anticipated).

To seal the samples within the Snap Sampler™ bottles, the following procedures should be followed:

1. The tabs should be carefully clipped from the vial caps. Care should be taken to avoid disturbing the seal. The cap should be cut flush to the cap to ease placement of the septa screw cap (Figure 6).

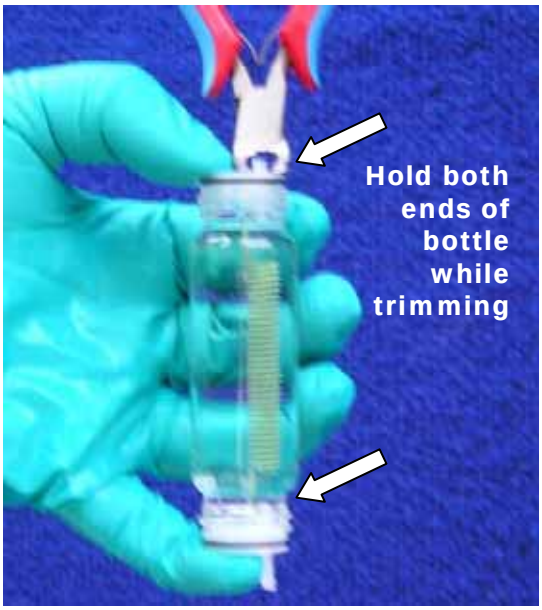

FIGURE 6

2. If no preservative is desired, or preservation will be conducted by the laboratory, firmly tighten the septa caps to seal the vial.

3. Tightening the caps compresses the o-ring and creates a PFA-to glass seal. Only PFA and glass touch the sample after the bottle is sealed with the septa caps.

4. If samples are to be field preserved, adding liquid acid preservative is relatively simple. Prepare *one* end of the vial as described in step #1 and gently tighten a septa cap on that end. Prepare the other end of the vial through step #1. Fill the remaining Snap Cap cavity with 1:1 HCl solution. Carefully pierce the membrane with the pointed end of the Snap Driver Tool (Figure 7). If needed, refill the cap cavity with preservative. Preservative should be added to create a meniscus covering most of the cap. Care should be taken not to introduce air into the sample

bottle. Both septa caps should be firmly tightened onto the bottle.

FIGURE 7

5. Once sample bottles are properly closed, bottles should be labeled and recorded in the sampling logs and chain-of-custody (Figure 8).

FIGURE 8

6. There are no special laboratory preparation procedures for Snap Sample bottles. The bottles can be analyzed using common 40-ml autosamplers. The spring inside the VOAs is PFA Teflon-coated and will deflect out of the way of the extraction needle during insertion.

<u>Appendix A</u> contains step-by-step field procedures for deployment of both 40 ml Snap Sampler VOAs and 125 ml Snap Sampler POLY bottles.

<u>Appendix B</u> contains step-by-step procedures for preparation of both 40 ml Snap Sampler VOAs and 125 ml Snap Sampler POLY bottles.

DECONTAMINATION PROCEDURES

The electronic water level indicator probe/steel tape, the water-quality field parameter sensors and Snap Sampler™ groundwater sampling device should be decontaminated by the following procedures:

1. The water level meter will be hand washed with phosphate-free detergent and a scrubber, then thoroughly rinsed with distilled water.

2. Water quality field parameter sensors with distilled water between sampling locations where utilized. No other decontamination procedures are necessary or recommended for these probes since they are sensitive. After the sampling event, the sensors

must be cleaned and maintained per the manufacturer's requirements.

3. The Snap Sampler™ and trigger tubing must be pressure-sprayed or bristle-brush scrubbed with soapy water, tap water, and distilled water. Depending on the condition of the Snap Sampler™, the release pin mechanism may need to be disassembled to effectively clean the pins and grooves. Disassembly can be accomplished by removing the lever screw.

FIELD QUALITY CONTROL

Quality control (QC) samples must be collected to verify that sample collection and handling procedures were performed adequately and that they have not compromised the quality of the groundwater samples. The appropriate EPA or other appropriate program guidance must be consulted in preparing the field QC sample requirements for the site-specific Quality Assurance Project Plan (QAPP).

There are five primary areas of concern for quality assurance (QA) in the collection of representative groundwater samples:

1. Obtaining a groundwater sample that is representative of the aquifer or zone of interest in the aquifer. Verification is based on the field log documenting that the field procedures were followed appropriately during sample deployment and collection.

2. Ensuring that the sampling devices are made of materials, and utilized in a manner that will not interact with or alter the analyses.

3. Ensuring that results generated by these procedures are reproducible; therefore, the sampling scheme should incorporate co-located samples (duplicates).

4. Preventing cross-contamination. Sampling should proceed from least to most contaminated wells, if known. Field equipment blanks should be incorporated for all sampling, and decontamination of the equipment is therefore required.

5. Properly preserving, packaging, and shipping samples.

All field QC samples must be prepared the same as regular investigation samples with regard to sample volume, containers, and preservation. The chain-of custody procedures for the QC samples will be identical to the field groundwater samples. The following are QC samples that should be collected during the sampling event:

Field duplicates	1 per 20 samples
Matrix spike	1 per 20 samples
Matrix spike dup.	1 per 20 samples
Equipment blank	per requirements
Trip blank (VOCs)	1 per sample cooler
Temperature blank	1 per sample cooler

HEALTH AND SAFETY CONSIDERATIONS

Depending on the site-specific contaminants, various protective programs must be implemented prior to sampling the first well. The site Health and Safety Plan should be reviewed with specific emphasis placed on the protection program planned for the sampling tasks. Standard safe operating practices should be followed, such as minimizing contact with potential contaminants in both the liquid and vapor phase through the use of appropriate personal protective equipment.

Depending on the type of contaminants expected or determined in previous sampling efforts, the following safe work practices should be employed:

Particulate or metals contaminants

1. Avoid skin contact with, and incidental ingestion of sample water.

2. Use protective gloves and splash protection.

Volatile organic contaminants

1. Avoid breathing constituents venting from well.

2. Pre-survey the well head space with an appropriate device as specified in the site Health and Safety Plan.

3. If monitoring results indicate elevated organic constituents, sampling activities may be conducted in elevated protective equipment (e.g. level C protection). At a minimum, skin protection will be afforded by disposable protective clothing, such as Tyvek®, appropriate gloves and face protection.

General practices should include avoiding skin contact with water from preserved sample bottles, as this water will have pH less than 2 or greater than 10. Also, when field acidifying VOA bottles, hydrochloric acid fumes may be released and should not be inhaled. Acid should not contact skin, eyes, or unprotected clothing.

POST-SAMPLING ACTIVITIES

Several activities need to be completed and documented once groundwater sampling has been completed.

These activities include, but are not limited to the following:

1. Ensuring that all field equipment has been decontaminated and returned to proper storage location. Once the individual field equipment has been decontaminated, tag it with date of cleaning, site name, and name of individual responsible.

2. Processing all sample paperwork, including copies provided to the appropriate sample handling and tracking facility.

3. Compiling all field data for site records.

4. Verifying all analytical data processed by the analytical laboratory against field sheets to ensure all data has been returned to sampler.

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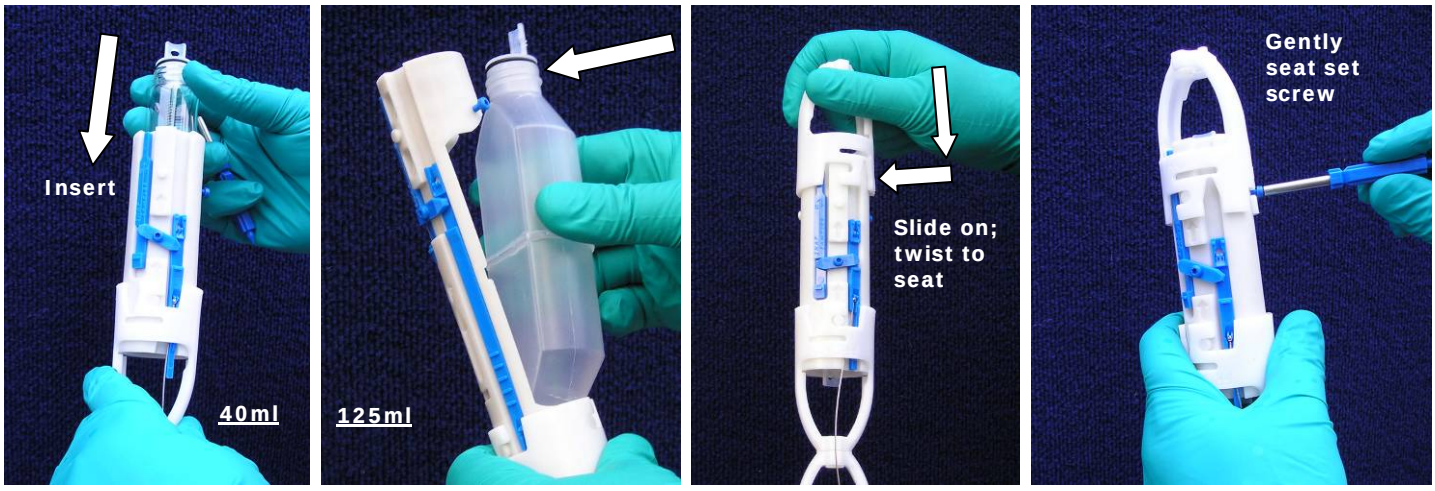
SNAP SAMPLER DEPLOYMENT (PAGE 1 OF 2)

INSERTING AND SECURING BOTTLES

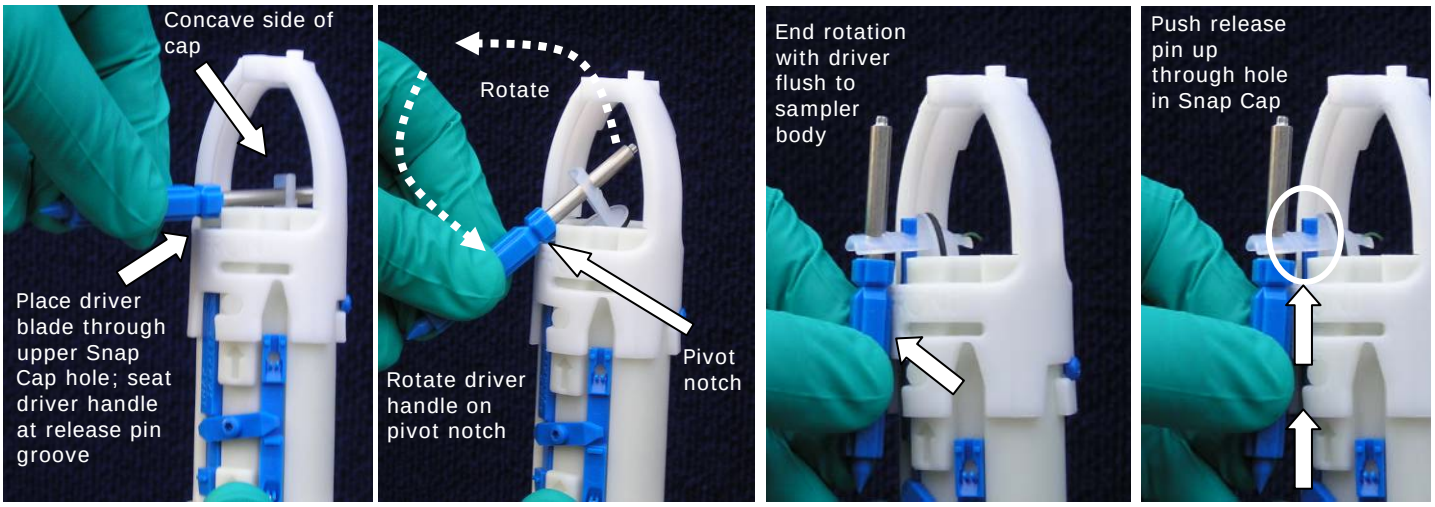


(A) (B) (C) (D)

A) Insert 40 ml VOA into top of 40 ml Snap Sampler <u>...or...</u>
B) Insert 125 ml POLY into back side of 125 ml Snap Sampler.
C) Slide connector over sampler and twist clockwise to seat.
D) Secure Connector and bottle with single set screw.
E) <u>Set All Bottom Snap Caps First, then Top Snap Caps.</u> Insert Snap Driver blade into the <u>upper</u> hole of the <u>concave</u> side of Snap Cap (insert the driver past the tip, to the <u>smooth part</u> of the driver blade shaft); seat driver handle at the release pin groove.
F) Rotate Snap driver on the pivot notch in the driver handle.
G) Pivot on driver pivot notch until driver handle is flush with sampler body and Snap Cap is in its seat; grasp driver so that fingers are kept clear of driver alignment with sampler body.
H) Use thumb of the hand holding the Sampler to push release pin up trough lower hole in the Snap Cap; repeat "E" through "H" for each Snap Cap in all Samplers.

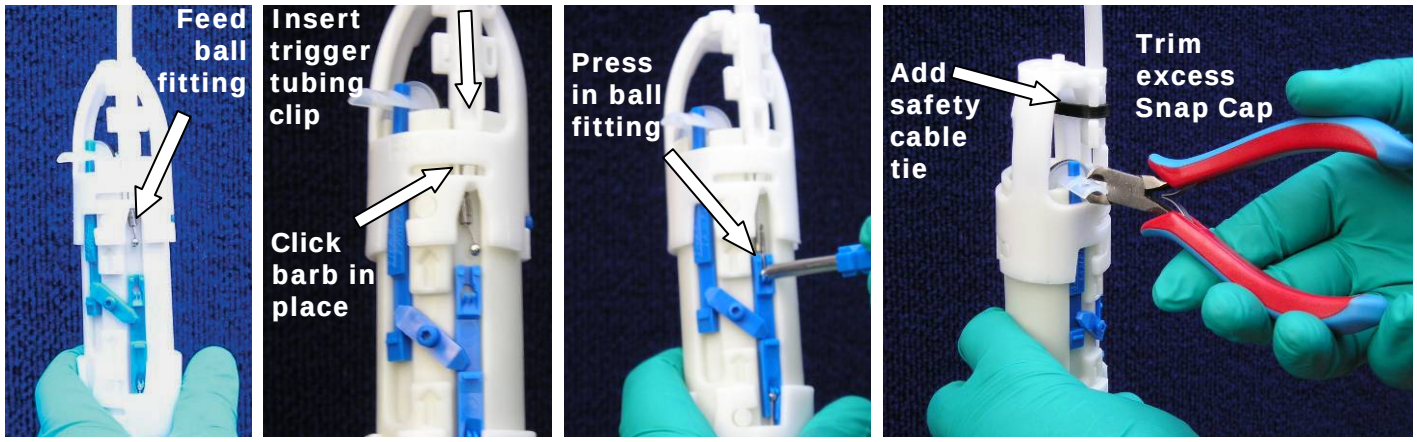
SETTING SNAP CAPS

(E) (F) (G) (H)



SNAP SAMPLER DEPLOYMENT (PAGE 2 OF 2)

ATTACHING TRIGGER



(A) (B) (C) (D) (E)

A) Insert ball end of trigger in upper release pin groove.

B) With trigger barb facing out, insert trigger until it clicks into position.

C) Press ball fitting into release pin.

D) Attach safety cable tie.

E) Trim protruding Snap Caps between ribs (required only for smaller diameter wells). Where more than one sampler is attached to one trigger, connect ball-end connector cables between each sampler (not shown).

F) Lower Sampler to depth, Seat plastic trigger clip into ramp on Dock Ring.

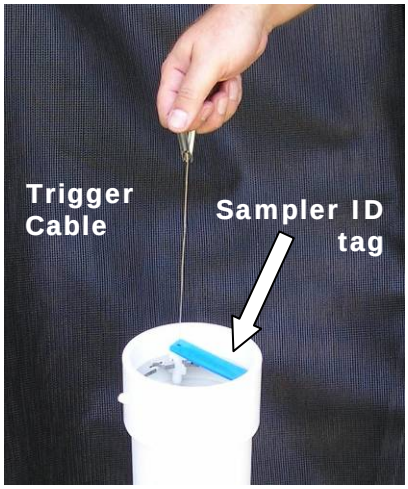
G) Close and lock well cap.

H) To sample, pull trigger cable while holding Dock Ring in place; remove trigger from dock and retrieve samplers.

WELL HEAD DOCK ATTACHMENT

(F) (G) (H)

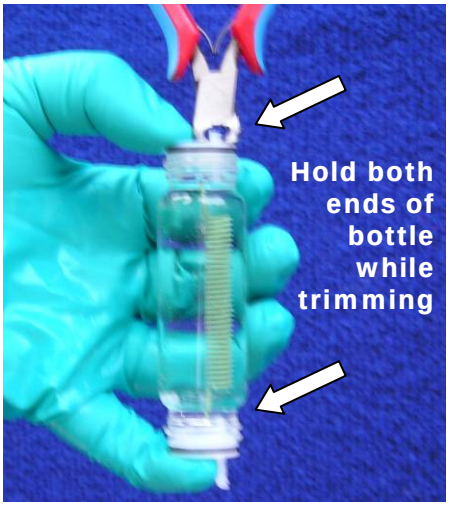
Slide trigger clip onto Dock Ring. Dock Ring ramp should point upward.



Snap Sampler Bottle Preparation
40 ml VOA

Trim Snap Caps

(A)



(B)

(C)

A) ***Snap Sampler VOA, removed from Snap Sampler.***

B) ***[<u>UNPRESERVED</u>] Carefully trim Snap Caps flush. To trim first Snap Cap, hold ends with finger and thumb while clipping--making sure not to dislodge seal. Carefully screw on first septa cap--making sure not to dislodge seal; trim second Snap Cap; screw on second septa cap, then retighten both septa caps to secure.***

C) ***Prepared, unpreserved bottle.***

D) ***[<u>PRESERVED</u>] After securing one end of the Snap VOA , trim the second Snap Cap; add preservative to the cavity in the Snap Cap.***

E) ***[<u>PRESERVED</u>] Pierce the Snap Cap membrane with the pointed end of the Driver Tool to allow preservative to mix with the sample; top off preservative to form a meniscus, then secure the second septa cap.***

F) ***Prepared, preserved bottle.***

Add Preservative (as required)

(D)

(E)

(F)

Snap Sampler Bottle Preparation
125 ml Poly

(For analytes where air exposure after collection is not a concern, Otherwise follow preparation procedure for 40 ml VOA on reverse)

Trim/Remove Snap Caps

(A)

(B)

(C)

A) Remove Snap POLY Bottle from Snap Sampler.

B) Trim one Snap Cap (see step "B" on reverse); secure septa cap lightly (you will remove it in step "E" below).

C) Invert bottle and remove second Snap Cap by hooking the internal Spring over the lip of the bottle.

D) Lift spring and release into the bottles; secure septa cap.

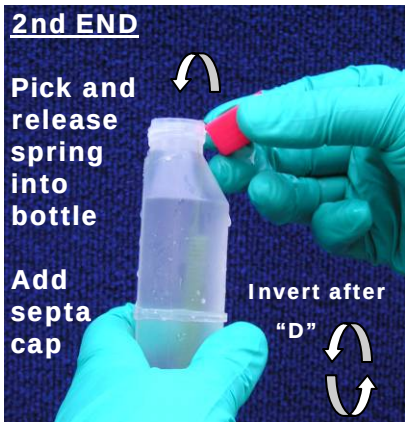
E) Re-invert the bottle; remove septa cap; remove the Snap Cap and spring.

F) Add preservative (if required), secure septa cap.

G) Prepared bottle

Remove spring

(D)



(E)

(F)

(G)

Notes on Snap Sampler™ Use:

Sometimes the Snap Sampler™ device doesn't "snap" correctly, which means that additional time will be spent resetting the Snap Sampler™ and returning to collect the sample.

It is possible that bubbles will form in the 40 mL vials when trying to place septa caps and snap caps on the vials.

It is recommended to order a few extra bottles, in the event that breakage occurs during shipment.

It is possible for the 125-mL polypropylene bottles to crack at the seam while deployed. It is advisable to check this prior to deploying the sampler.

Safety:

Inspect equipment setup prior to use, especially check for any broken, glass vials. When inserting the glass 40-mL vials into the sampler, be aware of finger placement. When placing the supplied driver into the concave side of the cap, use thumb and index finger and avoid placing fingers between the driver tool and sampler. Use the driver tool, not fingers to secure the ball fitting. Use the nipper tool carefully and be cautious of its sharpness; note that this is the correct tool for the task. Wear proper PPE including safety glasses when trimming the protruding caps. Potential hazards include pinch points and inappropriate use of supplied nipper tool. Relevant JSAs must be followed during sampling.

Kemmerer Well Sampler

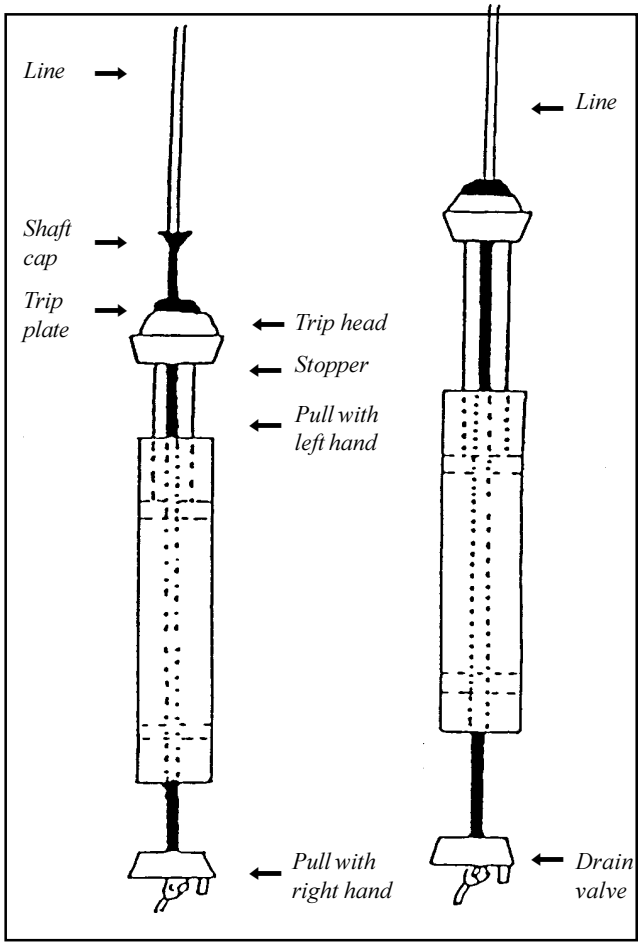
Wildlife Supply Company®

1280-A and 1280-B
Well Sampler Operating Instructions

Test before you sample!

We recommend that any new sampler be thoroughly cleaned prior to any sampling. In the event you are performing chemical sampling, before any sampling is done, first fill the sampler with distilled, contaminant-free water and test to determine what contaminants may be present in the sample.

We also recommend that this procedure be repeated throughout the sampling season.



Introduction:

The Kemmerer well sampler is lowered on a suitable line to a desired depth. Its patented trip automatically locks the stoppers open before lowering. Despite its ease of use, we recommend that you practice first in order to develop a good technique.

Call for advice with air drops greater than 30 feet (10 m). Well samplers are fragile and should be treated with care.

How to test your sampler before sampling:

- Run a line (or light chain) through the central tube and fasten securely below the lower stopper to prevent the line from being pulled back through the hole. Depending on the type of line used, tie or pin the line at the bottom of the sampler. We suggest using a washer or nut.
- To cock the sampler, pull the trip head into the trip plate. This is done by holding top and bottom stoppers and giving a short, hard pull to the bottom stopper. [Note: Bottom stopper must make watertight seal with main tube. Drain tube gasket must also make watertight seal.]
- A messenger is attached to the line. When the sampler is at the desired depth, release the messenger. This falls down the line and closes both the upper and lower stoppers. The stoppers seal by their own weight.

Note about contamination:

Samplers with blue seals may leach phosphorus and mercury and are not recommended for chemical sampling.

Safety:

To prevent personal injury, keep your hands clear of open ends of the main tube while the bottle is in the open position.

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Operation:

1. To set the sampler, pull the bottom stopper down until the shaft assembly snaps into the trip head.
2. If using a solid messenger, run a line through the messenger prior to attaching the line to the sampler. Attach the split messenger to the line once the sampler is at the desired depth.
3. We recommend using our 5 mm (3/16") braided polyester line, such as **62-C20**. The line should be run through the shaft assembly and secured by knotting it at the bottom of the sampler with a washer.
4. Lower the bottle down to the desired depth. Release the messenger to close the sampler. The stoppers seal by their own weight.

Important note: The maximum height a messenger should be dropped through the air is 30 feet (10m). Distances greater than this can damage the bottle.

Call 716-877-9518 for advice with air drops greater than 30 feet (10 m).

Do not use a messenger heavier than 8 oz! Damage to your sampler may result.

Well samplers are fragile and should be treated with extreme care.

Maintenance:

- Do not store sampler or net when wet, damp or dirty.
- When returned from sampling, rinse thoroughly to remove any soil, debris, chemicals and oils.
- Allow both sampler and case to air dry thoroughly before placing in storage.
- Mold, mildew, metal corrosion and plastic surface deterioration may occur if instruments or nets are stored wet and/or dirty.
- The foam interior and the case may be damaged or deteriorate if the product is not dried after use.
- Kemmerer end seals (stoppers) should not be sealed, seated or fully closed during storage. While end seals are made of tough elastomers, they all have a tendency to take a set under long periods of inactivity and stress. Store the Kemmerer bottle with the end seals slightly open and with the end seals sealing area not touching the outer cylinder.
- Before storing any water bottle, the entire bottle should be rinsed in fresh, clean water and allowed to completely air dry. When fully dry, store in its case or in a **dark, cool, dry** shelf or cabinet.

☑ Made to Order - this well sampler can be manufactured to your specifications. Please call our technical support team.

Warranty and Parts:

We replace all missing or defective parts free of charge. All products guaranteed free from defect in materials or workmanship for 90 days after date of shipment. This guarantee does not include accident, misuse, or normal wear and tear and applies to original purchaser only. **Made in U.S.A.**

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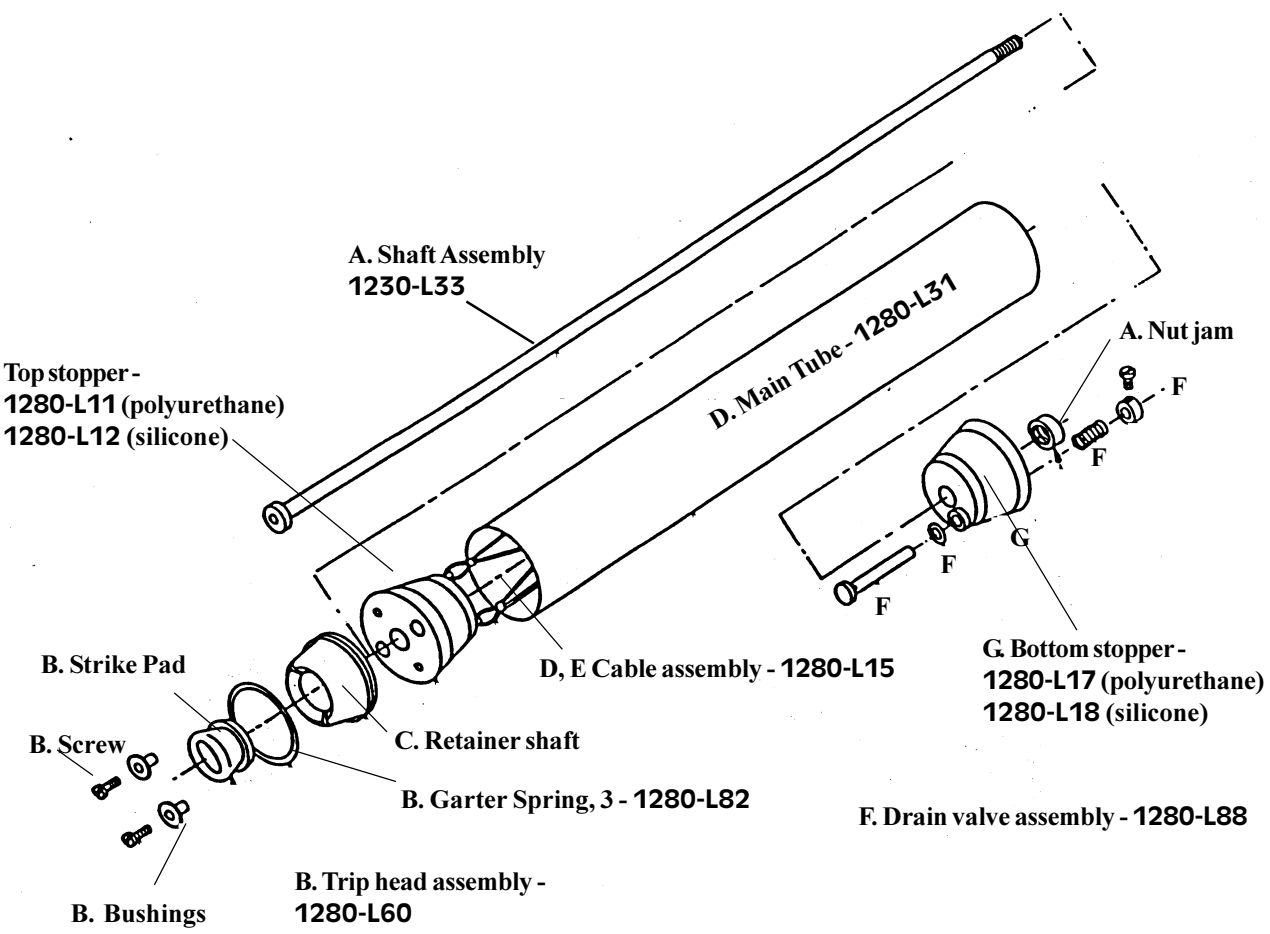

Part	Description	Part Number
A.	Shaft Assembly (shaft and nut)	1230-L33
B.	Trip head assembly	1280-L60
	2 screws, 2 bushings, strike pad, spring, retainer shaft	
C.	Top Stopper assembly, polyurethane	1280-L11
C.	Top Stopper, silicone	1280-L12
D.	Main tube assembly, stainless steel	1280-L31
E.	Cable assembly	1280-L15
F.	Drain valve	1280-L88
	Drain stem, washer, spring, ferrule with screw	
G.	Bottom Stopper, polyurethane	1280-L17
G.	Bottom stopper, silicone	1280-L18

Specifications for 1280-A12 and 1280-B22:

- Tube OD: 41 mm (1-5/8")
- Tube length: 606 mm (23-7/8")
- Takes 200', 3/16" diameter line (62-C20)
- Takes 46-D80 8 oz. messenger
- Choice of silicone or polyurethane end seals
- Volume: 0.6 L
- Takes carry case: 910-A25
- Tube material: Stainless steel

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Notes on Kemmerer Well Sampler Use:

Depending on how deep the well is, the combined buoyancy of the sampler (if plastic) and the polypropylene line can make it difficult to lower the sampler to the desired sampling depth. It is helpful to have a selection of stainless weights and a means to attach them to the bottom of the sampler to overcome this type of problem.

Use the heaviest messenger possible for a given sampler. If the messenger isn't heavy enough to trip the trigger to close the sampler, the sample will not be retrieved.

If there is any debris (leaves, sticks, bugs) in the water, it is possible that the debris will get stuck between the end seal and the sampler, allowing the water to run out of the sampler before you get it to the sample containers.

Safety: Inspect equipment setup prior to use. Use proper lifting techniques when moving equipment. Lift with legs and arms, not back (bend at knees, minimize twisting). When lifting, keep loads close to body, avoid twisting torso, and use legs, not back, to lift loads. Use two people if necessary; take breaks as needed. Wear safety glasses and gloves. Potential hazards include lifting hazards and muscle strain, and exposure to affected ground water. Relevant JSAs must be followed during sampling.

Passive Diffusion Bag (PDB)

Credit: U.S. Geological Survey

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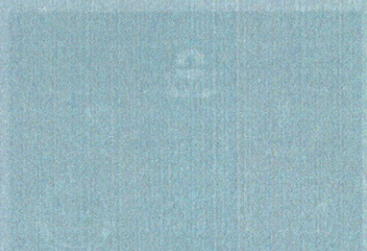
USER'S GUIDE FOR POLYETHYLENE-BASED PASSIVE DIFFUSION BAG SAMPLERS TO OBTAIN VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN WELLS

PART 1: DEPLOYMENT, RECOVERY, DATA INTERPRETATION, AND QUALITY CONTROL AND ASSURANCE

Water-Resources Investigations Report 01-4060



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User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells

Part 1: Deployment, Recovery, Data Interpretation, and Quality Control and Assurance

By Don A. Vroblesky

U.S. Geological Survey

Water-Resources Investigations Report 01–4060

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Table

1. Compounds tested under laboratory conditions for use with passive diffusion bag samplers 4

Conversion Factors, Vertical Datum, Acronyms, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09294	meter squared per day
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
inch per year (in/yr)	25.4	millimeter per year
	Volume	
gallon (gal)	3.785	liter

Temperature is given in degrees Celsius (°C), which can converted to degrees Fahrenheit (°F) by the following equation: °F = 9/5 (°C) + 32

Sea level refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentration in water is expressed in metric units as milligrams per liter (mg/L) or micrograms per liter (µg/L).

Additional Abbreviations	
EDB	1,2-Dibromomethane
AFCEE	Air Force Center for Environmental Excellence
*c*DCE	*cis*-1,2-Dibromoethene
ft^3/d	cubic feet per day
ft^3/mg	cubic feet per milligram
°C	degrees Celsius
g	gram
ITRC	Interstate Technology Regulatory Cooperation
LDPE	low-density polyethylene
L	liter
µg	microgram
µm	micrometer
µL	microliter
mg	milligram
mL	milliliter
mL/min	milliliter per minute
MTBE	Methyl-*tert*-butyl ether
NAVFAC	Naval Facilities Engineering Command
NAPL	non-aqueous phase liquid
PDB	passive diffusion bag
PCE	Tetrachloroethene
TCE	Trichloroethene
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOA	Volatile organic analysis
VOC	Volatile organic compound

User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells

Part 1: Deployment, Recovery, Data Interpretation, and Quality Control and Assurance

By Don A. Vroblesky

EXECUTIVE SUMMARY

Water-filled passive diffusion bag (PDB) samplers described in this report are suitable for obtaining concentrations of a variety of volatile organic compounds (VOCs) in ground water at monitoring wells. The suggested application of the method is for long-term monitoring of VOCs in ground-water wells at well-characterized sites.

The effectiveness of the use of a single PDB sampler in a well is dependent on the assumption that there is horizontal flow through the well screen and that the quality of the water is representative of the ground water in the aquifer directly adjacent to the screen. If there are vertical components of intra-bore-hole flow, multiple intervals of the formation contributing to flow, or varying concentrations of VOCs vertically within the screened or open interval, then a multiple deployment of PDB samplers within a well may be more appropriate for sampling the well.

A typical PDB sampler consists of a low-density polyethylene (LDPE) lay-flat tube closed at both ends and containing deionized water. The sampler is positioned at the target horizon of the well by attachment to a weighted line or fixed pipe.

The amount of time that the sampler should be left in the well prior to recovery depends on the time required by the PDB sampler to equilibrate with ambient water and the time required for the environmental disturbance caused by sampler deployment to return to ambient conditions. The rate that the water within the PDB sampler equilibrates with ambient water depends on multiple factors, including the type of compound being sampled and the water temperature. The concentrations of benzene, *cis*-1,2-dichloroethene, tetrachlorethene, trichloroethene, toluene, naphthalene, 1,2-dibromoethane, and total xylenes within the PDB samplers equilibrated with the concentrations in an aqueous mixture of those compounds surrounding the samplers under laboratory conditions within approximately 48 hours at 21 degrees Celsius (°C). A subsequent laboratory study of mixed VOCs at 10 °C showed that tetrachloroethene and trichloroethene were equilibrated by about 52 hours, but other compounds required longer equilabration times. Chloroethane, *cis*-1,2-dichloroethene, *trans*-1,2-dichloroethene, and 1,1-dichloroethene were not equilibrated at 52 hours, but appeared to be equilibrated by the next sampling point at 93 hours. Vinyl chloride, 1,1,1-trichloroethane, 1,2-dichloroethane, and 1,1-dichloroethane were not equilibrated at 93 hours, but were equilibrated by the next sampling point at 166 hours. Different equilibration times may exist for other compounds. Differences in equilibration times, if any, between single-solute or mixed VOC solutions have not yet been thoroughly examined.

The samplers should be left in place long enough for the well water, contaminant distribution, and flow dynamics to restabilize following sampler deployment. Laboratory and field data suggest that 2 weeks of equilibration probably is adequate for many applications; therefore, a minimum equilibration time of 2 weeks is suggested. In less permeable formations, longer equilibration times may be required. When applying PDB samplers in waters colder than previously tested (10 °C) or for compounds without sufficient corroborating data, a side-by-side comparison with conventional methodology is advisable to justify the field equilibration time.

Following the initial equilibration period, the samplers maintain equilibrium concentrations with the ambient water until recovery. Thus, there is no specified time for sampler recovery after initial equilibration. PDB samplers routinely have been left in ground waters having concentrations of greater than 500 parts per million (ppm) of trichloroethene for 3 months at a time with no loss of bag integrity, and at one site, the PDB samplers have been left in place in VOC-contaminated ground water for 1 year with no reported loss of sampler integrity. The effects of long-term (greater than 1 month) PDB-sampler deployment on sampler and sample integrity have not yet been thoroughly tested for a broad range of compounds and concentrations, however. Moreover, in some environments, development of a biofilm on the polyethylene may be a consequence of long-term deployment. Investigations of semipermeable membrane devices (SPMDs) have shown that the transfer of some compounds across a heavily biofouled polyethylene membrane may be reduced, but not stopped. If a heavy organic coating is observed on a PDB sampler, it is advisable to determine the integrity of the sample by comparison to a conventional sampling method before continuing to use PDB samplers for long-term deployment in that well.

Recovery consists of removing the samplers from the well and immediately transferring the enclosed water to 40-milliliter sampling vials for analysis. The resulting concentrations represent an integration of chemical changes over the most recent portion of the equilibration period (approximately 48 to 166 hours, depending on the water temperature and the type of compound).

The method has both advantages and limitations when compared to other sampling methods. Advantages include the potential for PDB samplers to eliminate or substantially reduce the amount of purge water associated with sampling. The samplers are relatively inexpensive and easy to deploy and recover. Because PDB samplers are disposable, there is no downhole equipment to be decontaminated between wells, and there is a minimum amount of field equipment required. The samplers also have the potential to delineate contaminant stratification in the formation across the open or screened intervals of monitoring wells where vertical hydraulic gradients are not present. In addition, the samplers integrate concentrations over time, which may range between about 48 to 166 hours depending on the compound of interest. Because the pore size of LDPE is only about 10 angstroms or less, sediment does not pass through the membrane into the bag. Thus, PDB samplers are not subject to interferences from turbidity. In addition, none of the data collected suggest that VOCs leach from the LDPE material, or that there is a detrimental effect on the VOC sample from the PDB material.

Water-filled polyethylene PDB samplers are not appropriate for all compounds. The samplers are not suitable for inorganic ions and have a limited applicability for non-VOCs and for some VOCs. For example, although methyl-*tert*-butyl ether and acetone and most semivolatile compounds are transmitted through the polyethylene bag, laboratory tests have shown that the resulting concentrations were lower than in ambient water. A variety of factors influence the ability of compounds to diffuse through the polyethylene. These factors include the molecular size and shape and the hydrophobic nature of the compound. Unpublished laboratory test data of semivolatile compounds in contact with PDB samplers showed a higher concentration of phthalates inside the PDB sampler than outside the PDB sampler, suggesting that the polyethylene may contribute phthalates to the enclosed water. Thus, the samplers should not be used to sample for phthalates.

VOC concentrations in PDB samplers represent concentrations in the vicinity of the sampler within the well screen or open interval. This may be a limitation for PDB samplers and some other types of sampling, such as low-flow sampling, if the ground-water contamination is above or below the screen or not in the sample intervals providing water movement to the PDB samplers. If there is a vertical hydraulic gradient in the well, then the concentrations in the sampler may represent the concentrations in the water flowing vertically past the sampler rather than in the formation directly adjacent to the sampler. Vertically spaced multiple PDB samplers may be needed in chemically stratified wells or where flow patterns through the screen change as a result of ground-water pumping or seasonal water-level fluctuations.

The purposes of this document are to present methods for PDB sampler deployment, and recovery; to discuss approaches to determine the applicability of passive diffusion samplers; and to discuss various factors influencing interpretation of the data. The intended audience for the methodology sections of this report is managers and field personnel involved in using PDB samplers. The discussion of passive diffusion sampler applicability and interpretation of the data is

suited for project managers, technical personnel, and the regulatory community. Part 2 of this report presents case studies of PDB sampler field applications.

INTRODUCTION

The use of PDB samplers for collecting ground-water samples from wells offers a cost-effective approach to long-term monitoring of VOCs at well-characterized sites (Vroblesky and Hyde, 1997; Gefell and others, 1999). The effectiveness of the use of a single PDB sampler in a well is dependent on the assumption that there is horizontal flow through the well screen and that the quality of the water is representative of the ground water in the aquifer directly adjacent to the screen. If there are vertical components of intra-borehole flow, multiple intervals of the formation contributing to flow, or varying concentrations of VOCs vertically within the screened or open interval, then deployment of multiple PDB samplers within a well may be more appropriate for sampling the well.

The samplers consist of deionized water enclosed in a LDPE sleeve (fig. 1) and are deployed adjacent to a target horizon within a screened or open interval of a well. The suggested application is for long-term monitoring of VOCs in ground-water wells. Where the screened interval is greater than 10 feet (ft), the potential for contaminant stratification and/or intra-borehole flow within the screened interval is greater than in screened intervals shorter than 10 ft. It is important that the vertical distribution of contaminants be determined in wells having 10-ft-long well screens, and that both the vertical distribution of contaminants and the potential for intra-borehole flow be determined in wells having screens longer than 10 ft. For many VOCs of environmental interest (table 1), the VOC concentration in water within the sampler approaches the VOC concentration in water outside of the PDB sampler over an equilibration period. The resulting concentrations represent an integration of chemical changes over the most recent part of the equilibration period (approximately 48 to 166 hours, depending on the water temperature and the type of compound being sampled). The approach is inexpensive and has the potential to eliminate or substantially reduce the amount of purge water removed from the well.

A variety of PDB samplers have been utilized in well applications (fig. 1). Although the samplers vary in specific construction details, a typical PDB sampler consists of a 1- to 2-ft-long LDPE tube closed at both ends and containing laboratory-grade deionized water (fig. 1). The typical diameter for PDB samplers used in a 2-inch-diameter well is approximately 1.2 inches; however, other dimensions may be used to match the well diameter. Equilibration times may be longer for larger diameter PDB samplers. On the outside of the PDB sampler, a low-density polyethylene-mesh sometimes is used for protection against abrasion in open boreholes and as a means of attachment at the prescribed depth. The PDB sampler can be positioned at the target horizon by attachment to a weighted line or by attachment to a fixed pipe.

PDB samplers for use in wells are available commercially. Authorized distributors as of March 2001 are Columbia Analytical Services (800-695-7222; www@caslab.com) and Eon Products (800-474-2490; www.eonpro.com). A current list of vendors and PDB-sampler construction details can be obtained from the U.S. Geological Survey Technology Transfer Enterprise Office, Mail Stop 211, National Center, 12201 Sunrise Valley Drive, Reston, Virginia 20192 (telephone 703-648-4344; fax 703-648-4408). PDB samplers employ patented technology (U.S. patent number 5,804,743), and therefore, require that the user purchase commercially produced samplers from a licensed manufacturer or purchase a nonexclusive license for sampler construction from the U.S. Geological Survey Technology Enterprise Office at the above address.

The purposes of this document are to present methods for PDB sampler deployment, and recovery; to discuss approaches for determining the applicability of passive diffusion samplers; and to discuss various factors influencing interpretation of the data. The intended audience for the methodology sections of this report is managers and field personnel involved in using PDB samplers. The discussion of PDB sampler applicability and interpretation of the data is suited for project managers, technical personnel, and the regulatory community. Part 2 of this report presents case studies of PDB-sampler field applications.

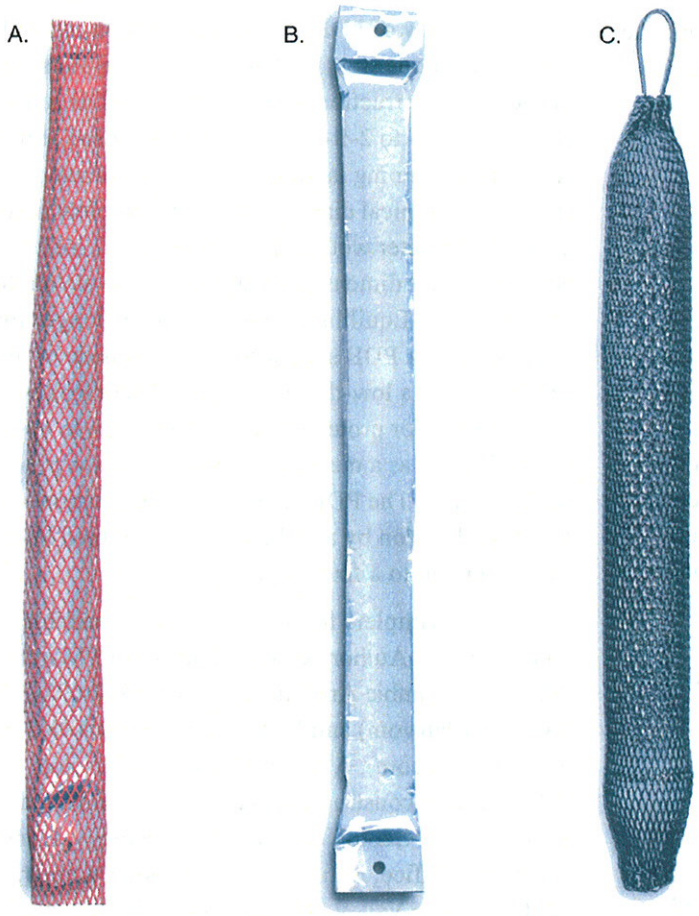

Figure 1. Typical water-filled passive diffusion bag samplers used in wells, including (A) diffusion bag with polyethylene mesh, (B) diffusion bag without mesh, and (C) bag and mesh attached to bailer bottom.

Table 1. Compounds tested under laboratory conditions for use with passive diffusion bag samplers
[From Vroblesky and Campbell, 2001]

Tested compounds showing good correlation (average differences in concentration of 11 percent or less between diffusion-sampler water and test-vessel water) in laboratory tests			
Benzene	2 Chlorovinyl ether	*cis*-1,2-Dichloroethene	1,1,1-Trichloroethane
Bromodichloromethane	Dibromochloromethane	*trans*-1,2-Dichloroethene	1,1,2-Trichloroethane
Bromoform	Dibromomethane	1,2-Dichloropropane	Trichloroethene
Chlorobenzene	1,2-Dichlorobenzene	*cis*-Dichloropropene	Trichlorofluoromethane
Carbon tetrachloride	1,3-Dichlorobenzene	1,2-Dibromoethane	1,2,3-Trichloropropane
Chloroethane	1,4-Dichlorobenzene	*trans*-1,3-Dichloropropene	1,1,2,2-Tetrachloroethane
Chloroform	Dichlorodifluoromethane	Ethyl benzene	Tetrachloroethene
Chloromethane	1,2-Dichloroethane	Naphthalene	Vinyl chloride
	1,1-Dichloroethene	Toluene	Total xylenes
Tested compounds showing poor correlation (average differences in concentration greater than 20 percent between diffusion-sampler water and test-vessel water) in laboratory tests			
Acetone*	Methyl-*tert*-butyl ether	Styrene	

*T.M Sivavec and S.S. Baghel, General Electric Company, written commun., 2000

Summary of Passive Diffusion Bag Sampler Advantages and Limitations

Advantages

1. PDB samplers have the potential to eliminate or substantially reduce the amount of purge water associated with sampling.

2. PDB samplers are inexpensive.

3. The samplers are easy to deploy and recover.

4. Because PDB samplers are disposable, there is no downhole equipment to be decontaminated between wells.

5. A minimal amount of field equipment is required.

6. Sampler recovery is rapid. Because of the small amount of time and equipment required for the sampling event, the method is practical for use where access is a problem or where discretion is desirable (that is, residential communities, business districts, or busy streets where vehicle traffic control is a concern).

7. Multiple PDB samplers, distributed vertically along the screened or open interval, may be used in conjunction with borehole flow meter testing to gain insight on the movement of contaminants into and out of the well screen or open interval or to locate the zone of highest concentration in the well. Analytical costs when using multiple PDB samplers sometimes can be reduced by selecting a limited number of the samplers for laboratory analysis based on screening by using field gas chromatography at the time of sample collection.

8. Because the pore size of LDPE is only about 10 angstroms or less, sediment does not pass through the membrane into the bag. Thus, PDB samplers are not subject to interferences from turbidity. In addition, none of the data collected suggest that VOCs leach from the LDPE material or that there is a detrimental effect from the PDB material on the VOC sample.

Limitations

1. PDB samplers integrate concentrations over time. This may be a limitation if the goal of sampling is to collect a representative sample at a point in time in an aquifer where VOC-concentrations substantially change more rapidly than the samplers equilibrate. Laboratory results obtained indicate that a variety of compounds equilibrated within 48 hours at 21 °C (Vroblesky and Campbell, 2001). Vinyl chloride, 1,1,1-trichloroethane, 1,2-dichloroethane, and 1,1-dichloroethane may require between 93 and 166 hours to equilibrate at 10 °C (T.M. Sivavec and S.S. Baghel, General Electric Company, written commun., 2000). The initial equilibration under field conditions may be longer to allow well water, contaminant distribution, and flow dynamics to restabilize following sampler deployment.

2. Water-filled polyethylene PDB samplers are not appropriate for all compounds. For example, although methyl-*tert*-butyl ether and acetone (Vroblesky, 2000; Paul Hare, General Electric Company, oral commun., 2000) and most semivolatile compounds are transmitted through the polyethylene bag, laboratory tests have shown that the resulting concentrations were lower than in ambient water. A variety of factors influence the ability of compounds to diffuse through the polyethylene membrane. These factors include the molecular size and shape and the hydrophobic nature of the compound. Compounds having a cross-sectional diameter of about 10 angstroms or larger (such as humic acids) do not pass through the polyethylene because the largest (transient) pores in polyethylene do not exceed about 10 angstroms in diameter (Flynn and Yalkowsky, 1972; Hwang and Kammermeyer, 1975; Comyn, 1985). The samplers are not appropriate for hydrophilic polar molecules, such as inorganic ions. A detailed discussion of the relation between hydrophobicity and compound transport through polyethylene can be found in Gale (1998). Unpublished laboratory test data (D.A. Vroblesky, U.S. Geological Survey, written commun., 1998) of semivolatile compounds in contact with PDB samplers showed a higher concentration of phthalates inside the PDB sampler than outside the PDB sampler, suggesting that the polyethylene may contribute phthalates to the enclosed water. Thus, the samplers should not be used to sample for phthalates.

3. PDB samplers rely on the free movement of water through the well screen. In situations where ground water flows horizontally through the well screen, the VOC concentrations in the open interval of the well probably are representative of the aquifer water in the adjacent formation (Gillham and others, 1985; Robin and Gillham, 1987; Kearl and others, 1992; Powell and Puls, 1993; Vroblesky and Hyde, 1997). In these situations, the VOC concentration of the water in contact with the PDB samplers, and therefore, the water within the diffusion samplers, probably represents local conditions in the adjacent aquifer. However, if the well screen is less permeable than the aquifer or the sandpack, then under ambient conditions, flowlines may be diverted around the screen. Such a situation may arise from inadequate well development or from iron bacterial fouling of the well screen. In this case, the VOC concentrations in the PDB samplers may not represent concentrations in

the formation water because of inadequate exchange across the well screen. PDB samplers have not yet been adequately tested to determine their response under such conditions.

4. VOC concentrations in PDB samplers represent ground-water concentrations in the vicinity of the screened or open well interval that move to the sampler under ambient flow conditions. This is a limitation if the ground-water contamination lies above or below the well screen or open interval, and requires the operation of a pump to conduct contaminants into the well for sampling.

5. In cases where the well screen or open interval transects zones of differing hydraulic head and variable contaminant concentrations, VOC concentrations obtained using a PDB sampler may not reflect the concentrations in the aquifer directly adjacent to the sampler because of vertical transport in the well. However, a vertical array of PDB samplers, used in conjunction with borehole flow meter testing, can provide insight on the movement of contaminants into or out of the well. This information then can be used to help determine if the use of PDB samplers is appropriate for the well, and to select the optimal vertical location(s) for the sampler deployment.

6. In wells with screens or open intervals with stratified chemical concentrations, the use of a single PDB sampler set at an arbitrary (by convention) depth may not provide accurate concentration values for the most contaminated zone. However, multiple PDB samplers distributed vertically along the screened or open interval, in conjunction with pump sampling (as appropriate), can be used to locate zone(s) of highest concentration in the well. Multiple PDB samplers also may be needed to track the zone of maximum concentration in wells where flow patterns through the screened interval change as a result of ground-water pumping or seasonal water-table fluctuations.

PASSIVE DIFFUSION BAG SAMPLER DEPLOYMENT

A variety of approaches can be used to deploy the PDB samplers in wells. A typical deployment approach, described in this section, is to attach the PDB samplers to a weighted line. It also is acceptable to attach the weights directly to the PDB sampler if the attachment point is of sufficient strength to support the weight. The weights attached to the bottom of the line are stainless steel and can be reused, but must be thoroughly decontaminated with a detergent before the first use or before using in a different well. Rope, such as 90 pound, 3/16 inch braided polyester, can be used as the line for single-use applications if it is of sufficient strength to support the weight and sampler, is nonbuoyant, and is subject to minimal stretch; however, the rope should not be reused because of the high potential for cross contamination. Stainless-steel or Teflon-coated stainless-steel wire is preferable. The weighted lines should not be reused in different wells to prevent carryover of contaminants. A possible exception is coated stainless-steel wire, which can be reused after sufficient decontamination. An alternative deployment approach, not discussed in this section, is to attach the PDB samplers to a fixed pipe in the well (Vroblesky and Peters, 2000, p. 3; also included in Part 2 of this publication). The PDB samplers should not contact non-aqueous phase liquid (NAPL) during deployment or retrieval to prevent cross contamination. An approach that can be utilized to deploy diffusion samplers through a layer of floating NAPL is described in the field test at Naval Station North Island, California (Vroblesky and Peters, 2000, p. 3-4; also included in Part 2 of this publication).

If the PDB sampler is to be compared with a conventional pumping approach to sampling, then it is suggested that both the pump and the PDB sampler be deployed at the same time, with the sampler attached near (such as directly below) the pump inlet. This approach eliminates potential concentration differences between the two methods that may result from well disturbance during equipment removal and deployment at the time of sampling. An alternative method is to deploy the PDB samplers independently of the pumps and recover the samplers immediately prior to placing the pump down the well.

PDB samplers are available either prefilled (field ready) with laboratory-grade deionized water or unfilled. The unfilled samplers are equipped with a plug and funnel to allow for field filling and sample recovery. To fill these samplers, remove the plug from the sampler bottom, insert the short funnel into the sampler, and pour laboratory-grade deionized water into the sampler. The sampler should be filled until water rises and stands at least half way into the funnel. Remove excess bubbles from the sampler. Remove the funnel and reattach the plug. A small air bubble from the plug is of no concern.

The following steps should be used for deploying PDB samplers in wells:

1. Measure the well depth and compare the measured depth with the reported depth to the bottom of the well screen from well-construction records. This is to check on whether sediment has accumulated in the bottom of the well, whether there is a nonscreened section of pipe (sediment sump) below the well screen, and on the accuracy of well-construction records. If there is an uncertainty regarding length or placement of the well screen, then an independent method, such as video imaging of the well bore, is strongly suggested.

2. Attach a stainless-steel weight to the end of the line. Sufficient weight should be added to counterbalance the buoyancy of the PDB samplers. This is particularly important when multiple PDB samplers are deployed. One approach, discussed in the following paragraphs, is to have the weight resting on the bottom of the well, with the line taut above the weight. Alternatively, the PDB sampler and weight may be suspended above the bottom, but caution should be exercised to ensure that the sampler does not shift location. Such shifting can result from stretching or slipping of the line or, if multiple samplers are attached end-to-end rather than to a weighted line, stretching of the samplers.

3. Calculate the distance from the bottom of the well, or top of the sediment in the well, up to the point where the PDB sampler is to be placed. A variety of approaches can be used to attach the PDB sampler to the weight or weighted line at the target horizon. The field-fillable type of PDB sampler is equipped with a hanger assembly and weight that can be slid over the sampler body until it rests securely near the bottom of the sampler. When this approach is used with multiple PDB samplers down the same borehole, the weight should only be attached to the lowermost sampler. An additional option is to use coated stainless-steel wire as a weighted line, making loops at appropriate points to attach the upper and lower ends of PDB samplers. Where the PDB sampler position varies between sampling events, movable clamps with rings can be used. When using rope as a weighted line, a simple approach is to tie knots or attach clasps at the appropriate depths. Nylon cable ties or stainless-steel clips inserted through the knots can be used to attach the PDB samplers. An approach using rope as a weighted line with knots tied at the appropriate sampler-attachment points is discussed below.

(a) For 5-ft-long or shorter well screens, the center point of the PDB sampler should be the vertical midpoint of the saturated well-screen length. For example, if the well screen is at a depth of 55 to 60 ft below the top of casing, and the measured depth of the well is 59 ft, then the bottom of the well probably has filled with sediment. In this case, the midpoint of the sampler between the attachment points on the line will be midway between 55 and 59 ft, or at 57 ft. Thus, for a 1.5-ft-long sampler, the attachment points on a weighted line should be tied at distances of 1.25 ft (2 ft – 0.75 ft) and 2.75 ft (2 ft + 0.75 ft) from the top of the sediment in the well, or the bottom of the well, making adjustments for the length of the attached weight. When the PDB sampler is attached to the line and installed in the well, the center of the sampler will be at 57-ft depth. If, however, independent evidence is available showing that the highest concentration of contaminants enters the well from a specific zone within the screened interval, then the PDB sampler should be positioned at that interval.

(b) For 5- to 10-ft-long well screens, it is advisable to utilize multiple PDB samplers vertically along the length of the well screen for at least the initial sampling (fig. 2). The purposes of the multiple PDB samplers are to determine whether contaminant stratification is present and to locate the zone of highest concentration. The midpoint of each sampler should be positioned at the midpoint of the interval to be sampled. For 1.5-ft-long samplers, at each sampling depth in the screened interval, make two attachment points on the weighted line at a distance of about 1.5 ft apart. The attachment points should be positioned along the weighted line at a distance from the bottom end of the weight such that the midpoint between the knots will be at the desired sampling depth along the well screen. Sampler intervals are variable, but a simple approach is to use the top knot/loop of one sampler interval as the bottom knot/loop for the overlying sampler interval.

Figure 2. Example of multiple PDB samplers prepared for deployment.

(c) PDB samplers should not be used in wells having screened or open intervals longer than 10 ft unless used in conjunction with borehole flow meters or other techniques to characterize vertical variability in hydraulic conductivity and contaminant distribution or used strictly for qualitative reconnaissance purposes. This is because of the increased potential for cross contamination of water-bearing zones and hydraulically driven mixing effects that may cause the contaminant stratification in the well to differ from the contaminant stratification in the adjacent aquifer material. If it is necessary to sample such wells, then multiple PDB samplers should be installed vertically across the screened or open interval to determine the zone of highest concentration and whether contaminant stratification is present.

4. The samplers should be attached to the weights or weighted line at the time of deployment. For samplers utilizing the hanger and weight assembly, the line can be attached directly to the top of the sampler. PDB samplers utilizing an outer protective mesh can be attached to a weighted line by using the following procedure:

(a) Insert cable ties through the attachment points in the weighted line.

(b) At each end of the PDB sampler, weave the ends of the cable ties or clamp through the LPDE mesh surrounding the sampler and tighten the cable ties. Thus, each end of the PDB sampler will be attached to a knot/loop in the weighted line by means of a cable tie or clamp. The cable ties or clamps should be positioned through the polyethylene mesh in a way that prevents the PDB sampler from sliding out of the mesh.

(c) Trim the excess from the cable tie before placing the sampler down the well. Caution should be exercised to prevent sharp edges on the trimmed cable ties that may puncture the LDPE.

5. When using PDB samplers without the protective outer mesh, the holes punched at the ends of the bag, outside the sealed portion, can be used to attach the samplers to the weighted line. Stainless-steel spring clips have been found to be more reliable than cable ties in this instance, but cable ties also work well.

6. Lower the weight and weighted line down the well until the weight rests on the bottom of the well and the line above the weight is taut. The PDB samplers should now be positioned at the expected depth. A check on the depth can be done by placing a knot or mark on the line at the correct distance from the top knot/loop of the PDB sampler to the top of the well casing and checking to make sure that the mark aligns with the lip of the casing after deployment.

7. Secure the assembly in this position. A suggested method is to attach the weighted line to a hook on the inside of the well cap. Reattach the well cap. The well should be sealed in such a way as to prevent surface-water invasion. This is particularly important in flush-mounted well vaults that are prone to flooding.

8. Allow the system to remain undisturbed as the PDB samplers equilibrate.

PASSIVE DIFFUSION BAG SAMPLER AND SAMPLE RECOVERY

The amount of time that the samplers should be left in the well prior to recovery depends on the time required by the PDB sampler to equilibrate with ambient water and the time required for environmental disturbances caused by sampler deployment to return to ambient conditions. The rate that the water within the PDB sampler equilibrates with ambient water depends on multiple factors, including the type of compound being sampled and the water temperature. The concentrations of benzene, *cis*-1,2-dichloroethene (*c*DCE), tetrachlorethene (PCE), trichloroethene (TCE), toluene, naphthalene, 1,2-dibromoethane (EDB), and total xylenes within the PDB samplers equilibrated with the concentrations in an aqueous mixture of those compounds surrounding the samplers under laboratory conditions within approximately 48 hours at 21 °C (Vroblesky and Campbell, 2001). A subsequent laboratory study of mixed VOCs at 10 °C showed that PCE and TCE were equilibrated by about 52 hours, but other compounds required longer equilibration times (T.M. Sivavec and S.S. Baghel, General Electric Company, written commun., 2000). Chloroethane, *c*DCE, *trans*-1,2-dichloroethene, and 1,1-dichloroethene were not equilibrated at 52 hours, but appeared to be equilibrated by the next sampling point at 93 hours. Vinyl chloride, 1,1,1-trichloroethane, 1,2-dichloroethane, and 1,1-dichloroethane were not equilibrated at 93 hours, but were equilibrated by the next sampling point at 166 hours. Different equilibration times may exist for other compounds. Differences in equilibration times, if any, between single-solute or mixed-VOC solutions have not yet been thoroughly examined.

Under field conditions, the samplers should be left in place long enough for the well water, contaminant distribution, and flow dynamics to restabilize following sampler deployment. The results of borehole dilution studies show that wells can recover to 90 percent of the predisturbance conditions within minutes to several hours for permeable to highly permeable geologic formations, but may require 100 to 1,000 hours (4 to 40 days) in muds, very fine-grained loamy sands, and fractured rock, and may take even longer in fractured shales, recent loams, clays, and slightly fractured solid igneous rocks (Halevy and others, 1967).

In general, where the rate of ground-water movement past a diffusion sampler is high, equilibration times through various membranes commonly range from a few hours to a few days (Mayer, 1976; Harrington and others, 2000). One field investigation showed adequate equilibration of PDB samplers to aquifer trichloroethene (TCE) and carbon tetrachloride (CT) concentrations within 2 days in a highly permeable aquifer (Vroblesky and others, 1999). In other investigations, PDB samplers recovered after 14 days were found to be adequately equilibrated to chlorinated VOCs (Obrien & Gere Engineers, Inc., 1997a, 1997b; Hare, 2000); therefore, the equilibration period was less than or equal to 14 days for those field conditions. Because it appears that 2 weeks of equilibration probably is adequate for many applications, a minimum equilibration time of 2 weeks is suggested. When applying PDB samplers in waters colder than previously tested (10 °C) or for compounds without sufficient corroborating field data, a side-by-side comparison with conventional sampling methodology is advisable to justify the field equilibration time.

In less permeable formations, longer equilibration times may be required. It is probable that water in the well bore eventually will equilibrate with the pore-water chemistry; however, if the rate of chemical change or volatilization loss in the well bore exceeds the rate of exchange between the pore water and the well-bore water, then the PDB samplers may under-

estimate pore-water concentrations. Guidelines for equilibration times and applicability of PDB samplers in low-permeability formations have not yet been established. Therefore, in such situations, a side-by-side comparison of PDB samplers and conventional sampling methodology is advisable to ensure that the PDB samplers do not underestimate concentrations obtained by the conventional method. A detailed discussion of diffusion rates relevant to diffusion sampler equilibrium in slow-moving ground-water systems can be found in Harrington and others (2000).

Following the initial equilibration period, the samplers maintain equilibrium concentrations with the ambient water until recovery. Thus, there is no specified maximum time for sampler recovery. PDB samplers have routinely been left in ground waters having concentrations of greater than 500 ppm of TCE for 3 months at a time with no loss of bag integrity, and at one site, the PDB samplers have been left in place in VOC-contaminated ground water for 1 year with no reported loss of sampler integrity (Paul Hare, General Electric Company, oral commun., 2000). The effects of long-term (greater than 1 month) PDB-sampler deployment on sampler and sample integrity have not yet been thoroughly tested for a broad range of compounds and concentrations. Moreover, in some environments, development of a biofilm on the polyethylene may be a consequence of long-term deployment. Investigations of semipermeable membrane devices (SPMDs) have shown that the transfer of some compounds may be reduced, but not stopped, across a heavily biofouled polyethylene membrane (Ellis and others, 1995; Huckins and others, 1996; Huckins and others, in press). If a heavy organic coating is observed on a PDB sampler, it is advisable to determine the integrity of the sample by comparing contaminant concentrations from the PDB sampler to concentrations from a conventional sampling method before continuing to use PDB samplers for long-term deployment in that well.

Recovery of PDB samplers is accomplished by using the following approach:

1. Remove the PDB samplers from the well by using the attached line. The PDB samplers should not be exposed to heat or agitated.

2. Examine the surface of the PDB sampler for evidence of algae, iron or other coatings, and for tears in the membrane. Note the observations in a sampling field book. If there are tears in the membrane, the sample should be rejected. If there is evidence that the PDB sampler exhibits a coating, then this should be noted in the validated concentration data.

3. Detach and remove the PDB sampler from the weighted line. Remove the excess liquid from the exterior of the bag to minimize the potential for cross contamination.

4. A variety of approaches may be used to transfer the water from the PDB samplers to 40-mL volatile organic analysis (VOA) vials. One type of commercially available PDB sampler provides a discharge device that can be inserted into the sampler. If discharge devices are used, the diameter of the opening should be kept to less than about 0.15 inches to reduce volatilization loss. Two options are presently available to recover water from the sample using discharge devices. One option involves removing the hanger and weight assembly from the sampler, inverting the sampler so that the fill plug is pointed upward, and removing the plug. The water can be recovered by directly pouring in a manner that minimizes agitation or by pouring through a VOC-discharge accessory inserted in place of the plug. The second approach involves piercing the sampler near the bottom with a small-diameter discharge tube and allowing water to flow through the tube into the VOA vials. In each case, flow rates can be controlled by tilting or manipulating the sampler. Alternatively, the PDB sampler can be cut open at one end using scissors or other cutting devices which have been decontaminated between use for different wells. Water can then be transferred to 40-ml VOA vials by gently pouring in a manner that minimizes water agitation. Acceptable duplication has been obtained using each method. Preserve the samples according to the analytical method. The sampling vials should be stored at approximately 4 °C in accordance with standard sampling protocol. Laboratory testing suggests that there is no substantial change in the VOC concentrations in PDB samplers over the first several minutes after recovery; however, the water should be transferred from the water-filled samplers to the sample bottles immediately upon recovery.

5. A cost-effective alternative when using multiple PDB samplers in a single well is to field screen water from each sampler using gas chromatography. These results can be used to decide which of the multiple PDB samplers should be sent to an EPA-approved laboratory for standard analysis. Typically, at least the sample containing the highest concentration should be analyzed by a laboratory.

6. If a comparison is being made between concentrations obtained using PDB samplers and concentrations obtained using a conventional sampling approach, then the well should be sampled by the conventional approach soon after (preferably on the same day) recovery of the PDB sampler. The water samples obtained using PDB samplers should be sent in the same shipment, as the samples collected by the conventional approach for the respective wells. Utilizing the same laboratory may reduce analytical variability.

7. Any unused water from the PDB sampler and water used to decontaminate cutting devices should be disposed in accordance with local, state, and Federal regulations.

DETERMINING APPLICABILITY OF PASSIVE DIFFUSION BAG SAMPLERS AND INTERPRETATION OF DATA

When attempting to determine whether the use of PDB samplers is appropriate at a particular well, a common approach is to do a side-by-side comparison with a conventional sampling method during the same sampling event. This approach is strongly suggested in wells having temporal concentration variability. In a well having relatively low temporal concentration variability, comparison of the PDB-sampler results to historical concentrations may provide enough information to determine whether the PDB samplers are appropriate for the well. In general, if both PDB and conventional sampling produce concentrations that agree within a range deemed acceptable by local, state, and Federal regulatory agencies and meet the site-specific data-quality objectives, then a PDB sampler may be approved for use in that well to monitor ambient VOC concentrations. If concentrations from the PDB sampler are higher than concentrations from the conventional method, it is probable that concentrations from the PDB sampler adequately represent ambient conditions because there usually is a greater potential for dilution from mixing during sampling using conventional methods than during sampling using PDB samplers.

If, however, the conventional method produces concentrations that are significantly higher than those obtained using the PDB sampler, then it is uncertain whether the PDB-sampler concentrations represent local ambient conditions. In this case, further testing can be done to determine whether contaminant stratification and/or intra-borehole flow is present. Multiple sampling devices can be used to determine the presence of contaminant stratification, and borehole flowmeters can be used to determine whether intra-borehole flow is present. When using flowmeters to measure vertical flow in screened boreholes, however, the data should be considered qualitative because of the potential for water movement through the sand pack. Borehole dilution tests (Halevy and others, 1967; Drost and others, 1968; Grisak and others, 1977; Palmer, 1993) can be used to determine whether water is freely exchanged between the aquifer and the well screen.

Once the source of the difference between the two methods is determined, a decision can be made regarding the well-specific utility of the PDB samplers. Tests may show that VOC concentrations from the PDB samplers adequately represent local ambient conditions within the screened interval despite the higher VOC concentration obtained from the conventional method. This may be because the pumped samples incorporated water containing higher concentrations either from other water-bearing zones induced along inadequate well seals or through fractured clay (Vroblesky and others, 2000), from other water-bearing zones not directly adjacent to the well screen as a result of well purging prior to sampling (Vroblesky and Petkewich; 2000), or from mixing of chemically stratified zones in the vicinity of the screened interval (Vroblesky and Peters, 2000).

The mixing of waters from chemically stratified zones adjacent to the screened interval during pumping probably is one of the more important sources of apparent differences between the results obtained from PDB sampling and conventional sampling because such stratification probably is common. Vertical stratification of VOCs over distances of a few feet has been observed in aquifer sediments by using multilevel sampling devices (Dean and others, 1999; Pitkin and others, 1999), and considerable variation in hydraulic conductivity and water chemistry has been observed in an aquifer in Cape Cod, Massachusetts, on the scale of centimeters (Wolf and others, 1991; Smith and others 1991; Hess and others, 1992). Multiple PDB samplers have been used to show a change in TCE concentration of 1,130 (µg/L over a 6-ft vertical screened interval in Minnesota (Vroblesky and Petkewich, 2000). Tests using PDB samplers in screened intervals containing VOC stratification showed that the PDB-sampler data appeared to be point-specific, whereas the pumped sample integrated water over a larger interval (Vroblesky and Peters, 2000).

The decision on whether to use PDB samplers in such situations depends on the data-quality objectives for the particular site. If the goal is to determine and monitor higher concentrations or to examine contaminant stratification within the screened interval, then the PDB samplers may meet this objective. If the goal is to determine the average concentrations for the entire screened interval, then a pumped sample or an average from multiple diffusion samplers may be appropriate.

As an aid in the decision-making process, the following section examines the influences that hydraulic and chemical heterogeneity of an aquifer can have on sample quality in long-screened wells. Because VOC concentrations from PDB samplers commonly are compared to VOC concentrations from other sampling methodologies, the second section examines the differences in sample quality between these methodologies in situations of hydraulic and chemical heterogeneity.

Influences of Hydraulic and Chemical Heterogeneity on Sample Quality in Long-Screened Wells

Sampling biases and chemical variability in long-screened wells, which can be loosely defined as wells having significant physical and chemical heterogeneity within the screened interval and in the adjacent aquifer (Reilly and Leblanc, 1998), have been the subject of numerous investigations. Sources of chemical variability in such wells include non-uniform flow into wells (Robbins and Martin-Hayden, 1991; Reilly and Gibs, 1993; Chiang and others, 1995; Church and Granato, 1996; Reilly and LeBlanc, 1998), lithologic heterogeneity (Reilly and others, 1989; Robbins, 1989; Martin-Hayden and others, 1991; Gibs and others, 1993; Reilly and Gibs, 1993), and in-well mixing. In a well open across a chemically or hydraulically heterogeneous section of the aquifer, differences in the sampling methodology can produce significant differences in the sampling results.

Long-screened wells have the potential to redistribute chemical constituents in the aquifer where there are vertical hydraulic gradients within the screened interval. Water can move into the well from one horizon and exit the well at a different horizon (Church and Granato, 1996; Reilly and LeBlanc 1998). If there is vertical flow in the screened or open interval, and the zone of low hydraulic head (outflow from the well) is within the contaminated horizon, then the PDB samplers (or any standard sampling methodology) can underestimate or not detect the contamination. The reason is that, in this case, the contaminated horizon does not contribute water to the well under static conditions. Instead, water from other horizons with higher hydraulic head will invade the contaminated horizon by way of the well screen. Under pumped conditions, the majority of the extracted water will be from the most permeable interval, which may not be the contaminated zone. Even when pumping induces inflow from the contaminated interval, much of that inflow will be a reflection of the residual invaded water from other horizons. In this situation, a substantial amount of purging would be required before water representative of the aquifer could be obtained (Jones and Lerner, 1995). Such sampling is not likely to reflect a significant contribution from the contaminated zone, and concentrations in the contaminated zone probably will be underestimated.

Similarly, if VOC-contaminated water is flowing into the well and is exiting the well at a different horizon, then VOCs will be present along the screened interval between the two horizons. In this case, VOC concentrations in the screened interval may be representative of aquifer concentrations at the inflow horizon, but may not be representative of aquifer concentrations near the outflow horizon.

In areas where vertical stratification of VOC concentrations is anticipated, using multiple PDB samplers may more fully characterize the contaminated horizon than using a single PDB sampler. This is particularly true in wells having screens 10 ft or longer; however, significant VOC stratification has been observed over intervals of less than 5 ft (Vroblesky and Peters, 2000). Because of the increased probability of vertical concentration or hydraulic gradients within the open interval of long-screened (greater than 10 ft) wells, it is advisable to determine the zones of inflow and outflow within the screened or open interval of these wells using borehole flowmeter analysis (Hess, 1982; 1984; 1986; 1990; Young and others, 1998).

Comparison of Passive Diffusion Bag Sampling Methodology to Conventional Methodologies

Traditional sampling methodologies, such as the purge-and-sample (or conventional purging method), low-flow or low-volume sampling, and using straddle packers and multilevel samplers, produce VOC

concentrations that may differ from VOC concentrations obtained from PDB samplers because the methodologies sometimes are influenced in different ways by aquifer hydraulic and chemical heterogeneity. This section examines potential sources of concentration differences between traditional methodologies and the PDB methodology.

The purge-and-sample approach to ground-water monitoring differs from the diffusion-sampler approach primarily because the area of the screened or open interval that contributes water to the purged sample typically is greater than for the PDB sampler, and the potential for mixing of stratified layers is higher. When pumping three or more casing volumes of water prior to collecting a sample, chemical concentrations in the discharging water typically change as the well is pumped (Keely and Boateng, 1987; Cohen and Rabold, 1988; Martin-Hayden and others, 1991; Robbins and Martin-Hayden, 1991; Reilly and Gibs, 1993; Barcelona and others, 1994; Martin-Hayden, 2000), due to mixing during pumping and other factors, such as the removal of stagnant water in the casing and changing patterns of inflow and outflow under ambient and pumping conditions (Church and Granato, 1996). The induction of lateral chemical heterogeneity during pumping also may produce variations in the sampled concentrations. The amount of mixing during purging can be highly variable (Barber and Davis, 1987; Church and Granato, 1996; Reilly and LeBlanc, 1998; Martin-Hayden, 2000), and may result in concentrations that are not locally representative (Reilly and Gibs, 1993). Substantial vertical hydraulic gradients, even in shallow homogeneous aquifers, have been observed to bias sampling using conventional purging because the majority of the pumped water may come from a particular horizon not related to the contaminated zone and because the intra-well flow that intruded the aquifer may not be adequately removed during purging (Hutchins and Acree, 2000). Thus, differences may be observed between concentrations obtained from a pumped sample and from a PDB sample in a chemically stratified interval if the pumped sample represents an integration of water collected from multiple horizons and the PDB sampler represents water collected from a single horizon.

Low-flow purging and sampling (Barcelona and others, 1994; Shanklin and others, 1995) disturbs the local ground water less than conventional purge-and-sample methods. Thus, samples obtained by PDB samplers are likely to be more similar to samples obtained by using low-flow purging than to those obtained by using conventional purge-and-sample methods. Even under low-flow conditions, however, purging still can integrate water within the radius of pumping influence, potentially resulting in a deviation from VOC concentrations obtained by PDB sampling. One investigation found that in low hydraulic conductivity formations, low-flow sampling methodology caused excessive drawdown, which dewatered the screened interval, increased local ground-water velocities, and caused unwanted colloid and soil transport into the ground-water samples (Sevee and others, 2000). The authors suggest that in such cases, a more appropriate sampling methodology may be to collect a slug or passive sample from the well screen under the assumption that the water in the well screen is in equilibrium with the surrounding aquifer.

Isolating a particular contributing fracture zone with straddle packers in an uncased borehole allows depth-discrete samples to be collected from the target horizon (Hsieh and others, 1993; Kaminsky and Wylie, 1995). Strategically placed straddle packers often can minimize or eliminate the impact of vertical gradients in the sampled interval. However, even within a packed interval isolating inflowing fracture zones, deviations between VOC concentrations in water from PDB samplers and water sampled by conventional methods still may occur if the conventional method mixes chemically stratified water outside the borehole or if the packed interval straddles chemically heterogeneous zones.

The use of multilevel PDB samplers and other types of multilevel samplers (Ronen and others, 1987; Kaplan and others, 1991; Schirmer and others, 1995; Gefell and others, 1999; Jones and others, 1999) potentially can delineate some of the chemical stratification. Diffusion sampling and other sampling methodologies, however, can be influenced by vertical hydraulic gradients within the well screen or the sand pack. When vertical hydraulic gradients are present within the well, water contacting the PDB sampler may not be from a horizon adjacent to the PDB sampler. Rather, the water may represent a mixing of water from other contributing intervals within the borehole. In a screened well, even multilevel samplers with baffles to limit vertical flow in the well cannot prevent influences from

vertical flow in the gravel pack outside the well screen. Such vertical flow can result from small vertical differences in head with depth. A field test conducted by Church and Granato (1996) found that vertical head differences ranging from undetectable to 0.49 ft were sufficient to cause substantial flows (as much as 0.5 liters/minute) in the well bore.

QUALITY CONTROL AND ASSURANCE

The sources of variability and bias introduced during sample collection can affect the interpretation of the results. To reduce data variability caused during sampling, a series of quality-control samples should be utilized.

Replicate samples are important for the quality control of diffusion-sampler data. Sample replicates provide information needed to estimate the precision of concentration values determined from the combined sample-processing and analytical method and to evaluate the consistency of quantifying target VOCs. A replicate sample for water-filled diffusion samplers consists of two separate sets of VOC vials filled from the same diffusion sampler. Each set of VOC vials should be analyzed for comparison. Approximately 10 percent of the samplers should be replicated.

The length of the PDB sampler can be adjusted to accommodate the data-quality objectives for the sampling event. The length can be increased if additional volume is required for collection of replicate and matrix spike/matrix spike duplicate samples.

Trip blanks are used to determine whether external VOCs are contaminating the sample due to bottle handling and/or analytical processes not associated with field processing. Trip blanks are water-filled VOA vials prepared offsite, stored and transported with the other bottles used for collecting the environmental sample, and then submitted for analysis with the environmental sample. Consideration also should be given to the collection of a predeployment PDB trip blank to determine if the PDB samplers are exposed to extraneous VOCs prior to deployment. The predeployment trip blank should be a PDB sampler that is stored and transported with the field PDB samplers from the time of sampler construction to the time of deployment in the wells. An aliquot of the predeployment blank water should be collected from the PDB sampler in a VOA vial and submitted for analysis at the time of sampler deployment.

Water used to construct the diffusion samplers should be analyzed to determine the presence of background VOCs. Although many VOCs accidentally introduced into the diffusion-sampler water probably will reequilibrate with surrounding water once the diffusion samplers are deployed, some VOCs may become trapped within the diffusion-sampler water. For example, acetone, which is a common laboratory contaminant, does not easily move through the polyethylene diffusion samplers (Paul Hare, General Electric Company, oral commun., 1999). Thus, acetone inadvertently introduced into the diffusion-sample water during sampler construction may persist in the samplers, resulting in a false positive for acetone after sampler recovery and analysis.

SUMMARY

Water-filled passive diffusion bag (PDB) samplers described in this report are suitable for obtaining a variety of VOCs in ground water at monitoring wells. The suggested application for PDB samplers is for long-term monitoring of VOCs in ground-water wells at well-characterized sites. Where the screened interval is greater than 10 ft, the potential for contaminant stratification and/or intra-borehole flow within the screened interval is greater than in screened intervals shorter than 10 ft. It is suggested that the vertical distribution of contaminants be determined in wells having 10-ft-long well screens, and that both the vertical distribution of contaminants and the potential for intra-borehole flow be determined in wells having screens longer than 10 ft. A typical PDB sampler consists of a 1- to 2-ft-long low-density polyethylene lay-flat tube closed at both ends and containing deionized water. The sampler is positioned at the target horizon by attachment to a weighted line or fixed pipe.

The amount of time that the samplers should be left in the well prior to recovery depends on the time required by the PDB sampler to equilibrate with ambient water and the time required for environmental disturbances caused by sampler deployment to return to ambient conditions. The rate that water within the PDB sampler equilibrates with ambient water depends on multiple factors, including the type of compound being sampled and the water temperature. Concentrations of benzene, *cis*-1,2-dichloroethene, tetrachlorethene, trichloroethene, toluene, naphthalene, 1,2-dibromoethane, and total xylenes within the PDB samplers equilibrated with the concentrations in an

aqueous mixture of those compounds surrounding the samplers under laboratory conditions within approximately 48 hours at 21 °C. A subsequent laboratory study of mixed VOCs at 10 °C showed that tetrachloroethene and trichloroethene were equilibrated by about 52 hours, but other compounds required longer equilabration times. Chloroethane, *cis*-1,2-dichloroethene, *trans*-1,2-dichloroethene, and 1,1-dichloroethene were not equilibrated at 52 hours, but appeared to be equilibrated by the next sampling point at 93 hours. Vinyl chloride, 1,1,1-trichloroethane, 1,2-dichloroethane, and 1,1-dichloroethane were not equilibrated at 93 hours but were equilibrated by the next sampling point at 166 hours. Different equilibration times may exist for other compounds. Differences in equilibration times, if any, between single-solute or mixed-VOC solutions have not yet been thoroughly examined.

The samplers should be left in place long enough for the well water, contaminant distribution, and flow dynamics to restabilize following sampler deployment. Laboratory and field data suggest that 2 weeks of equilibration probably is adequate for many applications. Therefore, a minimum equilibration time of 2 weeks is suggested. In less permeable formations, longer equilibration times may be required. When deploying PDB samplers in waters colder than previously tested (10 °C) or for compounds without sufficient corroborating data, a side-by-side comparison with conventional methodology is advisable to justify the field equilibration time.

Following the initial equilibration period, the samplers maintain equilibrium concentrations with the ambient water until recovery. Thus, there is no specified maximum time for sampler recovery after initial equilibration. PDB samplers have routinely been left in ground waters having concentrations of greater than 500 ppm of TCE for 3 months at a time with no loss of bag integrity, and at one site, the PDB samplers were left in place in VOC-contaminated ground water for 1 year with no reported loss of sampler integrity. The effects of long-term (greater than 1 month) PDB-sampler deployment on sampler and sample integrity have not yet been thoroughly tested for a broad range of compounds and concentrations. In some environments, development of a biofilm on the polyethylene may be a consequence of long-term deployment. Investigations of semipermeable membrane devices (SPMDs) have shown that the transfer of some compounds across a heavily biofouled polyethylene membrane may be reduced, but not stopped. If a heavy organic coating is observed on a PDB sampler, it is advisable to determine the integrity of the sample by comparing sampler results to a conventional sampling method concentrations before continuing to use PDB samplers for long-term deployment in that well.

PDB methodology is suitable for a broad variety of VOCs, including chlorinated aliphatic compounds and petroleum hydrocarbons. The samplers, however, are not suitable for inorganic ions and have a limited applicability for non-VOCs and for some VOCs. For example, although methyl-*tert*-butyl ether and acetone and most semivolatile compounds are transmitted through the polyethylene bag, laboratory tests have shown that the resulting concentrations were lower than in ambient water. The samplers should not be used to sample for phthalates because of the potential for the LDPE to contribute phthalates to the water sample.

When attempting to determine whether the use of PDB samplers is appropriate at a particular well, a common approach is to do a side-by-side comparison with a conventional sampling method. This approach is strongly suggested in wells having temporal concentration variability. In a well having relatively low temporal concentration variability, comparison of the PDB-sampler results to historical concentrations may provide enough information to determine whether the PDB samplers are appropriate for the well. In general, if the two approaches produce concentrations that agree within a range deemed acceptable by the local, state, and Federal regulatory agencies, then use of a PDB sampler in that well will provide VOC concentrations consistent with the historical record. If concentrations from the PDB sampler are higher than concentrations from the conventional method, then it is probable that the concentrations from the PDB sampler are an adequate representation of ambient conditions. If, however, the conventional method produces concentrations that are substantially higher than the concentrations found by using the PDB sampler, then the PDB sampler may or may not adequately represent local ambient conditions. In this case, the difference may be due to a variety of factors, including mixing or translocation due to hydraulic and chemical heterogeneity of the aquifer within the screened or open interval of the well and the relative permeability of the well screen.

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USGS VROBLESKY

USER'S GUIDE FOR POLYETHYLENE-BASED PASSIVE DIFFUSION BAG SAMPLERS TO OBTAIN VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN WELLS

PART 1: DEPLOYMENT, RECOVERY, DATA INTERPETATION, AND QUALITY CONTROL AND ASSURANCE

USGS WRIR 01-4060

Printed on recycled paper

Notes on PDB Use:

Depending on the depth of the well, the combined buoyancy of the sampler and the polypropylene line can make it difficult to lower the sampler to the desired sampling depth. It is helpful to have a selection of stainless weights and a means to attach them to the bottom of the sampler to overcome this type of problem.

The samplers come as bags with eyelets to attach to a rope, cable or hanger. Always get the plastic mesh covers and use them. If there are any burrs on the screen or inside the well, these will help prevent the PDB from getting punctured.

Columbia Analytical has arrangements with a vendor to manufacture hangers for the samplers that Columbia sells. Alternatively, it is possible to contact the vendor directly for these hangers as they will sell the hangers for less than what Columbia Analytical sells them for. The vendor is MS Laboratory Instruments http://www.mslabinstruments.com/gwps_rfq.htm. Columbia Analytical and/or MS Lab Instruments can make permanent hangers based on the depth requirements for each well. They use coated stainless steel line and attach sufficient weights to the bottoms to overcome sampler buoyancy. EON Products, Inc., will manufacture dedicated “tethers” for samplers that EON Products, Inc., sells. Each tether is made to a specific length for a given well. Polypropylene rope tethers or stainless steel tethers are available.

Safety: Inspect equipment setup prior to use. Lift with legs and arms, not back (bend at knees, minimize twisting). When lifting, keep loads close to body, avoid twisting torso, and use legs, not back, to lift loads. Use two people if necessary; take breaks as needed. Wear safety glasses and gloves Potential hazards include lifting hazards and exposure to affected ground water. Relevant JSAs must be followed during sampling.

Appendix E

Procedures for Selected Statistical Methods

United States
Environmental Protection
Agency

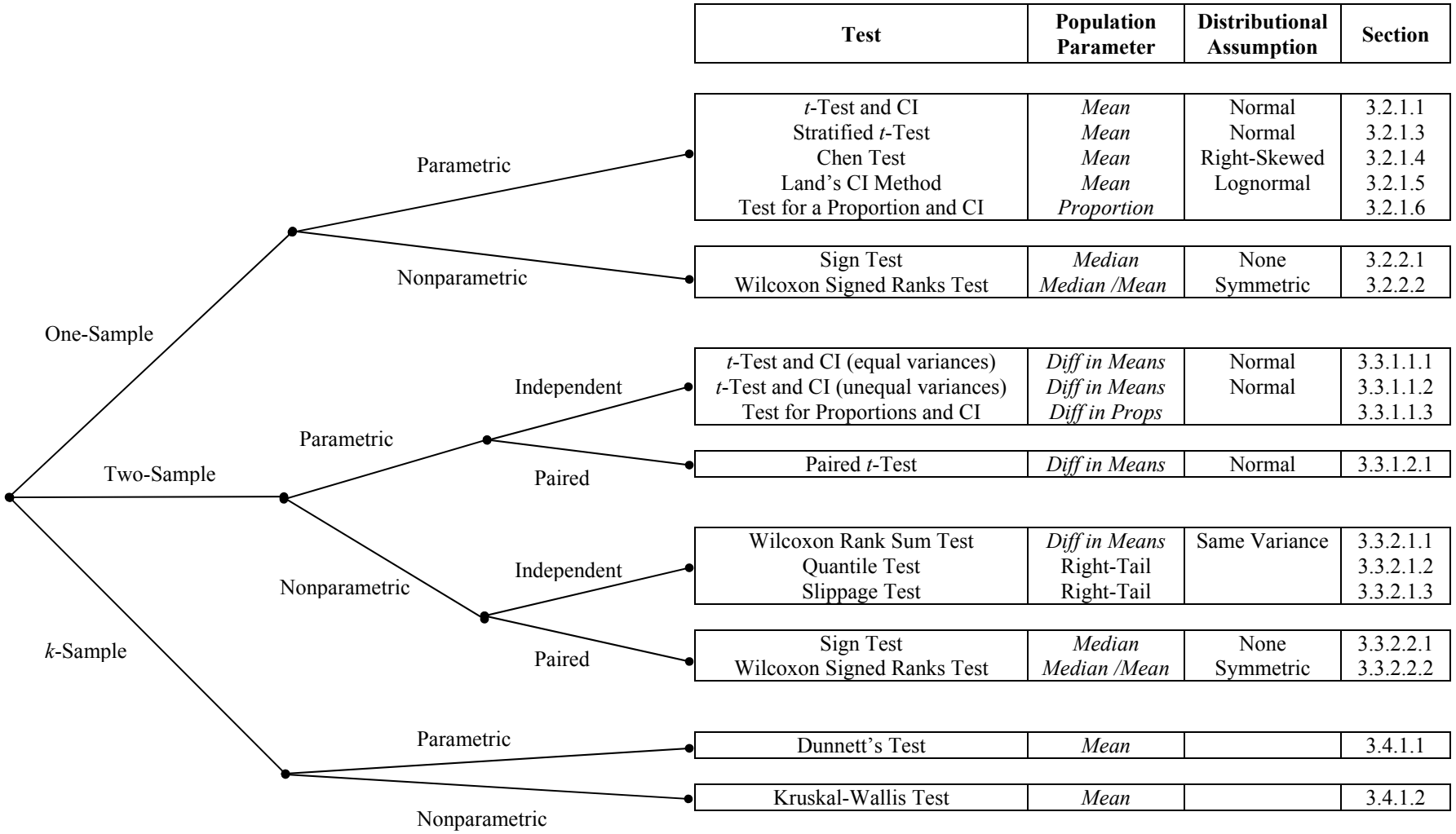
Office of Environmental
Information
Washington, DC 20460

EPA/240/B-06/003
February 2006

Data Quality Assessment: Statistical Methods for Practitioners

EPA QA/G-9S

Decision Tree for Selecting the Specific Method



Test	Population Parameter	Distributional Assumption	Section
t-Test and CI	*Mean*	Normal	3.2.1.1
Stratified *t*-Test	*Mean*	Normal	3.2.1.3
Chen Test	*Mean*	Right-Skewed	3.2.1.4
Land's CI Method	*Mean*	Lognormal	3.2.1.5
Test for a Proportion and CI	*Proportion*		3.2.1.6
Sign Test	*Median*	None	3.2.2.1
Wilcoxon Signed Ranks Test	*Median /Mean*	Symmetric	3.2.2.2
t-Test and CI (equal variances)	*Diff in Means*	Normal	3.3.1.1.1
t-Test and CI (unequal variances)	*Diff in Means*	Normal	3.3.1.1.2
Test for Proportions and CI	*Diff in Props*		3.3.1.1.3
Paired *t*-Test	*Diff in Means*	Normal	3.3.1.2.1
Wilcoxon Rank Sum Test	*Diff in Means*	Same Variance	3.3.2.1.1
Quantile Test	Right-Tail		3.3.2.1.2
Slippage Test	Right-Tail		3.3.2.1.3
Sign Test	*Median*	None	3.3.2.2.1
Wilcoxon Signed Ranks Test	*Median /Mean*	Symmetric	3.3.2.2.2
Dunnett's Test	*Mean*		3.4.1.1
Kruskal-Wallis Test	*Mean*		3.4.1.2

Box 3-32: Directions for the Wilcoxon Rank Sum Test

COMPUTATIONS: Rank the pooled data from smallest to largest assigning average rank to ties. Sum the ranks of the first population and denote this by R_1. Then compute

$$W_0 = R_1 - \frac{m(m+1)}{2}$$

STEP 1. Null Hypothesis: $H_0: \mu_X - \mu_Y = 0$ (no difference between population means)

STEP 2. Alternative Hypothesis:
i) $H_A: \mu_X - \mu_Y > 0$ (upper-tail test)
ii) $H_A: \mu_X - \mu_Y < 0$ (lower-tail test)
iii) $H_A: \mu_X - \mu_Y \neq 0$ (two-tail test)

STEP 3. Test Statistic: If *m* and *n* are at most 20, then the test statistic is W_0.

If *m* and *n* are greater than 20, then compute $z_0 = \frac{W_0 - mn/2}{\sqrt{\text{var}(W_0)}}$,

where $\text{var}(W_0) = \frac{mn(m+n+1)}{12} - \left\{ \frac{mn}{12(m+n)(m+n-1)} \sum_{j=1}^{g} t_j \left(t_j^2 - 1 \right) \right\}$,

g is the number of tied groups, and t_j is the number of ties in the j^{th} group.

STEP 4. a) Critical Value: to find:

If *m* and *n*< =20, use Table A-8 to find:
i) $mn - w_\alpha$
ii) w_α
iii) $w_{\alpha/2}$

If *m* and *n* >20 use Table A-1
i) $z_{1-\alpha}$
ii) z_α
iii) $z_{1-\alpha/2}$

STEP 4. b) p-value:

If *m* and *n* <=20, use Table A-8 to find:
i) $P(W_{rs} < mn - W_0)$
ii) $P(W_{rs} < W_0)$
iii) $2 \cdot \min\{P(W_{rs} < mn - W_0), P(W_{rs} < W_0)\}$

If *m* and *n* > 20 use Table A-1 to find:
i) $P(Z > z_0)$
ii) $P(Z < z_0)$
iii) $2 \cdot P(Z > |z_0|)$

STEP 5. a) Conclusion:

If *m* and *n* are at most 20, then
i) If $W_0 \geq mn - w_\alpha$, then reject the null hypothesis.
ii) If $W_0 \leq w_\alpha$, then reject the null hypothesis.
iii) If $W_0 \geq mn - w_{\alpha/2}$ or $W_0 \leq w_{\alpha/2}$, then reject the null hypothesis.

If *m* and *n* are greater than 20, then
i) If $z_0 > z_{1-\alpha}$, then reject the null hypothesis of no difference between population means.
ii) If $z_0 < z_\alpha$, then reject the null hypothesis.
iii) If $|z_0| > z_{1-\alpha/2}$, then reject the null hypothesis.

STEP 5. b) Conclusion: If p-value < significance level, then reject the null hypothesis

STEP 6. If the null hypothesis was not rejected, then the sample sizes necessary to achieve the DQOs should be computed. If the sample sizes are large, only one false acceptance error rate (β at δ_1) has been specified, then the false acceptance error rate has probably been satisfied if both *m* and *n* are at least

$$1.16 \cdot \left\{ \frac{2 \cdot \text{var}(W_0) \cdot (z_{1-\alpha'} + z_{1-\beta})^2}{\delta_1^2} + \frac{z_{1-\alpha'}^2}{4} \right\}.$$

NOTE: The value of α' is α for a one-sided test and $\alpha/2$ for a two-sided test. The large sample normal approximation is adequate as long as min(*m*, *n*) > 10.

Box 3-33: An Example of the Wilcoxon Rank Sum Test

At a hazardous waste site, an area cleaned (area 1) was compared with a relatively uncontaminated reference area (area 2). If the methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. The false rejection error rate was set at 10% (α) and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb. Seven random samples were taken from area 1 and 8 samples were taken from area 2:

Area 1: 17, 23, 26, 5, 13, 13, 12
Area 2: 16, 20, 5, 4, 8, 10, 7, 3

COMPUTATIONS: The ordered pooled data and their ranks are (Area 1 denoted by *):

Pooled data	3	4	5*	5	7	8	10	12*	13*	13*	16	17*	20	23*	26*
Rank	1	2	3.5*	3.5	5	6	7	8*	9.5*	9.5*	11	12*	13	14*	15*

The sum of the ranks of area 1 is $R_1 = 3.5 + 8 + 9.5 + 9.5 + 12 + 14 + 15 = 71.5$ and $W_0 = 71.5 - 7(7 + 1)/2 = 43.5$

STEP 1. Null Hypothesis: $H_0 : \mu_X - \mu_Y = 0$

STEP 2. Alternative Hypothesis: $H_A : \mu_X - \mu_Y > 0$

STEP 3. Test Statistic: Since m and n are less than 20, the test statistic is W_0.

STEP 4. a) Critical Value: Using Table A-8, $mn - w_{0.10} = 56 – 16 = 40$

STEP 4. b) p-value: Using Table A-8, $mn - w_{0.05} < W_0 < mn - w_{0.025}$, which implies 0.05 < p-value < 0.025. Using statistical software, p-value = 0.0410.

STEP 5. a) Conclusion: Since Test Statistic = 43.5 > 40 = Critical Value, we reject the null hypothesis of no difference between population means.

STEP 5. b) Conclusion: Since p-value = 0.0410 < 0.10 (significance level), we reject the null hypothesis

Directions for the Quantile test are contained in Box 3-35, with an example in Box 3-36.

3.3.2.1.3 The Slippage Test

Purpose: Test for a shift to the right in the extreme right-tail of population 1 (site) versus population 2 (background). This is equivalent to asking if a set of the largest values of the site distribution are larger than the maximum value of the background distribution.

Data: A simple or systematic random sample, $x_1, x_2, \ldots, x_m$, from the site population and an independent simple or systematic random sample, $y_1, y_2, \ldots, y_n$, from the background population.

Box 3-34: A Large Sample Example of the Wilcoxon Rank Sum Test

Arsenic concentrations (in ppm) from a site are to be compared to a reference area. The null hypothesis is that the means of the two areas are equal versus the upper-tail alternative. The false rejection error rate was set at 5% (α) and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppm.

Site concentrations (m = 22): 11.2, 11.3, 12.2, 13.2, 14.2, 15.9, 16.3, 17.1, 18.6, 19.2, 21.5, 22.3, 22.4, 22.7, 22.8, 23.3, 24.1, 25.8, 30.2, 30.7, 31.4, 37.1

background concentrations (n = 21): 6.1, 8.5, 11.1, 11.3, 12.6, 12.8, 13.6, 15.0, 15.2, 15.3, 16.1, 16.2, 17.0, 17.1, 17.6, 19.2, 19.2, 19.6, 21.1, 22.2, 25.0

COMPUTATIONS: The ordered pooled data and their ranks are (site concentrations are denoted by *):

Value	Rank
6.1	1
8.5	2
11.1	3
11.2*	4*
11.3	5.5
11.3*	5.5*
12.2*	7*
12.6	8
12.8	9
13.2*	10*
13.6	11

Value	Rank
14.2*	12*
15.0	13
15.2	14
15.3	15
15.9*	16*
16.1	17
16.2	18
16.3*	19*
17.0	20
17.1	21.5
17.1*	21.5*

Value	Rank
17.6	23
18.6*	24*
19.2	26
19.2	26
19.2*	26*
19.6	28
21.1	29
21.5*	30*
22.2	31
22.3*	32*
22.4*	33*

Value	Rank
22.7*	34*
22.8*	35*
23.3*	36*
24.1*	37*
25.0	38
25.8*	39*
30.2*	40*
30.7*	41*
31.4*	42*
37.1*	43*

The sum of the site ranks is

R_1 = 4 + 5.5 + 7 + 10 + 12 + 16 + 19 + 21.5 + 24 + 26 + 30 + 32 + 33 + 34 + 35 + 36 + 37 + 39 + 40 + 41 + 42 + 43 = 587

and $W_0 = 587 - 22(22 + 1)/2 = 334$.

STEP 1. Null Hypothesis: $H_0 : \mu_X - \mu_Y = 0$

STEP 2. Alternative Hypothesis: $H_A : \mu_X - \mu_Y > 0$

STEP 3. Test Statistic: Since m and n are greater than 20, the test statistic is $z_0 = \dfrac{W_0 - mn/2}{\sqrt{\text{var}(W_0)}}$. To compute var($W_0$), we need to determine the number of tied groups and the number of values in each group. There are 3 tied groups, so g = 3. The number of tied values in the groups are 2 (at 11.3), 2 (at 17.1), and 3 (at 19.2). Therefore,

$$\text{var}(W_0) = \frac{22 \cdot 21 \cdot (22 + 21 + 1)}{12} - \left\{ \frac{22 \cdot 21}{12 \cdot (22 + 21)(22 + 21 - 1)} \left[2 \cdot \left(2^2 - 1\right) + 2 \cdot \left(2^2 - 1\right) + 3 \cdot \left(3^2 - 1\right) \right] \right\} = 1693.23 .$$

Finally, $z_0 = \dfrac{334 - 22 \cdot 21/2}{\sqrt{1693.23}} = 2.50$.

STEP 4. a) Critical Value: Using Table A-1, $z_{0.95}$ = 1.645.

STEP 4. b) p-value: Using Table A-1, $P(Z > 2.50) = 1 - 0.9938 = 0.0062$.

STEP 5. a) Conclusion: Since Test Statistic = 2.50 > 1.645 = Critical Value, we reject the null hypothesis of no difference between population means.

STEP 5. b) Conclusion: Since p-value = 0.0062 < 0.05 = significance level, we reject the null hypothesis of no difference between population means.

Box 3-39: Directions for the Sign Test (Paired Samples)

COMPUTATIONS: Compute the deviations $d_i = x_i - y_i$. If any of the deviations are zero delete them and correspondingly reduce the sample size. Finally, compute B = number of differences greater than zero.

STEP 1. Null Hypothesis: H_0: median 1 = median 2

STEP 2. Alternative Hypothesis:
i) H_A: median 1 > median 2 (upper-tail test)
ii) H_A: median1 < median 2 (lower-tail test)
iii) H_A: median 1 $\neq$ median 2 (two-tail test)

STEP 3. Test Statistic: If $n \leq 20$, then the test statistic is B.

If $n > 20$, then the test statistic is $z_0 = \dfrac{B - n/2}{\sqrt{n/4}}$.

STEP 4. a) Critical Value:

If $n \leq 20$, then use Table A-18 to find:
i) $B_{upper}(n, 2\alpha)$
ii) $B_{lower}(n, 2\alpha) - 1$
iii) $B_{lower}(n, \alpha)$ and $B_{lower}(n, \alpha)$

If $n > 20$, then use Table A-1 to find:
i) $z_{1-\alpha}$
ii) z_{α}
iii) $z_{1-\alpha/2}$

STEP 4. b) p-value: If $n \leq 20$, then let $p(i) = \binom{n}{i}\frac{1}{2^n}$ where $\binom{n}{i} = \dfrac{n!}{(n-i)!i!}$

i) $\sum_{i=B}^{n} p(i)$

ii) $\sum_{i=o}^{B} p(i)$

iii) $2 \cdot \min\left\{\sum_{i=0}^{B} p(i), \sum_{i=B}^{n} p(i)\right\}$

If $n > 20$, then use Table A-1 to find:
i) $P(Z > z_0)$
ii) $P(Z < z_0)$
iii) $2 \cdot P(Z > |z_0|)$

STEP 5. a) Conclusion: If $n \leq 20$, then
i) If $B \geq B_{upper}(n, 2\alpha)$, then reject the null hypothesis that the two population medians are equal.
ii) If $B \leq B_{lower}(n, 2\alpha) - 1$, then reject the null hypothesis.
iii) If $B \geq B_{upper}(n, \alpha)$ or $B \leq B_{lower}(n, \alpha) - 1$, then reject the null hypothesis.

If $n > 20$, then
i) If $z_0 > z_{1-\alpha}$, then reject the null hypothesis that the two population medians are equal.
ii) If $z_0 < z_{\alpha}$, then reject the null hypothesis.
iii) If $|z_0| > z_{1-\alpha/2}$, then reject the null hypothesis.

STEP 5. b) Conclusion: If p-value < α, then reject the null hypothesis that the two population medians are equal.

Box 3-40: An Example of the Sign Test (Paired Samples)

Consider the following 9 pairs of data points (in ppb):

x_i	178	52	161	245	164	184	157	308	130
y_i	92	67	62	206	106	126	108	314	126

This data will be used to test the null hypothesis that there is no difference in medians versus the alternative that the median of the first population is greater than the median of the second population. The decision maker has specified a 5% false rejection error rate and a 10% false acceptance error rate at a difference of 50 ppb.

COMPUTATIONS: The table below displays the computations.

d_i	86	-15	99	39	58	58	49	-6	4

Therefore, B = the number of differences greater than zero = 7.

STEP 1. Null Hypothesis: H_0: $\tilde{\mu}_1 = \tilde{\mu}_2$

STEP 2. Alternative Hypothesis: H_A: $\tilde{\mu}_1 > \tilde{\mu}_2$

STEP 3. Test Statistic: Since $n \leq 20$, the test statistic is $B = 7$.

STEP 4. a) Critical Value: Since $n \leq 20$, Table A-18 is used to find $B_{upper}(n, 2\alpha) = 8$.

STEP 4. b) p-value: Since $n \leq 20$, p-value = $\sum_{i=7}^{9} \binom{9}{i} \frac{1}{2^9} = 0.0898$.

STEP 5. a) Conclusion: Since test statistic = 7 < 8 = critical value, we fail to reject H_0.

STEP 5. b) Conclusion: Since p-value = 0.0898 > 0.05 = significance level, we fail to reject H_0.

Data: Two paired data sets $x_1,\ldots,x_n$ and $y_1,\ldots,y_n$ selected randomly or systematically.

Assumptions: The data sets come from a approximately symmetric distributions.

Limitations and Robustness: For large sample sizes ($n > 50$), the paired t-test is more robust to violations of its assumptions than the Wilcoxon signed rank test. For small sample sizes, if the data are not approximately symmetric or normally distributed, the sign test should be used.

The Wilcoxon signed rank test may produce misleading results if there are many tied data values. Ties have the effect of diluting the statistical power of the Wilcoxon test. If possible, results should be recorded with sufficient accuracy so that a large number of tied values do not occur. Estimated concentrations should be reported for data below the detection limit, even if these estimates are negative, as their relative magnitude to the rest of the data is of importance. If this is not possible, substitute the value DL/2 for each value below the detection limit providing all the data have the same detection limit. When different detection limits are present, all data could be censored at the highest detection limit but this will substantially weaken the test. A statistician should be consulted on the potential use of Gehan ranking.

Directions for the paired sample Wilcoxon signed rank test are contained in Box 3-41, with an example in Box 3-42. Directions for the large sample version of the test are contained in the example in Box 3-43.

Box 3-41: Directions for the Wilcoxon Signed Rank Test (Paired Samples)

COMPUTATIONS: Compute the deviations $d_i = x_i - y_i$. If any of the deviations are zero delete them and correspondingly reduce the sample size. Rank the absolute deviations, $|d_i|$, from smallest to largest. If there are tied observations, then assign the average rank. Let R_i be the signed rank of $|d_i|$, where the sign of R_i is determined by the sign of d_i.

STEP 1. Null Hypothesis: H_0: $\text{location}_1 = \text{location}_2$

STEP 2. Alternative Hypothesis:
i) H_A: $\text{location}_1 > \text{location}_2$ (upper-tail test)
ii) H_A: $\text{location}_1 < \text{location}_2$ (lower-tail test)
iii) H_A: $\text{location}_1 \neq \text{location}_2$ (two-tail test)

STEP 3. Test Statistic: If $n \leq 20$, then $T^+ = \sum_{\{i:\, R_i > 0\}} R_i$, the sum of the positive signed ranks.

If $n > 20$, then $z_0 = \dfrac{T^+ - n(n+1)/4}{\sqrt{\text{var}(T^+)}}$,

where $\text{var}(T^+) = \dfrac{n(n+1)(2n+1)}{24} - \dfrac{1}{48}\sum_{j=1}^{g} t_j\left(t_j^2 - 1\right)$, g is the number of tied d_i groups and t_j is the size of group j.

STEP 4. a) Critical Value:

If $n \leq 20$, use Table A-7 to find:	If $n > 20$, use Table A-1 to find:
i) $n(n+1)/2 - w_\alpha$	i) $z_{1-\alpha}$
ii) w_α	ii) z_α
iii) $w_{\alpha/2}$	iii) $z_{1-\alpha/2}$

STEP 4. b) p-value:

If $n \leq 20$, use Table A-7 to find:	If $n > 20$, use Table A-1 to find:
i) $P\left(W \leq n(n+1)/2 - T^+\right)$	i) $P(Z > z_0)$
ii) $P\left(W \leq T^+\right)$	ii) $P(Z < z_0)$
iii) $2 \cdot \min\left\{P\left(W \leq n(n+1)/2 - T^+\right), P\left(W \leq T^+\right)\right\}$	iii) $2 \cdot P(Z > \lvert z_0 \rvert)$

STEP 5. a) Conclusion:

If $n \leq 20$,	If $n > 20$,
i) If $T^+ \geq n(n+1)/2 - w_\alpha$, then reject the null	i) If $z_0 > z_{1-\alpha}$, then reject the null
ii) If $T^+ \leq w_\alpha$, then reject the null hypothesis.	ii) If $z_0 < z_\alpha$, then reject the null
iii) If $T^+ \geq n(n+1)/2 - w_{\alpha/2}$ or $T^+ \leq w_\alpha$, then reject the null	iii) If $\lvert z_0 \rvert > z_{1-\alpha/2}$, then reject the null

STEP 5. b) Conclusion: If p-value < α, then reject the null hypothesis that the two population locations are equal.

STEP 6. If the null hypothesis was not rejected, then the sample sizes necessary to achieve the DQOs should be computed. If the sample size is large, only one false acceptance error rate (β at δ_1) has been specified, and

$$n \geq 1.16 \cdot \left\{ \frac{\text{var}\left(T^+\right)\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{\delta_1^2} + \frac{z_{1-\alpha}^2}{2} \right\},$$

then the false acceptance error rate has probably been satisfied. The value of α' is α for a one-sided test and $\alpha/2$ for a two-sided test.

Box 3-42: An Example of the Wilcoxon Signed Rank Test (Paired Samples)

Consider the following 9 pairs of data points (in ppb):

x_i	178	52	161	245	164	184	157	308	130
y_i	92	67	62	206	106	126	108	314	126

This data will be used to test the null hypothesis that there is no difference in medians versus the alternative that the median of the first population is greater than the median of the second population. The decision maker has specified a 5% false rejection error rate and a 10% false acceptance error rate at a difference of 50 ppb.

COMPUTATIONS: The table below displays the computations.

d_i	86	-15	99	39	58	58	49	-6	4
$\|d_i\|$	86	15	99	39	58	58	49	6	4
rank	8	3	9	4	6.5	6.5	5	2	1
R_i	8	-3	9	4	6.5	6.5	5	-2	1

STEP 1. Null Hypothesis: H_0: median1 = median 2

STEP 2. Alternative Hypothesis: H_A: median 1< median 2 (lower-tail test)

STEP 3. Test Statistic: Since $n \le 20$, compute $T^+ = \sum_{\{i: R_i > 0\}} R_i = 1 + 4 + 5 + 6.5 + 6.5 + 8 + 9 = 40$

STEP 4. a) Critical Value: Since $n \le 20$, Table A-7 is used to find $n(n+1)/2 - w_{0.05} = 45 - 8 = 37$.

STEP 4. b) p-value: Since $n \le 20$, Table A-7 is used to find the approximate p-value of 0.025. Using software, the p-value is found to be 0.0195.

STEP 5. a) Conclusion: Since test statistic = $40 \ge 37$ = critical value, we reject the null hypothesis of equal population medians.

STEP 5. b) Conclusion: Since p-value = 0.0195 < 0.05 = significance level, we reject the null hypothesis of equal population medians.

NOTE: The Sign test failed to reject the null hypothesis for this example. The Wilcoxon Signed Rank test has more power than the Sign test if the distribution of the population is symmetric.

3.4 COMPARING SEVERAL POPULATIONS SIMULTANEOUSLY

This section describes procedures for comparing several population means simultaneously. The comparison is made between several treatment populations versus a single control population. For example, we can simultaneously test for a difference between the concentrations at several sites versus a single background area.

The methods in section compare the several populations while controlling the overall significance level. If individual two-sample *t*-tests are performed at significance level α, then the overall significance level is higher than α. Possible much higher if there are many experimental groups. For example, comparing two experimental groups to a control using two two-sample *t*-tests at significance level 0.05 results in an overall significance level of 1-(1-0.05)(1-0.05) = 0.0975. The tests in this section are more powerful in detecting differences between the experimental groups and the control than other multiple comparison methods that compare all possible pairs of population means, e.g., the ANOVA *F*-test and the Kruskal-Wallis test.

Box 3-43: A Large Sample Example of the Wilcoxon Signed Rank Test (Paired Samples)

A hazardous waste site has recently gone through remediation. To determine if the remediation method was effective, 24 paired samples (before and after clean-up) will be compared. The following data will be used to test the null hypothesis that there is no difference in medians versus the alternative that the median concentration before is greater than the median concentration after clean-up. The decision maker has specified a 5% false rejection error rate and a 10% false acceptance error rate at a difference of 30 ppb.

before: 331, 351, 259, 323, 305, 336, 196, 233, 336, 349, 352, 341, 172, 253, 275, 285, 212, 349, 301, 343, 368, 332, 374, 311
after: 246, 270, 229, 326, 295, 238, 278, 302, 331, 264, 267, 249, 288, 272, 270, 313, 337, 284, 271, 253, 295, 271, 289, 281

COMPUTATIONS: The table below displays the computation of the signed ranks.

d_i	$\|d_i\|$	rank	R_i
85	85	17.5	17.5
81	81	14	14
30	30	8	8
-3	3	1	-1
10	10	4	4
98	98	22	22
-82	82	15	-15
-69	69	12	-12

d_i	$\|d_i\|$	rank	R_i
5	5	2.5	2.5
85	85	17.5	17.5
85	85	17.5	17.5
93	93	21	21
-117	117	23	-23
-19	19	5	-5
5	5	2.5	2.5
-28	28	6	-6

d_i	$\|d_i\|$	rank	R_i
-125	125	24	-24
65	65	11	11
30	30	8	8
90	90	20	20
73	73	13	13
60	60	10	10
85	85	17.5	17.5
30	30	8	8

STEP 1. Null Hypothesis: H_0: median 1 = median 2

STEP 2. Alternative Hypothesis: H_A: median 1 > median 2 (upper-tail test)

STEP 3. Test Statistic: Since $n > 20$, compute $z_0 = \dfrac{T^+ - n(n+1)/4}{\sqrt{\text{var}(T^+)}}$. First,

$T^+ = \sum_{\{i:\, R_i > 0\}} R_i = 17.5 + 14 + \cdots + 8 = 214$. To compute $\text{var}(T^+)$, we need to identify the number of tied groups and the number of values in each of the tied groups. There are 3 tied groups so $g = 3$. The number of values in the tied groups are 2 (at 2.5), 3 (at 30), and 4 (at 85). Therefore,

$$\text{var}(T^+) = \frac{24 \cdot (24+1)(2 \cdot 24+1)}{24} - \frac{1}{48}\left\{2 \cdot \left(2^2 - 1\right) + 3 \cdot \left(3^2 - 1\right) + 4 \cdot \left(4^2 - 1\right)\right\} = 1223.125 .$$

Finally, $z_0 = \dfrac{214 - 24 \cdot (24+1)/4}{\sqrt{1223.125}} = 1.83$

STEP 4. a) Critical Value: Since $n > 20$, Table A-1 is used to find $z_{0.95} = 1.645$.

STEP 4. b) p-value: Since $n > 20$, Table A-1 is used to find $P(Z > z_0) = 1 - 0.9664 = 0.0336$.

STEP 5. a) Conclusion: Since test statistic = 1.83 > 1.645 = critical value, we reject the null hypothesis of equal population medians.

STEP 5. b) Conclusion: Since p-value = 0.0336 < 0.05 = significance level, we reject the null hypothesis of equal population medians.

The Dunnett test of Section 3.4.1.1 is a parametric test that compares several treatment means to a control mean. Section 3.4.2.1 presents a nonparametric alternative to the Dunnett test.

TABLE A-1. STANDARD NORMAL DISTRIBUTION

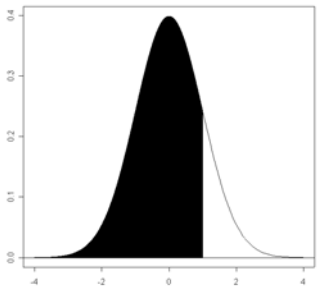


Table values are $P(Z \le z_p) = p$.

z_p	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641
-0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
-0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
-0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
-0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
-0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
-0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
-0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
-0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
-0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
-1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
-1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
-1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
-1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
-1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
-1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
-1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
-1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
-1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
-1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
-2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
-2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
-2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
-2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
-2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
-2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
-2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
-2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
-2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
-2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
-3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
-3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
-3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
-3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
-3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002

TABLE A-1. STANDARD NORMAL DISTRIBUTION (CONT.)

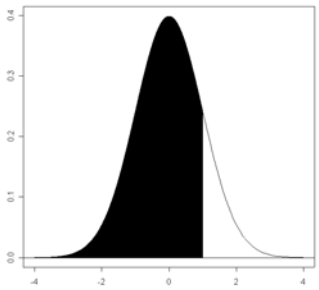


Table values are $P(Z \leq z_p) = p$.

z_p	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6247	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8897	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9889	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9137	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

TABLE A-7. QUANTILES OF THE WILCOXON SIGNED RANKS TEST

Values in the table are such that $P(T^+ \leq w_\alpha)$ is approximately equal to, but less than α. For example, if $n = 12$, then $P(T^+ \leq 17) = 0.0461$, which is slightly less than 0.05. Note the exact probability was computed using the statistical software package R.

N	$w_{0.005}$	$w_{0.01}$	$w_{0.025}$	$w_{0.05}$	$w_{0.075}$	$w_{0.10}$	$w_{0.15}$	$w_{0.20}$
4	-	-	-	-	0	0	1	2
5	-	-	-	0	1	2	2	3
6	-	-	0	2	2	3	4	5
7	-	0	2	3	4	5	7	8
8	0	1	3	5	7	8	9	11
9	1	3	5	8	9	10	12	14
10	3	5	8	10	12	14	16	18
11	5	7	10	13	16	17	20	22
12	7	9	13	17	19	21	24	27
13	9	12	17	21	24	26	29	32
14	12	15	21	25	28	31	35	38
15	15	19	25	30	33	36	40	44
16	19	23	29	35	39	42	47	50
17	23	27	34	41	45	48	53	57
18	27	32	40	47	51	55	60	65
19	32	37	46	53	58	62	68	73
20	37	43	52	60	65	69	76	81

TABLE A-8. CRITICAL VALUES FOR THE WILCOXON RANK-SUM TEST

Table values are the largest x values such that $P(W_{rs} \le x) \le \alpha$. Therefore, significance levels, α, are approximate. If there are ties, then the test is approximate.

min(m, n)	α	max(m, n)								
		2	3	4	5	6	7	8	9	10
2	0.010	-	-	-	-	-	-	-	-	-
	0.025	-	-	-	-	-	-	0	0	0
	0.050	-	-	-	0	0	0	1	1	1
	0.100	-	0	0	1	1	1	2	2	3
3	0.010		-	-	-	0	0	0	1	1
	0.025		-	-	0	1	1	2	2	3
	0.050		0	0	1	2	2	3	4	4
	0.100		1	1	2	3	4	5	5	6
4	0.010			-	0	1	1	2	3	3
	0.025			0	0	2	3	4	4	5
	0.050			1	2	3	4	5	6	7
	0.100			3	4	5	6	7	9	10
5	0.010				1	2	3	4	5	6
	0.025				2	3	5	6	7	8
	0.050				4	5	6	8	9	11
	0.100				5	7	8	10	12	13
6	0.010					3	4	6	7	8
	0.025					5	6	8	10	11
	0.050					7	8	10	12	14
	0.100					9	11	13	15	17
7	0.010						6	7	9	11
	0.025						8	10	12	14
	0.050						11	13	15	17
	0.100						13	16	18	21
8	0.010							9	11	13
	0.025							13	15	17
	0.050							15	18	20
	0.100							19	22	25
9	0.010								14	16
	0.025								17	20
	0.050								21	24
	0.100								25	28
10	0.010									13
	0.025									23
	0.050									27
	0.100									32

TABLE A-8. CRITICAL VALUES FOR THE WILCOXON RANK-SUM TEST (CONT.)

Table values are the largest x values such that $P(W_{rs} \leq x) \leq \alpha$. Therefore, significance levels, α, are approximate. If there are ties, then the test is approximate.

min(m, n)	α	max(m, n)									
		11	12	13	14	15	16	17	18	19	20
2	0.010	-	-	0	0	0	0	0	0	1	1
	0.025	0	1	1	1	1	1	2	2	2	2
	0.050	1	2	2	3	3	3	3	4	4	4
	0.100	3	4	4	4	5	5	6	6	7	7
3	0.010	1	2	2	2	3	3	4	4	4	5
	0.025	3	4	4	5	5	6	6	7	7	8
	0.050	5	5	6	7	7	8	9	9	10	11
	0.100	7	8	9	10	10	11	12	13	14	15
4	0.010	4	5	5	6	7	7	8	9	9	10
	0.025	6	7	8	9	10	11	11	12	13	14
	0.050	8	9	10	11	12	14	15	16	17	18
	0.100	11	12	13	15	16	17	18	20	21	22
5	0.010	7	8	9	10	11	12	13	14	15	16
	0.025	9	11	12	13	14	15	16	18	19	20
	0.050	12	13	15	16	18	19	20	22	23	25
	0.100	15	17	18	20	22	23	25	27	28	30
6	0.010	9	11	12	13	15	16	18	19	20	22
	0.025	13	14	16	17	19	21	22	24	25	27
	0.050	16	17	19	21	23	25	26	28	30	32
	0.100	19	21	23	25	27	29	31	34	36	38
7	0.010	12	14	16	17	19	21	23	24	26	28
	0.025	16	18	20	22	24	26	28	30	32	33
	0.050	19	21	24	26	28	30	33	35	37	39
	0.100	23	26	28	31	33	36	38	41	43	46
8	0.010	15	17	20	22	24	26	28	30	32	34
	0.025	19	22	24	26	28	31	34	36	38	41
	0.050	23	26	28	31	33	36	39	41	44	47
	0.100	27	30	33	36	39	42	45	48	51	54
9	0.010	18	21	23	26	28	31	33	36	38	40
	0.025	23	26	28	31	24	37	39	42	45	48
	0.050	27	30	33	36	39	42	45	48	51	54
	0.100	31	35	38	41	45	48	52	55	58	62
10	0.010	22	24	27	30	33	36	38	41	44	47
	0.025	26	29	33	36	39	42	45	48	52	55
	0.050	31	34	37	41	44	48	51	55	58	62
	0.100	36	39	43	47	51	54	58	62	66	70

TABLE A-8. CRITICAL VALUES FOR THE WILCOXON RANK-SUM TEST (CONT.)

Table values are the largest x values such that $P(W_{rs} \le x) \le \alpha$. Therefore, significance levels, α, are approximate. If there are ties, then the test is approximate.

min(m, n)	α	max(m, n)									
		11	12	13	14	15	16	17	18	19	20
11	0.010	25	28	31	34	37	41	44	47	50	53
	0.025	30	33	37	40	44	47	51	55	58	62
	0.050	34	38	42	46	50	54	57	61	65	69
	0.100	40	44	48	52	57	61	65	69	73	78
12	0.010		31	35	38	52	46	48	53	56	60
	0.025		37	41	45	49	53	57	61	65	69
	0.050		42	47	51	55	60	64	68	72	77
	0.100		49	53	58	63	68	72	77	81	86
13	0.010			39	43	47	51	55	59	63	67
	0.025			45	50	54	59	63	67	72	76
	0.050			51	56	61	65	70	75	80	84
	0.100			58	63	68	74	79	84	89	94
14	0.010				47	51	56	60	65	69	73
	0.025				55	59	64	69	74	78	83
	0.050				61	66	71	77	82	87	92
	0.100				69	74	80	85	91	97	102
15	0.010					56	61	66	70	75	80
	0.025					64	70	75	80	85	90
	0.050					72	77	83	88	94	100
	0.100					80	86	92	98	104	110
16	0.010						66	71	76	82	87
	0.025						75	81	86	92	98
	0.050						83	89	95	101	107
	0.100						93	99	106	112	119
17	0.010							77	82	88	93
	0.025							87	93	99	105
	0.050							96	102	109	115
	0.100							106	113	120	127
18	0.010								88	94	100
	0.025								99	106	112
	0.050								109	116	123
	0.100								120	128	135
19	0.010									101	107
	0.025									113	119
	0.050									123	130
	0.100									135	143
20	0.010										114
	0.025										127
	0.050										138
	0.100										151

TABLE A-18. CRITICAL VALUES FOR THE SIGN TEST

The table values are such that for order statistics $x_{[lower]}$ and $x_{[upper]}$, $P\left(x_{[lower]} < \text{true median} < x_{[upper]}\right) \geq 1-\alpha$. Note that the significance levels are for two-sided tests. For one-sided test, divide the significance level in half.

n	α									
	0.20		0.10		0.05		0.02		0.01	
	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper
5	1	5	1	5	-	-	-	-	-	-
6	1	6	1	6	1	6	-	-	-	-
7	2	6	1	7	1	7	1	7	-	-
8	2	7	2	7	1	8	1	8	1	8
9	3	7	2	8	2	8	1	9	1	9
10	3	8	2	9	2	9	1	10	1	10
11	3	9	3	9	2	10	2	10	1	11
12	4	9	3	10	3	10	2	11	2	11
13	4	10	4	10	3	11	2	12	2	12
14	5	10	4	11	3	12	3	12	2	13
15	5	11	4	12	4	12	3	13	3	13
16	5	12	5	12	4	13	3	14	3	14
17	6	12	5	13	5	13	4	14	3	15
18	6	13	6	13	5	14	4	15	4	15
19	7	13	6	14	5	15	5	15	4	16
20	7	14	6	15	6	15	5	16	4	17
21	8	14	7	15	6	16	5	17	5	17
22	8	15	7	16	6	17	6	17	5	18
23	8	16	8	16	7	17	6	18	5	19
24	9	16	8	17	7	18	6	19	6	19
25	9	17	8	18	8	18	7	19	6	20
26	10	17	9	18	8	19	7	20	7	20
27	10	18	9	19	8	20	8	20	7	21
28	11	18	10	19	9	20	8	21	7	22
29	11	19	10	20	9	21	8	22	8	22
30	11	20	11	20	10	21	9	22	8	23
31	12	20	11	21	10	22	9	23	8	24
32	12	21	11	22	10	23	9	24	9	24
33	13	21	12	22	11	23	10	24	9	25
34	13	22	12	23	11	24	10	25	10	25
35	14	22	13	23	12	24	11	25	10	26
36	14	23	13	24	12	25	11	26	10	27
37	15	23	14	24	13	25	11	27	11	27
38	15	24	14	25	13	26	12	27	11	28
39	16	24	14	26	13	27	12	28	12	28
40	16	25	15	26	14	27	13	28	12	29

Appendix F

Regulatory Agency Letter Template

The letter presents background regarding no-purge sampling and briefly describes how a no-purge comparison study will be conducted. (Items in boldface text need to be replaced by site- and project-specific information.)

[Date]

[RecipientName]
[Address Max. 6 lines]

Subject:
Revised Sampling Methodology Request
[State/Province/Territory, Site Name (if applicable)]

Dear [**Salutation]**:

This letter was prepared to propose an alternative groundwater sampling method for the above mentioned site. Currently monitoring wells at the site are purged and sampled using **[current sampling method]**. **[Project manager/consultant]** has reviewed information regarding no-purge sampling, and proposes **[no-purge sampling method]** as an alternative to **[current sampling method]**.

BASIS FOR NO-PURGE SAMPLING

During no-purge sampling, a sampling device is deployed into the screened interval of a well, where ambient groundwater flow occurs. As in standard low-flow purging and sampling protocols (e.g., United States Environmental Protection Agency [USEPA] 1998), the no-purge sample is commonly collected at the approximate midpoint of the saturated screened interval.

Studies have demonstrated that no-purge sampling methods can produce groundwater analytical data comparable to the data obtained using more conventional (e.g., low-flow and traditional [three-volume purge]) groundwater sampling methods for: aromatic and chlorinated hydrocarbons, and other volatile organic compounds; semivolatile organic compounds; PCBs; pesticides; metals; and other inorganics (ITRC, 2006, 2007; Parker and Clark, 2002; Parsons, 2005).

With no-purge groundwater sampling, it is assumed that the water inside the open interval of a monitoring well represents ambient groundwater. This assumption is based on the fact that wellbore hydraulic conductivity is higher than that of the surrounding formation in almost all geologic settings. The low-flow purging and

sampling procedure, which is a standard groundwater sampling method, is also based on the observations of many researchers that water moving through the formation also moves through the well screen. Preferential flushing of the well by ambient groundwater flow can, therefore, produce representative water quality within the open interval without well purging (e.g., Robin and Gillham, 1987; Powell and Puls, 1993).

No-purge sampling is usually conducted for routine sampling of a plume to identify changes over time and to assess the progress of plume remediation or attenuation. If required, standard sampling such as **[current sampling method]** will be used for site closure confirmation.

In many cases, no-purge sampling is applicable and is capable of providing useful, representative groundwater quality data. No-purge sampling also offers logistical and technical advantages over other groundwater sampling methods.

- waste handling and disposal are minimized
- site interference is reduced
- equipment requirements and associated hazards are reduced (e.g., no need for electrical power supply, reduced equipment lifting, little or no need for equipment decontamination)
- due to the simplicity of the field procedure, sampling repeatability is increased
- potential for decreased turbidity, little or no agitation or off-gassing, no dilution, and appropriate for a wide variety of geologic settings
- overall sampling cost is reduced

JUSTIFICATION - SITE **[OR REGION]** SPECIFIC

[Discuss where the no-purge study is proposed, including the selected site(s) and wells, or if all the wells at a given site will be sampled for the study, and why the specified wells were selected.

Include in this section a description of the site(s), particularly the constituents of concern and geologic setting(s) and how the proposed no-purge sampling technique is the appropriate method for the site(s) and setting(s). Mention additional characteristics such as well screen lengths, well construction and whether the wells have been re-developed, if necessary.

Mention which section of the screen will be targeted for sampling, if discrete intervals will be sampled or if a composite of groundwater in a long screen (> 10 ft) will be collected.]

FIELD DEMONSTRATION

A field demonstration is proposed to verify the appropriateness of no-purge sampling using **[selected no-purge method].** During the field demonstration, no-purge sampling will be performed concurrently with a standard sampling event using **[current sampling method]**. **[For "region x", a select number of sites will be chosen to complete the field demonstration, namely ___]** The field activities will be conducted so that the samples are collected in the shortest period of time practicable within a given well, with minimal disturbance to the water column within the well. Because standard purge-based sampling causes more perturbation to the water column in the well than no-purge sampling, the no-purge sample(s) will be obtained before the standard sample.

The analytical results from the standard sampling method and the no-purge sampling method(s) will then be evaluated to assess the comparability of the data sets. For the purpose of this field demonstration, we propose to conduct no-purge sampling at **[number]** monitoring wells, concurrent with the standard sampling event scheduled for **[dates]**.

DATA EVALUATION AND REPORTING

Following receipt of the analytical data for the standard method and the no-purge method(s), the data sets for each detected analyte will be tabulated. Graphical and/or statistical methods will be used to compare the data obtained using both sampling methods. In addition, results will be compared to the applicable regulatory criteria or site-specific target criteria. Results will be provided in a letter report within **[time]** of receipt of the analytical laboratory data.

We look forward to hearing back from you regarding this proposal. Thank you for considering this request.

Sincerely,

[Author Name]
[Author Title]

Copies:
[Copies]

References

Interstate Technology and Regulatory Council (ITRC). 2006. Technology overview of passive sampler technologies.

Interstate Technology and Regulatory Council (ITRC). 2007. Protocol for use of five passive samplers to sample for a variety of contaminants in groundwater.

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Parsons Engineering Science, Inc. 2005. Final results report for the demonstration of no-purge groundwater sampling devices at former McClellan Air Force Base, California. October.

Powell, R.M., and R.W. Puls. 1993. Passive sampling of ground-water monitoring wells without purging: multilevel well chemistry and tracer disappearance. Journal of Contaminant Hydrology, Vol. 12, pp. 51-77.

Robin, M.J.L., and R.W. Gillham. 1987. Field evaluation on well purging procedures. Ground Water Monitoring Review, Vol. 7, No. 4, pp. 85-93.

United States Environmental Protection Agency (USEPA) Region II. March 16, 1998. Low Stress (Low-Flow) Purging and Sampling. Final Ground Water Sampling SOP # G001.

Appendix F. Quality Assurance and Quality Control

Appendix F - Quality Assurance and Quality Control

The following Quality Assurance and Quality Control Plan (QA/QC Plan) is written with consideration of best practices and laboratory requirements.

The consultant performing the work is required to follow the protocols outlines herein and to provide a summary of QA/QC results and interpretation within the annual groundwater monitoring report.

F.1 Field Measurements, Sampling, and Handling QA/QC

Throughout the duration of any groundwater sampling event the following standards are employed:

- Nitrile gloves are worn and replaced at each groundwater well location (multiples times as appropriate) to eliminate the potential for cross-contamination.
- All meters used for field measurement testing are calibrated on site, daily.
- Bottles and equipment used in groundwater sampling are triple rinsed with deionized water before.
- Bailing rope, as used, is discarded after each sample and new rope is used for subsequent samples.
- Sampling equipment (bailers, tubing, waterra sleeves) are dedicated to each well or are disposed of after each sample, depending on method.
- All samples are collected into analyte-specific bottles supplied directly by an accredited laboratory.
- All samples are stored and shipped in coolers with adequate ice to maintain required temperatures (i.e., between 0 and 10°C).
- All samples are packaged in accordance with laboratory contractor recommended packaging techniques, chain of custody seals intact and completed Chain of Custody (CoC) forms, completed to Imperial standards.
- Samples are shipped from Norman Wells to the laboratory on the next available commercial flight.

Prior to collection of groundwater samples, the water and level is measured from the top of the monitoring well polyvinyl chloride (PVC) casing using a Solinst or other commercially available electric water level meter. Groundwater from each monitoring well is collected for field measurements and laboratory analysis using one of the following three methods based on the static groundwater elevation relative to the top and bottom of well screen:

1. If static water level in the well is less than 0.5 meter above top of screen and greater than 1.0 meter above base of well screen, the water samples are collected using no-purge disposable HydraSleeve equipment.
2. If static water level in the well is less than 1.0 meter above the base of the well screen, water samples are collected with a dedicated bailer by a no-purge method.

3. If static water level in the well is more than 0.5 meter above the top of the well screen, the water is purged either to dryness or to three times the volume of standing water. Once a sufficient amount of fresh groundwater has re-entered the well, samples are collected using dedicated bailers or Waterra tubing.

Prior to collecting samples for laboratory analysis several time-sensitive water quality field measurements are conducted:

- Temperature: measured at surface using a pH or EC meter temperature probe.
- pH: measured with a field water pH meter, calibrated using buffer solutions of pH 4, pH 7 and/or pH 10.
- EC: electrical conductivity (temperature-corrected) measured with a field water EC meter, calibrated with standard potassium chloride (KCl) solution (≈1,413 µS/cm at 25°C).

Once field measurements are completed, samples are collected for laboratory analysis as per Table 3-2). All samples are collected as per laboratory sampling instructions and are preserved at the time of collection, where required.

A Chain of Custody (COC) form outlining sample collection information (sample name, sample date, sample time) and the parameters to be tested is completed. Sampler details along with site-specific tracking documentation are included on the COC. A copy of the COC is shipped with the samples. Chain of custody seals on the coolers are to remain intact throughout the shipping process from consultant field sampler to the third-party laboratory.

F.2 Laboratory Quality Assurance and Quality Control

F.2.1 Sample Integrity

Upon receipt of samples, the laboratory will inspect the COC and submitted samples for data integrity deficiencies, including:

- Incomplete COC information such as missing analysis for bottles submitted, sample collection information (dates and time) or clerical information such as sampler names.
- Missing or damaged bottles required for requested analysis.
- Sample temperature.
- Damaged custody seals.
- Missing or damaged labelling on sample bottles.

The laboratory will then provide the consultant staff with Sample Receipt Confirmation (SRC) that summarizes the requested analysis and any deficiencies noted in the sample submission. Upon arrival of the sample receipt confirmation from the third-party laboratory, consultant staff will review the confirmation form to verify that all the samples have been received, are intact and that the requested parameters have been logged for analysis.

F.2.2 Data Integrity

For quality assurance purposes, the third-party laboratory regularly uses calibration checks, surrogate matrix spikes, blanks, and laboratory duplicates during analyses. Any deviations or exceptions to the above are reported.

The laboratory dataset is entered into the consultant's internal data set for data management purposes following receipt and review of any Certificate of Analysis (final results report).

The consultant is responsible for reviewing the laboratory QA/QC results and providing an assessment, within the annual report, of the QA/QC results' effects, if any, on data accuracy and the interpretations drawn from the data.

F.3 Field QA/QC

The following quality assurance samples are submitted to the third-party laboratory, as appropriate during each sampling event.

Field Duplicate Samples

The purpose of field duplicates is to determine repeatability and accuracy of analytical results. For low-level concentrations (<0.1 mg/L), duplicate data within an order of magnitude is considered adequate. Higher analytical concentrations are typically assessed in terms of relative percent difference (RPD). The RPD between an original field sample and its blind field duplicate is calculated as follows:

$$RPD = \left\{ \frac{(|x1 - x2|)}{(\frac{(x1 + x2)}{2})} \right\} * 100\%$$

Where: $x1$ = original field sample.

$x2$ = blind field duplicate or replicate sample.

Field duplicates RPDs are compared to the following alert limits. RPDs within these alert limits are considered representative of acceptable data:

- 80% for BTEX, PHC F1 and F2.
- 50% for all metals, major ions and indicator parameters (Imperial 2004; Appendix B).

The target field duplicate collection and submission rate is 10% (e.g., 30 groundwater samples = 3 field duplicate samples).

Blank Samples

Coded trip blank samples consisting of laboratory supplied and certified deionized and organic-free water are submitted with each sample submission for analysis of PHC parameters (BTEX, F1, F2). The purpose of a trip blank is to identify whether the inadvertent introduction of hydrocarbons, during sample handling, transport, or in the laboratory has occurred. One trip blank is submitted during each sampling event.

Field blank samples are created by filling clean sample bottles with laboratory supplied and certified deionized and organic-free water in the same field locations and following the same sampling procedures as during collection of regular groundwater samples. Field blank samples are typically analyzed for the full analytical suite as the groundwater samples. One field blank is submitted during each sampling event.

Field and trip blank sample results are compared to alert limits as summarized below:

- 5 x reportable detection limit (RDL) for BTEX and inorganics parameter (as applicable).
- 2 x RDL for PHC F1 and F2 (Imperial 2004; Appendix B).

Appendix G. Current Baseline Dataset

Well Included in GMP	Parameter	Well data in Trend Charts	Date range of data	>8 data points?	>50% detections?	Baseline?	Trend (using MK from full data set, >50% detections)?	UCL Calculate	LCL Calculate	UCL 2x/5x and no LCL
C27-16-2-3	Chloride	Y	2016-2019	N	Y	N	N	ISF	ISF	ISF
	TDS	Y	2016-2019	N	Y	N	N	ISF	ISF	ISF
	Benzene	Y	2016-2019	N	N	N	ND	ISF	ISF	5x
	Ethylbenzene	Y	2016-2019	N	N	N	ND	ISF	ISF	5x
	Xylenes – Total	Y	2016-2019	N	N	N	ND	ISF	ISF	5x
	Toluene	Y	2016-2019	N	N	N	ND	ISF	ISF	5x
	Arsenic	Y	2016-2019	N	Y	N	N	ISF	ISF	ISF
	Barium	Y	2016-2019	N	Y	N	N	ISF	ISF	ISF
	Boron	Y	2016-2019	N	Y	N	N	ISF	ISF	ISF
	Iron	Y	2016-2019	N	N	N	N	ISF	ISF	ISF
CPF 97-7-5	Chloride	Y	1997-2022	Y	Y	Y	N	Y	Y	N
	TDS	Y	1997-2022	Y	Y	Y	Visual	Y	Y	N
	Benzene	Y	1999-2022	Y	N	Y	ND	N	N	5x
	Ethylbenzene	Y	1999-2022	Y	N	Y	ND	N	N	5x
	Xylenes – Total	Y	1999-2022	Y	N	Y	ND	N	N	5x
	Toluene	Y	1999-2022	Y	N	Y	ND	N	N	5x
	Arsenic	Y	1997-2022	Y	Y	Y	N	Y	Y	N
	Barium	Y	1997-2022	Y	Y	Y	N	Y	Y	N
	Boron	Y	1997-2022	Y	Y	Y	N	Y	Y	N
	Iron	Y	1997-2022	Y	Y	Y	Increasing MK	No, due to trend	No, due to trend	N
CPF 23-1-3	Chloride	Y	2024	N	Y	N	ISF	ISF	ISF	ISF
	TDS	Y	2024	N	Y	N	ISF	ISF	ISF	ISF
	Benzene	Y	2024	N	N	N	ND	ISF	ISF	5x
	Ethylbenzene	Y	2024	N	N	N	ND	ISF	ISF	5x
	Xylenes – Total	Y	2024	N	N	N	ND	ISF	ISF	5x
	Toluene	Y	2024	N	N	N	ND	ISF	ISF	5x
	Arsenic	Y	2024	N	Y	N	ISF	ISF	ISF	ISF
	Barium	Y	2024	N	Y	N	ISF	ISF	ISF	ISF
	Boron	Y	2024	N	Y	N	ISF	ISF	ISF	ISF
	Iron	Y	2024	N	Y	N	ISF	ISF	ISF	ISF
MTF-97-1-5	Chloride	Y	1997-2024	Y	Y	Y	N	Y	Y	N
	TDS	Y	1997-2024	Y	Y	Y	Visual	Y	Y	N
	Benzene	Y	2001-2024	Y	N	Y	ND	ISF	ISF	5x
	Ethylbenzene	Y	2001-2024	Y	N	Y	ND	ISF	ISF	5x
	Xylenes – Total	Y	2001-2024	Y	N	Y	ND	ISF	ISF	5x
	Toluene	Y	2001-2024	Y	N	Y	ND	ISF	ISF	5x
	Arsenic	Y	1997-2024	Y	N	Y	N	N	N	2x

Well Included in GMP	Parameter	Well data in Trend Charts	Date range of data	>8 data points?	>50% detections?	Baseline?	Trend (using MK from full data set, >50% detections)?	UCL Calculate	LCL Calculate	UCL 2x/5x and no LCL
	Barium	Y	1997-2024	Y	Y	Y	N	Y	Y	N
	Boron	Y	1997-2024	Y	Y	Y	N	Y	Y	N
	Iron	Y	1997-2024	Y	N	Y	N	N	N	2x
TF 03-11-4	Chloride	Y	2003-2019	Y	Y	Y	N	Y	Y	N
	TDS	Y	2003-2010	N	Y	N	N	ISF	ISF	ISF
	Benzene	Y	2003-2019	Y	Y	Y	N	Y	Y	N
	Ethylbenzene	Y	2003-2019	Y	Y	Y	Visual	Y	Y	N
	Xylenes – Total	Y	2003-2019	Y	Y	Y	Visual	Y	Y	N
	Toluene	Y	2003-2019	Y	Y	Y	N	Y	Y	N
	Arsenic	Y	2003-2019	Y	Y	Y	N	Y	Y	N
	Barium	Y	2003-2019	Y	Y	Y	N	Y	Y	N
	Boron	Y	2003-2019	Y	Y	Y	N	Y	Y	N
	Iron	Y	2003-2019	Y	Y	Y	Visual	Y	Y	N
TF 03-12-3	Chloride	Y	2003-2023	Y	Y	Y	Visual	Y	Y	N
	TDS	Y	2003-2023	Y	Y	Y	N	Y	Y	N
	Benzene	Y	2003-2023	Y	N	Y	ND	ISF	ISF	5x
	Ethylbenzene	Y	2003-2023	Y	N	Y	ND	ISF	ISF	5x
	Xylenes – Total	Y	2003-2023	Y	N	Y	ND	ISF	ISF	5x
	Toluene	Y	2003-2023	Y	N	Y	ND	ISF	ISF	5x
	Arsenic	Y	2003-2023	Y	Y	Y	N	Y	Y	N
	Barium	Y	2003-2023	Y	Y	Y	N	Y	Y	N
	Boron	Y	2003-2023	Y	Y	Y	Visual	Y	Y	N
	Iron	Y	2003-2023	Y	Y	Y	MK increasing	No, due to trend	No, due to trend	N
MW23-36	NO DATA									
MW23-35	NO DATA									
MW23-48	NO DATA									
BIB98-1-3 (R)	NOT DRILLED YET									
C27-16-1-3	NO DATA--WELL DRY									
C27-16-3-4	NO DATA--WELL DRY									
BIB98-3-4	NO DATA--FROZEN, ABANDONED IN 2002									
BI N42 09-1-3	NO DATA--DRY/FROZEN									
BIBT1-12-3-5	NO DATA--DRY/FROZEN/DAMAGED									

Well Included in GMP	Parameter	Well data in Trend Charts	Date range of data	>8 data points?	>50% detections?	Baseline?	Trend (using MK from full data set, >50% detections)?	UCL Calculate	LCL Calculate	UCL 2x/5x and no LCL

NOTES:

UCL	Upper Control Limit
LCL	Lower Control Limit
ISF	Insufficient Data
MK	Mann-Kendall
ND	Non-detect
5x	5 times the reportable detection limit (RDL) for the specific parameter
2x	2 times the reportable detection limit (RDL) for the specific parameter

For data below detection limits: In cases where less than 50% of the baseline data set are detectable, the UCL will be set to five or two times the typical RDL (as applicable) and the LCL will not be calculated (not applicable).