

PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, IGNACE AREA

*WP07 Data Report - Opportunistic Groundwater
Sampling for IG_BH01*

APM-REP-01332-0236

November 2018

Golder Associates Ltd.

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REPORT

Phase 2 Initial Borehole Drilling and Testing, Ignace Area

WP7 Data Report - Opportunistic Groundwater Sampling for IG_BH01

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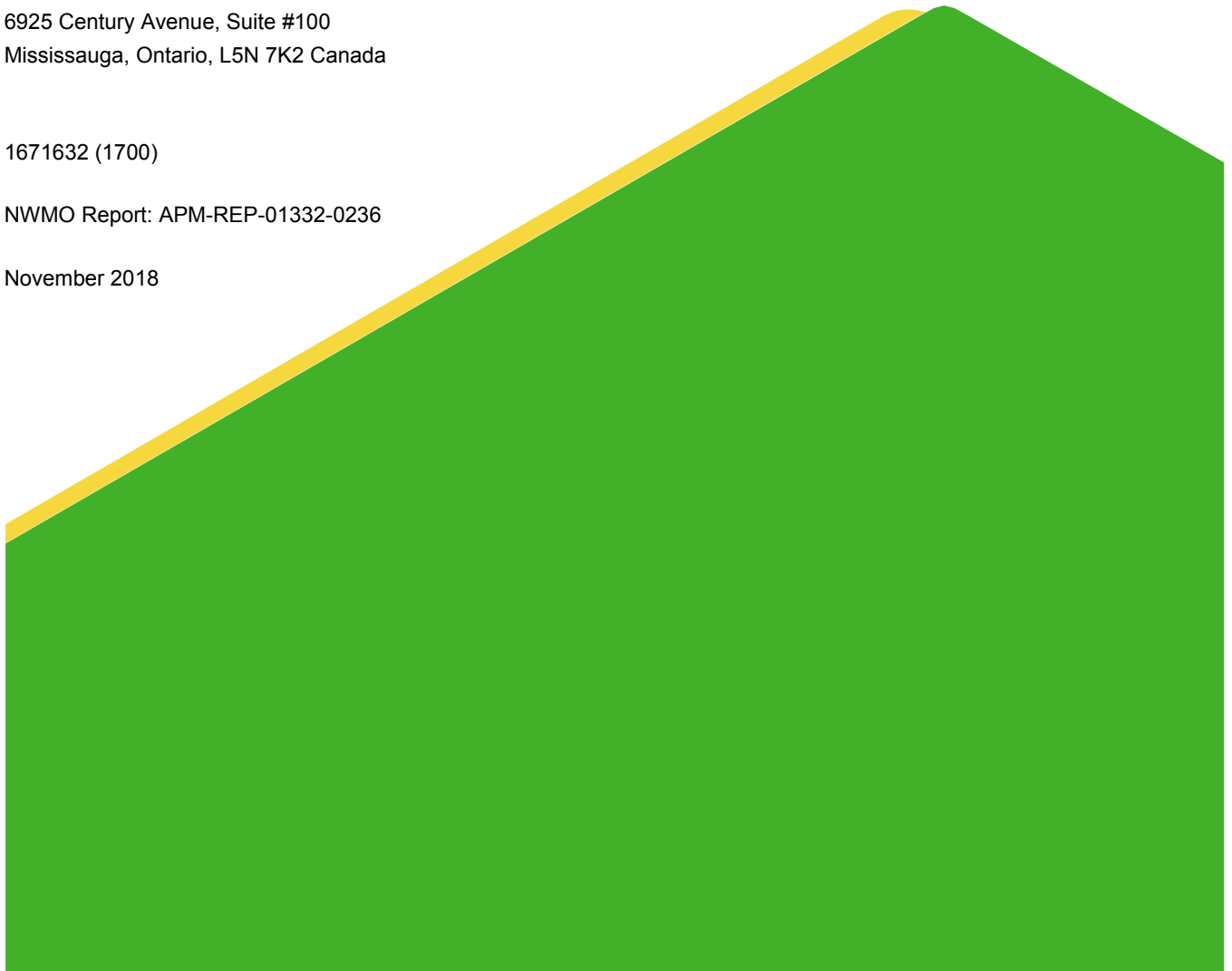
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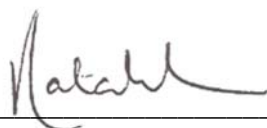
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1.0 INTRODUCTION

The Initial Borehole Drilling and Testing project in the Wabigoon and Ignace Area, Ontario is part of Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's Adaptive Phased Management (APM) Site Selection Phase.

This project involves the drilling and testing of the first of three deep boreholes within the northern portion of the Revell batholith. The first drilled borehole, IG_BH01, is located a direct distance of approximately 21 km southeast of the Wabigoon Lake Ojibway Nation and a direct distance of 43 km northwest of the Town of Ignace. Access to the IG_BH01 drill site is via Highway 17 and primary logging roads, as shown on Figure 1.

The project was carried out by a team led by Golder Associates Ltd. (Golder) on behalf of the NWMO. This report describes the methodology, activities and results for Work Package 7 (WP7): Opportunistic Groundwater Sampling for IG_BH01, which includes: identification of permeable intervals during drilling or hydraulic testing (WP6), collection and in-field analysis, and laboratory analysis of samples. This report also describes the analysis of the fresh water and drill water collected as part of Work Package 2 (WP2): Borehole Drilling and Coring for IG_BH01.

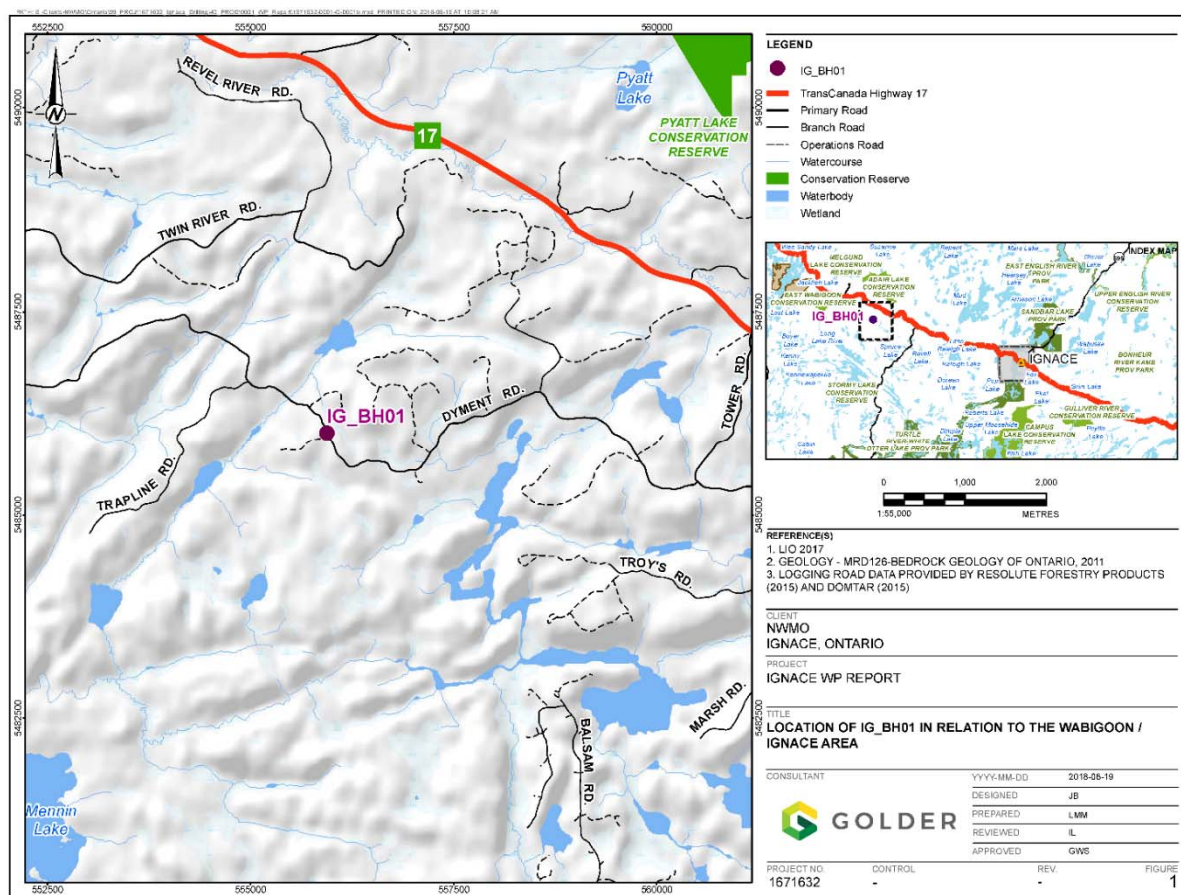


Figure 1: Location of IG_BH01 in relation to the Wabigoon / Ignace Area

2.0 BACKGROUND INFORMATION

2.1 Geological Setting

The approximately 2.7 billion year old Revell batholith is located in the western part of the Wabigoon Subprovince of the Archean Superior Province. The batholith is roughly elliptical in shape trending northwest, is approximately 40 km in length, 15 km in width, and covers an area of approximately 455 km². It is likely that the batholith is approximately 2 km to 3 km thick through the center of the northern portion (SGL, 2015). The Revell batholith is surrounded by the Raleigh Lake (to the north and east) and Bending Lake (to the southwest) greenstone belts (Figure 2).

Borehole IG_BH01 is within an investigation area of approximately 19 km² in size situated in the northern portion of the Revell batholith. Bedrock exposure in this area is very good due to minimal overburden, few water bodies, and relatively recent logging activities. Ground elevations generally range from 400 to 450 m above sea level. The ground surface broadly slopes towards the northwest as indicated by the flow direction of the main rivers in the area (Revell and Mennin rivers). Local water courses within the investigation area tend to flow to the southwest towards Mennin Lake.

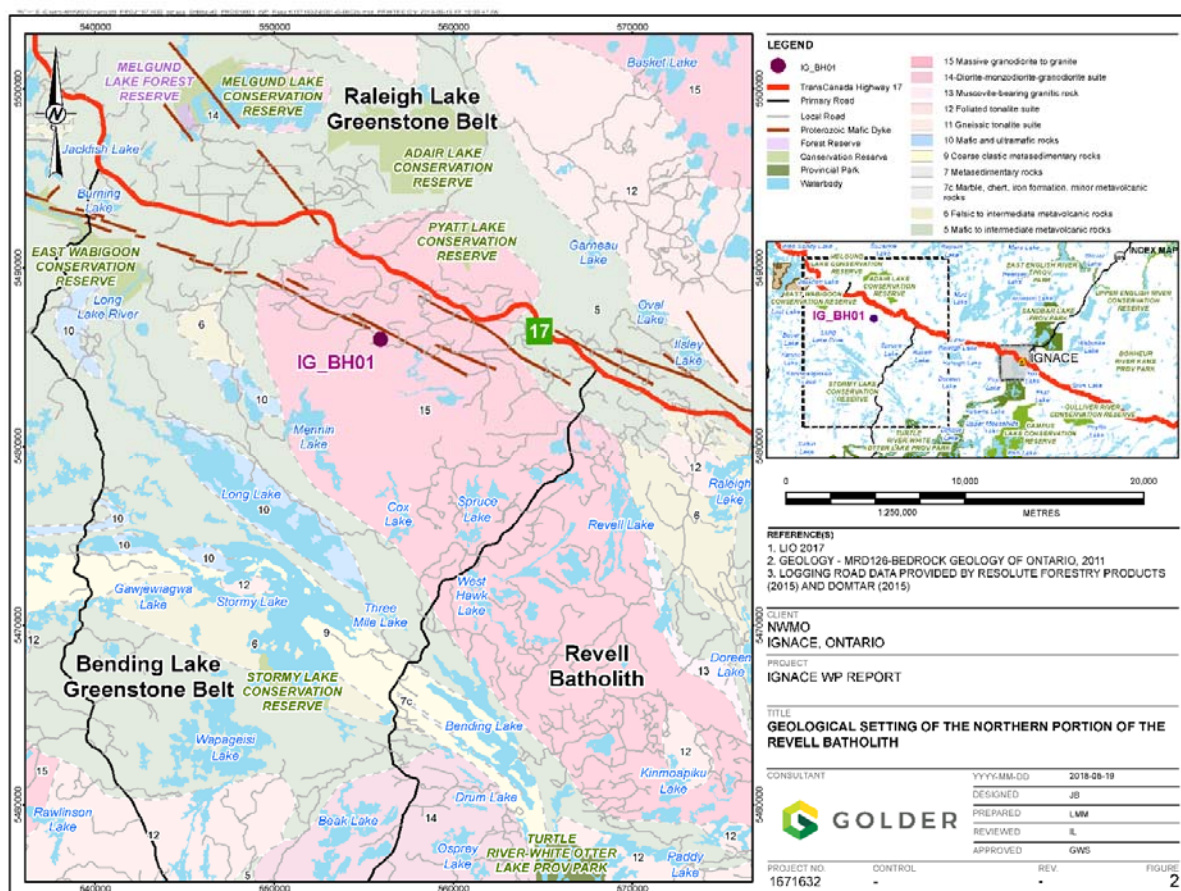


Figure 2: Geological setting of the northern portion of the Revell batholith

The northern portion of the Revell batholith is composed mainly of granodiorite and tonalite, which together form a relatively homogeneous intrusive granitoid complex. The granodiorite and tonalite are massive to weakly foliated. Overall, the tonalite transitions gradationally into granodiorite and no distinct contact relationships between these two rock types are typically observed. There is also a younger granite intrusion, which is observed southeast of the investigation area and primarily in the central portion of the Revell batholith. The granite, which is massive to weakly foliated, post-dates and intrudes into the granodiorite-tonalite intrusive complex (Golder and PGW, 2017). In the centre of the investigation area, a west-northwest trending mafic dyke is interpreted from aeromagnetic data and observed during detailed mapping to be approximately 15-20 m wide (Figure 2). This dyke is associated with a similarly-orientated mafic dyke that stretches along the entire northern limit of the investigation area. Both dykes, along with others in the northern portion of the Revell batholith, have a similar character and are interpreted to be part of the Wabigoon dyke swarm. It is assumed based on surface measurements that these mafic dykes are sub-vertical (Golder and PGW, 2017).

Long, narrow valleys are located along the western and southern limits of the investigation area (Figure 1). These local valleys host creeks and small lakes that drain to the southwest and may represent the surface expression of structural features that extend into the bedrock. A broad valley is located along the eastern limits of the investigation area and hosts a more continuous, un-named water body that flows to the south. The linear and segmented nature of this waterbody's shorelines may also represent the surface expression of structural features that extend into the bedrock.

Details of the lithological units and structures found within the investigation area are provided in Golder and PGW (2017).

2.2 Technical Objectives

The technical and scientific objectives of WP7, opportunistic groundwater (OGW) sampling, were the following:

- Identification, while drilling and post-drilling during WP6 packer testing, of permeable intervals for collecting OGW samples;
- Collection and preservation of OGW sample volumes for geochemical analysis;
- Measurement of field parameters (tracer concentrations [fluorescein], temperature, pH, oxidation-reduction potential [ORP], electrical conductivity [EC], turbidity, and density) and in-field analysis (alkalinity, dissolved oxygen [DO], total dissolved sulphide, and ferrous iron);
- Laboratory analysis of collected OGW samples;
- Determining chemical and isotopic character of groundwater with depth; and
- Identify the presence or absence of recent, older post-glacial and glacial recharge, interglacial recharge and very old pre-glacial groundwater with depth.

In the crystalline rock of the Revel Batholith, groundwater was expected to be encountered through fractures in the bedrock. A maximum of 10 sample intervals were planned, following the depth guidelines below:

- 1 sample in the upper 100 m;
- 3 samples in the upper 400 m (including the 1 sample in the upper 100 m); and
- 7 samples in the potential repository zone (400 to 800 m) or below the repository horizon if active or flowing features were encountered.

3.0 DESCRIPTION OF ACTIVITIES

3.1 Types of Samples Collected

The following samples were collected for laboratory analysis, in-field geochemistry and microbiology research and development as described in the following section.

- Water supply samples – These were collected under WP2 to characterize the source water prior to introducing it to the drill system. They were denoted IG_BH01_WSXXX (“water source”) and included laboratory analyses, in-field parameters and in-field geochemistry analyses. In-field geochemistry was not performed for water source samples after sufficient confidence was gained in the consistency of the measured parameters (not performed for samples IG_BH01_WS013 to IG_BH01_WS019).
- Drilling water return, designated IG_BH01_DWXXX, included the following types of samples:
 - Archive samples of the drill water return were collected under WP2 every 50 m during drilling;
 - Drill water samples associated with OGW samples were collected for laboratory analyses, in-field parameters, in-field geochemistry and microbiology analysis; and
 - Samples were specifically collected for microbiology research and development at corresponding core intervals and included laboratory analyses, in-field parameters and microbiology analysis.
- OGW samples and attempted samples collected during drilling included laboratory analyses, in-field parameters, in-field geochemistry and microbiology analyses, as well as QA/QC samples for laboratory analyses.
- Post drilling samples included two grab samples using the Mount Sopris in-situ sample probe and a third grab sample of attempted purging interval HT009 (WP6). Due to the limited sample volume available from the in-situ probe, only select laboratory analyses were selected for these samples.

A summary description of all fluid samples collected for IG_BH01 can be found in Table A-1, and details of all analyses for these samples are provided in Table A-2 (Appendix A). OGW sample intervals are individually described in Section 3.2, with results presented and discussed in Section 4.0.

3.2 Methodology

3.2.1 Roles and Responsibilities

Golder drilling supervisors, with assistance from the WP3 core loggers also on site, were responsible for all activities associated with WP7 on site sampling, including:

- Equipment decontamination;
- Lowering the wireline packer assembly and purging the sample interval;
- Collection of the OGW sample;
- Sample in-field geochemistry analyses; and
- Laboratory analysis of collected samples by Maxxam Analytics (Maxxam) and Isotope Tracer Technologies (IT2).

The Golder WP7 Lead corresponded with the NWMO WP7 Lead and provided direction to the field staff on confirmation to proceed with purging assessments and sample collection.

Table 1: Sample bottle requirements for Maxxam Analytics and Isotope Tracer Technologies

Parameter Group	Parameter List	Bottle Type Requirement	Sample Volume Requirement	Head Space Requirement	Field Filtering Requirement	Preservative Requirement
Major Elements & Metals (Maxxam)	Na, K, Ca, Mg, Sr, Li, Si, S _{Total} , Fe _{Total}	HDPE plastic bottles	120 mL	Fill line	Yes, 0.45 µm filter	Trace grade nitric acid
	SiO ₂	HDPE plastic bottles	250 mL	None	Yes, 0.45 µm filter	None
	S ²⁻ _{Total}	HDPE plastic bottles	125 mL	Fill line	Yes, 0.45 µm filter	Zinc acetate & sodium hydroxide solution
Anions & Nutrients (Maxxam)	Br, F, Cl, I, SO ₄ , PO ₄ , NO ₃ , NO ₂	HDPE plastic bottles	500 mL	None	Yes, 0.45 µm filter	None
	NH ₄ +NH ₃ , N _{Total}	HDPE plastic bottles	250 mL	Fill line	Yes, 0.45 µm filter	Trace grade sulphuric acid
	P _{Total}					
Stable Isotopes (IT2)	δ ¹⁸ O, δ ² H	HDPE plastic bottles	30 mL	No headspace	Yes, 0.45 µm filter	None
	⁸⁷ Sr/ ⁸⁶ Sr	HDPE plastic bottle	1000 mL	No headspace	Yes, 0.45 µm filter	None
	δ ¹³ C DIC	Amber glass vials, teflon cap	2 x 40 mL glass vials with septa caps	No headspace	Yes, 0.45 µm filter	None
Radioisotopes (IT2)	¹⁴ C-DIC	HDPE plastic bottle	500 mL	No headspace	Yes, 0.45 µm filter	None
	³ H	HDPE plastic bottle	500 mL	No headspace	Yes, 0.45 µm filter	None

Data Delivery

The data delivery was provided to the NWMO and contains the following components, referred to throughout this report:

- DQC workbooks for each sample and attempted sample (these include all notes associated with in-field and laboratory activities, instrument calibration records);
- Groundwater purging data spreadsheets for samples GW001 and GW005;
- Chain of custody records and sample submission reports from Maxxam and IT2; and
- Certificates of analyses for all samples from Maxxam and IT2.

3.2.2 Source Water and Water Tracing

Fresh water was brought from a municipal source in Ignace. Municipal water in Ignace is sourced from Michel Lake and treated to adhere to Ontario drinking water standards; the water undergoes filtering processes and is chlorinated. Once water was collected from Ignace and brought to site, it was stored in designated tanks. As described in the Work Package 2 (WP2) Drilling and Coring Report (Golder 2018a), samples were collected from these fresh water tanks (water source samples) for initial characterization before a fluorescein tracer was added to achieve the desired concentration of 100 ppb for regular drilling activities, and 25 ppb for flushing and post drilling activities. After sampling and tracer addition, the fresh water was introduced to the borehole and drill fluid system with approval from the Golder drilling supervisor.

The fluorescein concentration was measured at the start (from fluid going down hole) and end of each drill run (from the return fluid) to track any changes in concentration during coring of each run. All other drill fluid parameters (temperature, pH, EC, ORP, DO, turbidity and density) were measured from the return fluid at the completion of each run so that run to run changes could be observed. The volume of the drill fluid in the system was measured at the end of each run during continuous drilling and measured before resuming drilling after a significant pause in drilling activities or the addition of fresh water to the system. All drill fluid data and observations are presented in the WP2 Drilling and Coring Report (Golder 2018a).

3.2.3 Interval Selection

During drilling, potential opportunistic groundwater sample intervals were identified by a combination of the following:

- Indications from core sample descriptions, such as fractured zones, weathered or stained fractures, large fracture apertures;
- Drilling fluid circulation measurements, such as fluid loss or gain, changes in drilling fluid parameters (see Table 2);
- Drill pump pressure changes that may indicate loss of circulation or the presence of a water producing feature; and
- Drilling performance indicators, such as rod drops, changes in advance rates, or changes in drive head torque.

The observed criteria to initiate WP7 are described in the “Justification to Initiate WP7” tab of the DQC workbooks.

Table 2: Drill Fluid Field Parameters Measured, and Triggers Observed to Initiate WP7

Field Parameter	Instrument	Trigger to Initiate WP7
Fluorescein dye (tracer)	Aquafluor Handheld Fluorimeter/Turbidimeter	20% decrease in concentration. Note: Minimum detection limit of the fluorimeter (0.4 ppb)
Turbidity	Horiba U52-2, multi-probe	10% change from the original drill fluid
Dissolved Oxygen		10% change from the original drill fluid
Electrical conductivity		10% change from the original drill fluid
pH		change of at least 0.5 from original drill fluid
Temperature		N/A
Density	Hydrometer	N/A

Post-drilling potential sample intervals were identified based on a combination of observations from borehole geophysical surveys (WP5) and preliminary hydraulic conductivity estimates while completing WP6. During WP5, the Fluid Temperature and Resistivity (FTR) log, the Flowing Fluid Electrical Conductivity (FFEC) log and the heat pulse flow meter (HPFM) identified intervals where there is potential fluid movement. Intervals tested during WP6 that demonstrated hydraulic conductivity capable of sustaining purging were selected by the NWMO to attempt purging and sample collection while completing WP6.

3.2.4 Interval Isolation

For sample intervals identified during drilling, a single inflatable wireline packer tool was used to isolate the interval at the bottom of the borehole. During post-drilling sample collection, intervals were isolated using an inflatable straddle packer system lowered on combination of specialty aluminum rods and NQ sized drill rods used for WP6 hydraulic testing. Schematics showing these two configurations are shown in Figure 3. Recorded measurements and calculations for the interval configurations can be found in the “Test Zone Specification” tab of the DQC workbooks for intervals identified during drilling. Post-drilling sample intervals used the WP6 tool configurations as described in the WP6 Data Report – Hydraulic Testing for IG_BH01 (Golder, 2018b).

For sample intervals identified during drilling, the interval’s ability to sustain the minimum required purge rate of 3 system volumes in 72 hours was assessed by performing a multiple step, constant rate pumping test, as documented in the “Purge Rate Assessment” tab of the DQC workbooks. The available purge rates for sample intervals identified during the post-drilling hydraulic testing were estimated based on preliminary field assessments of the intervals’ transmissivity.

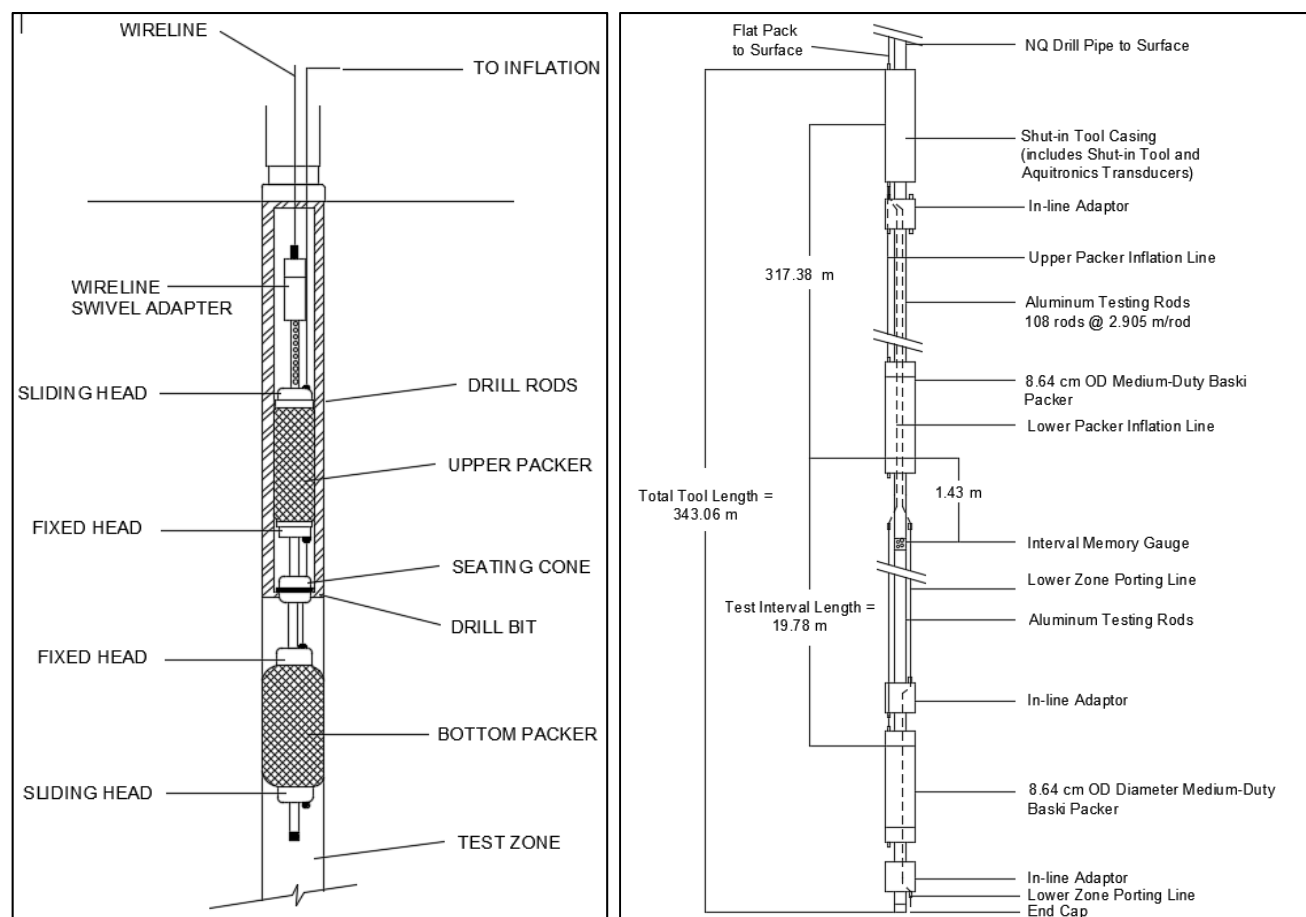


Figure 3: Wireline (left) and post-drilling (right) packer schematics

3.2.5 Purging

Once sample collection from the selected interval was determined to be feasible, purging was carried out to remove the drill fluid from the drill rods, the sample interval and the rock formation to obtain a groundwater sample that was representative of the isolated interval. In all configurations, interval purging was achieved using a Grundfos Redi-Flo2 pump, lowered into the drill or testing rods. Purged water was conveyed to surface via tubing connected to the pump. The purge rate was recorded every 30 minutes in the relevant Purge Data workbook provided to the NWMO in the data deliverable.

3.2.6 Collection of Field Parameters

During purging, the drill fluid field parameters (fluorescein concentration, pH, ORP, DO, EC, turbidity and temperature) were monitored with a Horiba U52-2 multi-parameter water quality meter and recorded every 30 minutes. The Horiba was set up on surface during purging using a flow-through cell and readings were recorded in the relevant Purge Data workbook.

Analytical in-field parameter measurements included alkalinity, total dissolved sulfide, DO (colorimetric method) and ferrous iron, with results recorded in the relevant data tabs of the DQC workbooks, as well as the acQuire DE-07 Groundwater Sample object. The field procedures for these can be found in Appendix C.

3.2.7 Sample Collection

OGW sample collection was initiated once the monitored field parameters were within the specified range and confirmation to proceed was given by the NWMO, as documented in the “Sample Collection Data” tab of the DQC workbooks. The field parameter targets for groundwater sample collection are shown in Table 3.

Table 3: Field Parameter Targets for Groundwater Sample Collection Determination

Field Parameter	Instrument	Drilling Fluid Concentration (prior to purging)	Target to Initiate Sample Collection
Fluorescein dye (tracer)	Aquafluor Handheld Fluorimeter/Turbidimeter	≥100 ppb	<1% of drilling fluid concentration. Note: Minimum detection limit of the fluorimeter (0.4 ug/L)
Turbidity	Horiba U52-2, multi-probe	As measured at the start of purging	Stabilized within ± 10% or ± 5 NTU if <50 NTU
DO			Stabilized within ± 10%
Electrical conductivity			Stabilized within ± 10%
Temperature			Stabilized within ± 0.5 degrees C
ORP			Stabilized within ± 10%
pH			Stabilized within ± 0.1 standard pH units
Purge Volume	Electronic flow meter and totalizer	N/A	Three system volumes or total drilling fluid loss or 72 hours, whichever is greater

OGW sample collection included the following components:

- Collection of groundwater for commercial laboratory analyses and in-field analysis of alkalinity using the Grundfos pump and via the flow-through cell outlet at surface; the samples for commercial analyses were submitted for major elements and metals, anions and nutrients, stable isotopes and radioisotopes (see Table 1 for complete list of parameters; exception is total dissolved sulphide as per below).
- Collection of groundwater for microbiology research and analysis from the Grundfos pump outlet on surface.
- Collection of groundwater using the Mount Sopris in-situ sample probe for commercial laboratory analysis of total dissolved sulphide and in-field analysis of total dissolved sulphide, DO and ferrous iron.

3.2.8 QA/QC

For each sample or sample attempt, a Data Quality Confirmation (DQC) workbook was filled out by the field staff on site to record the sample interval details, equipment decontamination, purge rate assessment, Horiba

calibration details and sample collection details. The DQC workbooks were completed over the length of the sampling period, from identification of the potential interval to collection of the actual sample.

Instrument Calibration Checks

Instrument calibration checks were typically carried out for the Horiba probe and AquaFluor at the start of every day shift during regular coring activities (WP2), and all records can be found in the WP2 data delivery.

Full manual calibration checks and calibrations of each sensor of the Horiba probe were carried out according to the manufacturer's instructions prior to in-field geochemistry analyses for water source or drill water samples, and groundwater sample purging or purging attempts. The appropriate reference solutions were used for each sensor's calibration, as listed in the "pH, Eh, Conductivity" tab of the DQC workbook.

Drill Fluid Sampling

Drill fluid samples associated with the OGW samples were collected when potential sample intervals were identified, to provide baseline chemistry parameters. For Interval 1 (GW001), this sample was collected from the centrifuge tank once confirmation to assess the purge rate was received. Post-drilling, for Intervals 4 (GW006) and 5 (GW009), the initial drill fluid sample was collected from the water purged out of the tubing with the submersible pump.

Equipment Decontamination

All equipment lowered downhole was decontaminated prior to use. Field staff used new, powder-free latex or nitrile gloves while cleaning and handling decontaminated equipment. Alconox® powdered detergent was used with distilled water to remove any dirt, grease or residue from the equipment, followed by a thorough rinse with laboratory grade deionized water. The equipment was then laid on a clean surface and allowed to dry free from dust and contaminants before going downhole. If the equipment was cleaned pre-emptively, it was stored in new plastic bags until required for use. The packer assembly, water level tape indicator, RST transducer, Grundfos submersible pump with electrical cable and Waterra tubing, the flow-through cell, and the in-situ sample probe were decontaminated as required, and recorded in the "Equipment Decontamination" tab of the DQC workbooks for each interval.

A rinsate blank sample was collected from the in-situ sample probe by rinsing the decontaminated sample chamber in deionized water and collecting this rinse water in the appropriate laboratory bottles for Maxxam and IT2. This QA/QC sample type was collected for Interval 1 and Interval 5.

Field Blanks

Field blanks for laboratory analyses at Maxxam and IT2 were collected with laboratory grade deionized water following the same sampling procedures used for the actual groundwater sample. This QA/QC sample type was collected for Interval 1 and Interval 5.

Duplicates

A full suite of QA/QC samples for laboratory analyses, including a rinsate blank, field blank and full sample duplicate was collected for Interval 1 (GW001) at a QA/QC frequency of 1 set for every 3 OGW samples. The duplicate sample was collected immediately subsequent to the actual groundwater sample using the same sampling procedures. A duplicate sulphide sample for laboratory analysis was not able to be collected from Interval 1 due to requirement that it be collected using the in-situ sample probe and the limited sample volume retrieved by the probe.

To follow the frequency of 1 set of QA/QC samples for every 3 OGW samples, a duplicate sample was planned for Interval 5; however, the collection of a set of QA/QC samples was not possible with the modified sampling plan and the limited volume of water that was obtained during the sampling.

Sample Handling and Laboratory Documentation

Both Maxxam and IT2 adhere to the requirements of ISO 17025:2005. Chain of custody (COC) forms were filled out by site staff to ship all samples to the required laboratories. If multiple samples were sent in a single shipment, they were included on a single COC and all results that followed contained all samples that were shipped together in a single report. The DE-09 Chain of Custody object in acQuire was used to document COCs and reconcile samples sent to the laboratories with results received from the laboratories.

Sample bottle labels were filled out before the sample was collected in the bottles. Information included on sample bottle labels included the sample name, date and time collected, preservative and analysis required. Once the collected samples were transferred to the sample bottles as listed in Table 1, the bottles were temporarily stored in a refrigerator on site. As part of the WP3 daily quality confirmation checks, the temperature of the refrigerators was checked to ensure they remained at 4°C. Sample bottles were prepared for shipment by packing them in coolers with ice packs and the appropriate COC.

Upon receipt by Maxxam and IT2, Golder was notified via email and a sample submission report was provided. Maxxam included a copy of the COC, verifying the received condition of the sample and confirming the analyses to be performed. IT2 did not document the condition on the 'as received' samples on the COC, but documented the condition received on the corresponding sample submission form. The documented received sample condition from the laboratories included the temperature received and any broken bottles. For samples where limited volume was obtained and sample bottles were not able to be filled completely, Golder documented this on the COC and the laboratory confirmed in the sample submission document. Laboratory QA/QC is described in Section 4.5.

3.2.9 Methods of Chemical and Isotopic Analysis

For the commercial and in-field analyses, information on the chemical and isotopic analyses, including the method, accuracy, and method detection limit (MDL) for each parameter is attached in Appendix A (Table A-3).

3.2.10 Method to Calculate Drill Water Ratio in Ground Water samples

During drilling, pressurized drill water will enter aquifers or fractures from which groundwater samples are to be collected. The extent of drill water remaining in the water-bearing features can be reduced through purging prior to collection of a ground water sample. Fluorescein tracer was added to drill water to permit evaluation of the extent of drill water present in ground water samples. This evaluation requires measurement of the fluorescein concentration in both the drill water and groundwater sample. It is assumed that the initial fluorescein concentration in groundwater is zero. Equation 1 permits determination of the proportion of drill water by evaluating the difference in fluorescein concentrations. Equation 2 determines the proportion of groundwater in a sample, given a known proportion of drill water from equation 1. Finally, equation 3 permits correction of measured groundwater concentrations based upon the proportion of drill water and groundwater in a sample, and the measured concentration of a given parameter in drill water and groundwater. Equation 3 applies to any single parameter where the parameter was measured above detection limits in both drill water and groundwater. Equation 3 must be repeated for each parameter to be corrected in a given sample, whereas equations 1 and 2 will have a single result for each drill water and groundwater sample pair.

$$Proportion_{DW} = \frac{Fluorescein_{GW}}{Fluorescein_{DW}} \quad (1)$$

$$Proportion_{GW} = 1 - Proportion_{DW} \quad (2)$$

$$GW\ Conc_{actual} = \frac{GW\ Conc_{measured} - (DW\ Conc \times Proportion_{DW})}{Proportion_{GW}} \quad (3)$$

Where:

DW = Drill Water

GW = Groundwater

4.0 RESULTS

Sample intervals were expected to be identified during drilling from drill fluid volume losses or apparent gains and / or drill fluid parameter changes, as outlined in Table 2. During the drilling of IG_BH01, only 1 interval was encountered where there was sufficient inflow into the borehole for the purge volume requirements to be met and a groundwater sample to be collected; this sample interval was located in the upper 100 m of the borehole. As described herein, the general low permeability of the bedrock did not allow sufficient purging to collect further OGW samples during drilling.

Potential sample intervals were identified for post-drilling opportunistic groundwater sample collection using results of the core logging (WP3) and FFEC logging (WP5) with the preliminary results of hydraulic testing (WP6). Highly fractured intervals or intervals with potentially adequate hydraulic conductivity for sampling were targeted.

Golder drilling supervisors (WP2) were responsible for the field identification of potential sample intervals and corresponded with the Golder work package Lead for WP7 when these were identified. As discussed in the WP2 Drilling and Coring Data Report (Golder 2018a), parameter triggers for DO, EC and pH were encountered with some frequency, but were typically attributed to the addition of fresh, traced water and subsequent equalizing in the drill system. The drill fluid was observed to become increasingly saturated with the drill cuttings as drilling progressed, which caused a gradual change of the drill fluid parameters with each run, but turbidity was above the Horiba multi-probe's measurement range for the majority of the program (turbidity was greater than 1000 NTU).

Fluorescein concentration was found to generally decrease in the system as drilling progressed and cuttings were removed from the drill fluid with the centrifuge. Therefore, the drill water required the addition of fluorescein by directly mixing the fluorescein into the drill tank to bring the concentration back to the desired range. The system was also required to be topped up with fresh, traced water as the volume of the hole increased and drill fluid was lost to the rock formation. These two actions required time for the system to equalize and mix, which caused fluorescein concentration decreases below the trigger threshold to be observed frequently.

Volume loss, in combination with observations of the drill core were therefore found to be the most reliable indications of water bearing fractures in the crystalline rock.

A total of thirty-five (35) water samples were submitted for analysis in WP7. Of these, nineteen (19) were water supply samples, supplied from the Town of Ignace municipal water supply. Six (6) samples of drill water return were collected, plus one sample of drill water additive, which was added to the drill water tank on December 12th, 2017. Four (4) OGW samples were collected; however, only sample IG_BH01_GW001 achieved the planned

three system volumes for purging. The other three (3) OGW samples did not meet the three system volumes purging requirement, but were collected as additional sampling attempts as requested by NWMO. Two (2) blank samples of de-ionized water were submitted to verify the expected composition of de-ionized water used in WP7. Two (2) rinsate samples were submitted to confirm adequate decontamination of the in-situ sample probe. One duplicate sample (of IG_BH01_GW001) was submitted for QA/QC, insufficient sample volume prevented submission of additional duplicates of OGW samples.

Complete analytical results of water source, drill water, and drill water additive, are presented in Table A-4. Opportunistic groundwater samples and QA/QC samples (blank and rinsate) are presented in Table A-5. Calculated values for ferric iron are not presented due to the calculation yielding negative values for ferric iron; this may be due to heterogeneity in iron content of the water submitted for laboratory analysis versus that used for the field measurements. Fluorescein concentrations were measured in field but not in the laboratory because no commercial laboratory was identified that was able to complete this analysis. Sulphide concentrations were reported below detection limit in all field and laboratory measurements; accordingly, calculated values for hydrogen sulphide and bisulphide are not presented.

4.1 Interval Selection and Purging

Sample Interval 1 (GW001)

During core run CR18 from 41.26 to 44.27 mbgs, a volume loss of 208 L was encountered, and several stained, broken fractures were observed in the drill core indicating a possible location for collecting an OGW sample. This was communicated to the Golder work package Lead and the decision was made to isolate the interval and assess the achievable purge rate.

The drill string was pulled up, with the bit at 38.24 mbgs, to position the single packer above the suspected water bearing fractures and isolate the interval from 39.55 – 44.27 mbgs.

Once the packer was in place and inflated, and the groundwater stabilized to the assumed static level, the purge rate was assessed in a 3-step constant rate pumping test. A Grundfos Redi-Flo2 submersible pump was lowered to 30.07 mbgs, with the groundwater flow conveyed to surface through 12.7 mm diameter poly tubing. The tubing was directed out of the hole and to a flow-through cell and electronic flowmeter set up in the water storage trailer, where one poly tank (3000 litre capacity) was designated to contain the purge water. Due to the low flow rate, the electronic flowmeter did not provide consistently accurate flow rates, so the flow rate was manually verified using a 1 litre container and stopwatch.

With an interval volume of approximately 171 litres, the minimum purge rate required to achieve 3 system volumes in 72 hours was 0.12 litres per minute (L/min), but the interval was able to sustain an average rate of 0.9 litre per minute without drawing down the water level.

Water quality parameters were continuously monitored with the Horiba probe installed in the flow-through cell and were read every 30 minutes during purging along with a manual check of the flow rate, which averaged 0.9 litre per minute. Purging was carried out for 35 hours, with a total purge volume of 1835 litres or 10.8 system volumes removed, and EC, ORP, DO and turbidity stabilized within 10% variability between readings, temperature within 0.5 degrees C, and 0.1 pH. Fluorescein concentration was approximately 5% of the source drill fluid and slowly dropping when the rest of the field parameters were within their targets. Sample collection was initiated at 5% fluorescein concentration with the decision confirmed by the NWMO, given the extended time it would take to get to the 1% specified in the Table 3.

Prior to setting up the packer for the purge rate assessment, a drill fluid sample was taken from the drill tank, IG_BH01_DW001, and was sampled for laboratory analyses and in-field analyses; this was completed at the time when the decision was made to proceed with purging for sampling the interval. Archive samples of the purge water were collected at one and two system volumes, and the third archive was collected at 10.75 system volumes, just prior to the groundwater sample collection. These samples were subsequently sent to the laboratory for analysis (IG_BH01_GW010, GW011 and GW012). The groundwater sample was collected with a full suite of quality assurance / quality control (QA/QC) samples, including a field blank, a rinsate blank and a duplicate. Tables A-1 and A-2 in Appendix A contain the descriptions and full list of bottle sets and in-field parameters and analyses collected for Interval 1, with the results presented and discussed in Section 4.0.

Following collection of the OGW samples from the outlet of the flow through cell, the Mount Sopris in-situ sample probe was deployed and one litre of sample volume was collected into the nitrogen purged chamber without exposure to the atmosphere. This sample volume was used to fill a bottle for laboratory analysis of total dissolved sulphide, and perform in-field analyses of ferrous iron, DO and total dissolved sulphide content.

Sample Interval 2

During drilling of run CR79, from 215.26 to 218.28 mbgs, a 264 litre volume loss was observed, along with a shear feature in the drill core at the bottom of the previous run, CR078, with aperture and staining, indicating a possible location for collecting an OGW sample. No other field parameter triggers were observed. After communication with the NWMO, the decision was made to assess the purge rate of the interval as a potential OGW sample interval.

The drill string was pulled up to position the drill bit at 213.26 mbgs, and the bottom of the packer set at 214.56 mbgs. The submersible pump was lowered to 68 mbgs and the Horiba probe set up in the flow-through cell in the water storage trailer, as with Interval 1. With a system volume of 968 litres, a minimum purge rate of 0.67 L/min was required to remove three system volumes in 72 hours. The interval was not able to sustain this rate without drawing down the water level to the pump intake, therefore the attempt was abandoned. The packer assembly and purging equipment were removed from the borehole and regular coring activities resumed. No groundwater or drill water samples were collected for attempted sample Interval 2.

No further potential OGW sample intervals were encountered during drilling of IG_BH01. The remainder of the sample attempts were performed before and during WP6 post-drilling packer testing.

Sample Interval 3 (GW005)

During the post-drilling optical televiewer survey on January 30, 2018, a turbid zone was identified between approximately 408 and 420 mbgs. A modified protocol to collect an OGW sample from this zone was developed by the NWMO and communicated to the Golder geophysics staff on site who collected the sample with guidance from WP7 Golder staff.

One litre of sample volume was collected via the Mount Sopris in-situ sample probe, with no interval purging prior, and no nitrogen flushing of the probe sample chamber. The turbid interval was observed in a subsequent optical televiewer survey to have migrated further down the borehole at the time of sample collection, and the sample was therefore collected from a depth of 545 mbgs.

Laboratory samples were collected for analysis of dissolved metals, total metals and major anions at Maxxam, and $\delta^{18}\text{O}$ and $\delta^2\text{H}$ analysis at IT2.

Sample Interval 4 (GW006)

A modified protocol was developed to collect an OGW sample from the hydraulic testing interval (see WP6) HT008 (538.00 – 557.78 mbgs). The interval was selected as a potential OGW sample zone due to indications of measurable water inflow in the WP5 FFEC logging and its location within the repository horizon. Refer to the WP6 Report – Hydraulic Testing for IG_BH01 (Golder 2018b) for further details of the test zone selection and packer tool configuration.

The packers were inflated to isolate the interval, which was allowed to recover with the shut-in tool closed. After the recovery phase, the tubing water level was then drawn down 40 m for the slug phase using the Grundfos submersible pump, and this water sampled as a drill water sample for the initial water chemistry. After the interval recovered 4.5 m (or 13 litres) in the test tubing, the shut-in tool was closed and the pressure recovery was monitored for 10 hours to estimate transmissivity as part of WP6. The resulting transmissivity indicated that the isolated interval would not sustain any reasonable purging rates. However, given the interval's location with a potential repository zone, a decision was made with the NWMO to proceed with an attempt to collect a groundwater sample. With the shut-in tool still closed, the Mount Sopris in-situ sample probe was lowered to a depth of 528 mbgs.

With the in-situ sample probe in place, the shut-in tool was opened allowing formation water to enter the test tubing from the sample interval. The sample chamber remained closed as the water level recovered 17 m (48.6 litres) in the test tubing over 5 hours. After the recovery time, the sample chamber was opened to collect one litre of sample volume from the test tubing. The sample chamber was purged with nitrogen prior to sample collection, and the sample was retrieved into the appropriate sample bottles using displacement via nitrogen gas.

The one litre of sample volume retrieved was used to collect field parameters and samples for laboratory analysis for metals, major anions and sulphide from Maxxam and a reduced sample volume for tritium analysis at IT2 (Table A-2).

Sample Interval 5 (GW009)

Modified protocol was developed to collect an OGW sample from the hydraulic testing interval HT009 (625.16 – 644.94 mbgs). Refer to the WP6 Report – Hydraulic Testing for IG_BH01 (Golder 2018b) for details of the test zone selection and packer tool configuration. The interval was preliminarily assessed with a transmissivity of approximately $1\text{E-}7\text{ m}^2/\text{sec}$, corresponding to a theoretical purge rate of approximately 0.5 L/min. The system volume for this test interval was approximately 1300 litres, indicating that one system volume could be purged in approximately 43 hours. After consultation with the NWMO, purging of the interval proceeded since it presented the highest measured transmissivity within the borehole to that point.

Purging was set up so that the tubing from the Grundfos pump was connected to the flow-through cell near the collar of the hole in the heated drill containment area, with the outflow from the flow-through cell conveyed to the poly tank within the drill rig. A digital flow meter / totalizer was set up inline with the flow-through cell, but the flow rate was manually verified using a stopwatch and measuring cup during purging. A drill water sample was collected at the start of purging to represent the initial water chemistry, with a full suite of in-field analyses and laboratory analyses carried out (see tables in Appendix A).

Once purging was underway, it was found that the interval could not sustain a constant flow of 0.5 L/min. To facilitate purging at the lower flow rate, the water level was drawn down over a period of approximately 1 hour, during which time the water quality and fluorescein concentration readings were collected and recorded. Following this, the pump was stopped, and the water level was allowed to recover before being drawn down again. With a lower average flow rate being achieved, the system volume was adjusted to a modified system volume of the

interval straddled by the packers, plus the length of aluminum test rods below the shut-in tool (approximately 308 m). The shut-in tool prevented the in-situ sample probe from passing. One modified system volume of 744 litres was purged from the interval in 47.7 hours, with an overall average flow rate of 0.26 L/min achieved. With this volume removed, it was assumed that some formation water would have recovered above the level of the shut-in tool.

During purging, field parameters were not observed to stabilize, and remained close to the initial drill water. Purging was stopped after the removal of one modified system volume, and the Grundfos pump removed from the borehole. The nitrogen purged Mount Sopris in-situ sampler was then lowered to 300.7 mbgs, where the OGW sample was collected in the test tubing above the shut-in tool.

Field parameters were collected from the OGW sample, as well as bottles for laboratory analyses of major anions and cations and sulphide by Maxxam, and $\delta^{18}\text{O}$ and $\delta^2\text{H}$ analyses by IT2. A limited volume was filled for tritium analyses by IT2.

4.2 Water Supply Samples

Water supply samples are generally of relatively consistent composition (except for pH) over the duration of WP7, which is expected given that the samples are taken from municipal water supply for drinking water. Ignace's municipal water is sourced from Michel Lake, with water supply for IG_BH01 collected from the municipal source from 5 November 2017 to 16 February 2018. The results are summarized as follows:

- Field pH ranged from 5.77 to 8.47;
- Total alkalinity ranged from 13 to 25 mg/L CaCO_3 (16 to 30 mg/L HCO_3);
- Sulphate ranged from <1.0 to 1.9 mg/L;
- Total dissolved sulphide was below the method detection limit (<0.02 mg/L) in all samples;
- Dissolved oxygen ranged from 7.54 to 14.8 mg/L;
- Oxygen-18 ($\delta^{18}\text{O}$) ranged from -8.5 to -8.1 ‰ VSMOW;
- Deuterium ($\delta^2\text{H}$) ranged from -70.3 to -67.6 ‰ VSMOW;
- $\delta^{13}\text{C}$ -DIC ranged from -13.2 to -5.5 ‰ PDB;
- ^{14}C -DIC ranged from 67 to 97 percent Modern Carbon (pMC);
- ^3H ranged from 6.7 to 12 TU; and
- $^{87}\text{Sr}/^{86}\text{Sr}$ ratio ranged from 0.728 to 0.732.

Relative results of key major ions are presented in a piper plot in Figure 4. Water supply samples are clustered and demonstrate that the major ion composition is generally consistent. The major ion chemistry of the water supply samples is represented by similar proportions of calcium and sodium, with lesser concentrations of magnesium, and a higher proportion of bicarbonate relative to other anions.

Oxygen-18 and deuterium results are presented in Figure 5, and are compared to the Global Meteoric Water Line (GMWL) and Local Meteoric Water Line (LMWL). The LMWL presented is for Atikokan, Ontario (Fritz et al., 1987). This LMWL is considered a reasonable representation (based on distance) of the LMWL for Ignace, Ontario, for

which a closer published LMWL has not been identified. All water supply samples plot below and to the right of the LMWL and GMWL.

Supply water samples are collected from the municipal water supply which is sourced from a local lake, therefore it is known that the samples are primarily composed of modern precipitation. Tritium results are consistent with this origin, as tritium contents greater than 5 TU in natural waters are a consequence of anthropogenic nuclear activities.

4.3 Drill Water Samples

Drill water samples demonstrate a greater extent of variability in composition as compared to water supply samples. High turbidity was observed in the drill water samples. Sample IG_BH01_DW001 is associated with water sample IG_BH01_GW001 taken from the interval 39.55 – 44.27 m, sample IG_BH01_DW024 is associated with water sample IG_BH01_GW006 taken from the interval 538.00 – 557.78 m, and sample IG_BH01_DW025 is associated with water sample IG_BH01_GW009 taken from the interval 625.16-644.94 m. The results are summarized as follows:

- Field pH ranged from 7.04 to 10.6;
- Total alkalinity ranged from 22 to 192 mg/L CaCO₃ (27 to 65 mg/L HCO₃);
- Sulphate ranged from 2.0 to 6.1 mg/L;
- Total dissolved sulphide was below method detection limit (<0.02 mg/L) in all samples;
- DO concentrations ranged from 2.38 to 13.9 mg/L;
- Oxygen-18 ($\delta^{18}\text{O}$) ranged from -8.6 to -8.0 ‰ VSMOW;
- Deuterium ($\delta^2\text{H}$) ranged from -70.2 to -67.4 ‰ VSMOW;
- $\delta^{13}\text{C}$ -DIC ranged from -14.7 to -10.1 ‰ PDB;
- ^{14}C -DIC ranged from 61 to 91 % modern carbon;
- ^3H ranged from 8.6 to 11 TU; and
- $^{87}\text{Sr}/^{86}\text{Sr}$ ratio ranged from 0.716 to 0.796.

Relative results of key major ions are presented in a piper plot in Figure 4. Two drill water samples are clustered and demonstrate that they are of generally consistent composition, while a third sample (IG_BH01_DW025) plots in isolation from all drill water and other samples. The major ion compositions of the clustered samples are more dominated by sodium, potassium, and bicarbonate. Sample IG_BH01_DW025 has no dominant cation type, but is magnesium-poor, and is chloride dominant among anions. Total cation concentrations (and chloride concentrations for IG_BH01_DW025 only) in drill water are an order of magnitude greater than supply water samples.

Oxygen-18 and deuterium results are presented in Figure 5, and all drill water samples plot below and to the right of the LMWL.

Drill water samples are derived from supply water, which is collected from the municipal water supply. This water is sourced from Lake Michel, therefore it is known that the samples are primarily comprised of modern

precipitation. Tritium results are consistent with this origin, as tritium contents greater than 5 TU in natural waters are a consequence of anthropogenic nuclear activities.

A sample of drill water additive (IG_BH01_DW026) was collected and analyzed according to a revised analytical parameter set defined by NWMO. Alkalinity and isotopic parameters were not analyzed and therefore the sample does not appear on either figure. The key results are summarized as follows:

- Field pH of 9.68;
- Turbidity greater than 1000 NTU;
- Fluoride concentration of 0.94 mg/L;
- Sulphate concentration of 3.1 mg/L; and
- Sodium concentration of 86 mg/L.

4.4 Groundwater Samples

Collection of samples IG_BH01_GW005, IG_BH01_GW006, and IG_BH01_GW009 was limited by low transmissivity of the rock formation. The decision to collect OGW samples from these intervals was taken under direction from NWMO, with the understanding that a reduced sample volume would be collected, and the likelihood of collecting a sample dominantly comprised of formation water (as opposed to drill water) would be reduced. Samples with reduced volume did not have sufficient volume to permit the full range of analyses, and therefore prioritization of parameters was provided by NWMO. Alkalinity measurements were not completed due to low sample volumes, and therefore these samples are not presented on Figure 4. Sample IG_BH01_GW001 was analyzed for the complete range of planned analytical parameters. Additional discussion pertaining to the collection of each sample is provided in Section 3.0.

Sample Interval 1 (39.55 – 44.27 m)

Sample IG_BH01_GW001 was collected at shallow depth within the borehole (39.55 – 44.27 mbgs). Key analytical results are summarized as follows:

- Field pH of 6.27;
- Total alkalinity of 49.7 mg/L CaCO_3 (61 mg/L HCO_3);
- Sulphate concentration of 1.1 mg/L;
- Total dissolved sulphide was below method detection limit (<0.02 mg/L) in all samples;
- Oxygen-18 ($\delta^{18}\text{O}$) of -13.5 ‰ VSMOW;
- Deuterium ($\delta^2\text{H}$) of -96.6 ‰ VSMOW;
- $\delta^{13}\text{C}$ -DIC of -21.8 ‰ PDB;
- ^{14}C -DIC of 75 pMC;
- ^3H of 6.9 TU; and
- $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.731.

Results for key major ions are presented in a piper plot in Figure 4. Based on the major ion chemistry, the dominant major ions in IG_BH01_GW001 are bicarbonate and to a lesser extent calcium and sodium. Concentrations of chloride and sulphate were low as compared to other samples.

Oxygen-18 and deuterium results are presented in Figure 5, and the sample plots in isolation from all other WP7 samples, in the lower left area of the plot on both the LMWL and GMWL.

Analytical results of tritium indicate relatively lower proportions of modern precipitation as compared to the average water supply and drill water values, but within the range indicative of modern precipitation. Tritium results are consistent with this origin, as tritium contents greater than 5 TU in natural waters are a consequence of anthropogenic nuclear activities.

Sample Interval 2 (215.26 – 218.28 m)

As described in Section 3.0, the attempt to collect a sample from this interval was abandoned and no sample was collected.

Sample Interval 3 (408 – 420 m)

Sample IG_BH01_GW005 was collected to investigate the nature of a reddish cloudy zone observed in the televiewer between 408 and 420 mbgs, and collected at 545 mbgs as the target dropped. The majority of metals were not found to contain a large particulate fraction as total metals values were generally less than twice the dissolved concentration. Dissolved fraction results were not notable for any parameter. The exception to this finding is iron, which was below detection for the dissolved fraction, and measured at 6 mg/L as total iron. Therefore, the particulate iron fraction may be responsible for the reddish cloudy zone observed. Analyses followed a revised parameter set provided by NWMO, and key results are summarized as follows:

- Field pH of 7.94;
- Sulphate concentration of 21 mg/L;
- DO concentration of 10.4 mg/L;
- Oxygen-18 ($\delta^{18}\text{O}$) of -9.1 ‰ VSMOW; and
- Deuterium ($\delta^2\text{H}$) of -71.5 ‰ VSMOW.

Oxygen-18 and deuterium results are presented in Figure 5. The sample plots in proximity to water supply and drill water samples, below and to the right of the LMWL and GMWL. The sample plotting in the proximity of the water supply and drill water indicates that the sample composition is mostly drill water.

Although no corresponding drill water sample is available for IG_BH01_GW005, concentrations of bromide, chloride, sulphate, calcium, and total sulphur are notably greater than in typical drill water concentrations indicating an input of ground water with higher concentrations of these elements. The fluorescein concentration implies this sample is partially composed of drill water, therefore concentrations of these parameters would be greater again in pure formation water.

Sample Interval 4 (538.00 – 557.78 m)

Sample IG_BH01_GW006 was collected at 538.00 – 557.78 mbgs. Analyses followed a reduced parameter set due to low sample volume, and key results are summarized as follows:

- Field pH of 7.20;

- Sulphate concentration of 6.5 mg/L;
- Total dissolved sulphide was below the method detection limit (<0.02 mg/L) in all samples;
- DO concentration of 8.74 mg/L; and
- ^3H of 8.1 TU.

Concentrations of bromide and chloride are notably greater than in the corresponding drill water sample, IG_BH01_DW024. The fluorescein concentration of 15.92 ppb implies this sample is 61% drill water, therefore concentrations of these parameters would be greater again in pure formation water. A calculated corrected value is presented in Section 4.6. No correction calculation is possible for bromide because the concentration of bromide in the drill water sample was below the method detection limit. Analytical results of tritium indicate similar proportions of modern precipitation as compared to the average water supply and drill water values. Tritium results are consistent with this origin, as tritium contents greater than 5 TU in natural waters are a consequence of anthropogenic nuclear activities.

Sample Interval 5 (625.16-644.94 m)

Sample IG_BH01_GW009 was collected at 625.16 – 644.94 mbgs. Analyses followed a reduced parameter set due to low sample volume, and key results are summarized as follows:

- Field pH of 7.51;
- Sulphate concentration of 13 mg/L;
- Total dissolved sulphide was below method detection limit (<0.02 mg/L) in all samples;
- Dissolved oxygen concentration of 8.99 mg/L;
- Oxygen-18 ($\delta^{18}\text{O}$) of -8.8 ‰ VSMOW;
- Deuterium ($\delta^2\text{H}$) of -70.8 ‰ VSMOW; and
- ^3H of 8.1 TU.

Oxygen-18 and deuterium results are presented in Figure 5. The sample plots in proximity to water supply and drill water samples, below and to the right of the LMWL. The sample plotting in the proximity of the water supply and drill water indicates that the sample composition is mostly drill water. Analytical results of tritium indicate similar proportions of modern precipitation as compared to the average water supply and drill water values. Tritium results are consistent with this origin, as tritium contents greater than 5 TU in natural waters are a consequence of anthropogenic nuclear activities.

Concentrations of bromide, chloride, and sulphate are notably greater than in the corresponding drill water sample, IG_BH01_DW025. The fluorescein concentration of 20.27 ppb implies this sample is 98% drill water, therefore concentrations of these parameters would be greater again in pure formation water.

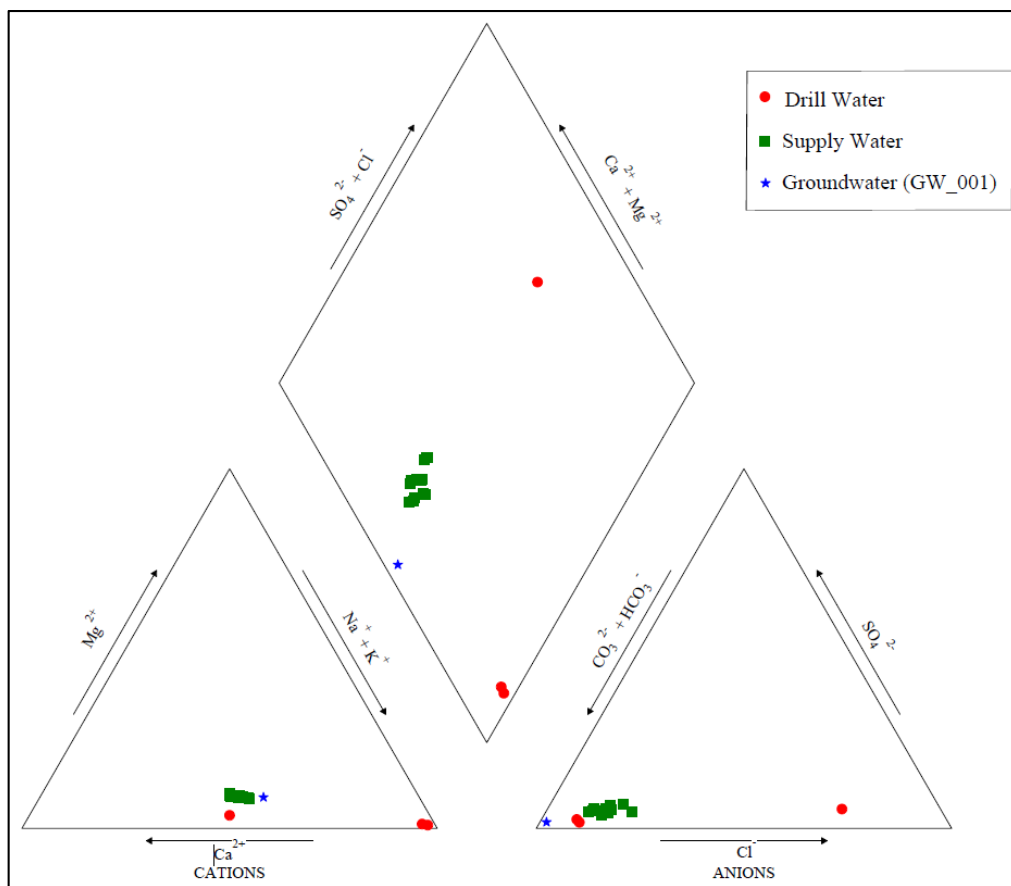


Figure 4: Piper plot of select WP7 water samples

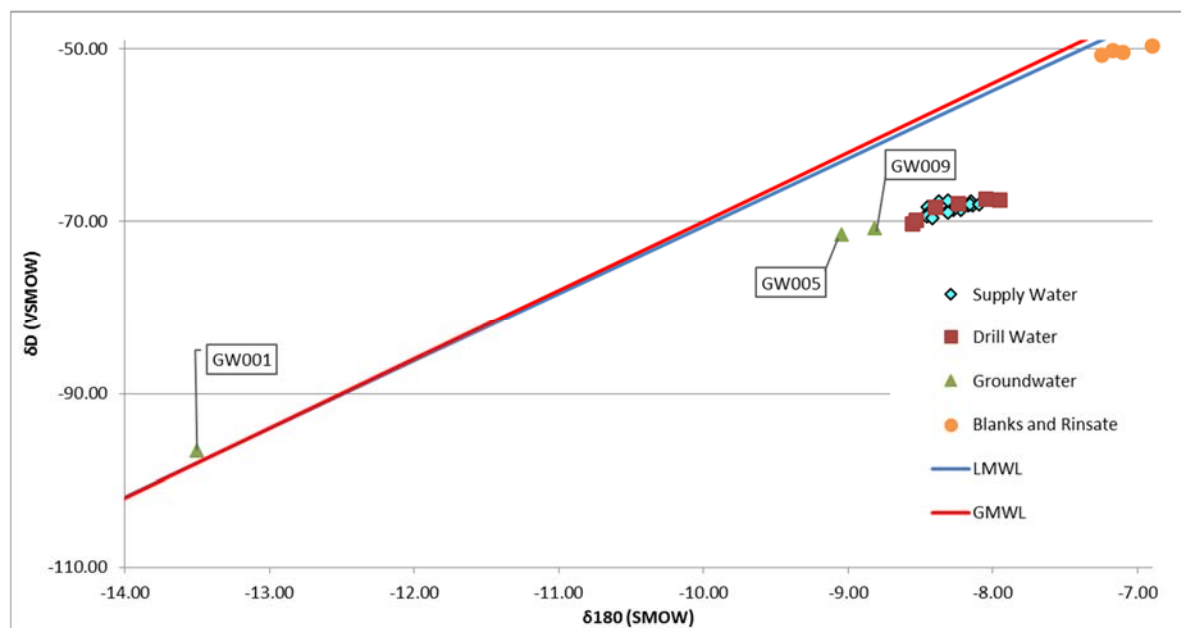


Figure 5: Oxygen ($\delta^{18}\text{O}$) - Deuterium ($\delta^2\text{H}$) plot of WP7 water samples. Local Meteoric Water Line for Atikokan, Ontario (Fritz et al., 1987).

4.5 QA/QC Samples

To evaluate the consistency of analytical results for IG_BH01_GW001 and duplicate sample IG_BH01_GW002, relative percent difference (RPD) was calculated for all laboratory reported parameters above detection limit as well as field measured alkalinity. A single set of field measurements was completed for all other field parameters. All RPD values were below 10%, within the screening criteria of less than 20%, a typical limit for identifying variation in sample results outside normal ranges.

Two field blanks were submitted for analysis and all parameters were reported below the method detection limits. Two field rinsate samples were submitted to confirm the cleanliness of rinsate from in-situ sample probe after decontamination. In rinsate sample IG_BH01_GW003, all parameters were reported below the method detection limits, while in rinsate sample IG_BH01_GW008, all parameters except total ammonia and total phosphorus were below the method detection limits. The three parameters above detection in sample IG_BH01_GW008 were all less than or equal to twice the method detection limit, and are within acceptable limits for rinsate quality.

Laboratory completed duplicate analyses (laboratory QA/QC on single samples submitted in addition to blind duplicate results submitted by field staff) for select parameters were completed for nineteen (19) samples. RPD was calculated for all duplicate results, with all RPD values less than 20%.

The QA/QC program for WP7 water samples did not identify any data quality concerns.

4.6 Comparison of Water Supply, Drill Water, and Groundwater Results

Water supply samples (Section 4.2) generally contain lower concentrations of most constituents as compared to drill water and groundwater samples. This is consistent with the nature of the water as a treated potable supply. Comparison of drill water and groundwater samples is limited by extent of drill water contamination present in samples IG_BH01_GW005, IG_BH01_GW006, and IG_BH01_GW009 (Section 4.3). Comparing drill water results to IG_BH01_GW001, the drill water samples contain higher concentrations of most parameters, while bromide, nitrite, nitrate, orthophosphate, and sulphide are below the method detection limits in all drill water samples as well as IG_BH01_GW001. Drill water samples (except IG_BH01_DW024) were turbid, and samples IG_BH01_DW001, IG_BH01_DW002, IG_BH01_DW006, IG_BH01_DW013 all reported turbidity greater than 1000 NTU. No clear pattern was evident between sample types for key parameters pH, sulphate, or sulphide, while total alkalinity was greater in drill water and groundwater samples as compared to water supply samples.

Drill water samples have a cation composition (Figure 4), which is sodium and potassium dominant as compared to water supply samples and IG_BH01_GW001, with the exception of IG_BH01_DW025. Sample IG_BH01_DW025 has a similar cation composition to the water supply samples and an anion composition which is chloride dominant, while all other water samples have a bicarbonate dominant anion composition. Groundwater sample IG_BH01_GW001 generally has similar relative cation and anion characteristics to water supply samples, with a stronger bicarbonate signature while absolute cation concentrations are approximately double supply water samples, and chloride was below the method detection limit.

Drill water and water supply samples plot in a cluster on Figure 5, indicating the oxygen-18 – deuterium composition of drill water is reflective of the original water supply it was derived from. Samples IG_BH01_GW005 and IG_BH01_GW009, which are interpreted to contain drill water contamination, plot relatively close to the water supply and drill water samples, but slightly left of the water source and drill water cluster, indicating that the sample contained some natural groundwater. IG_BH01_GW001 plots well to the lower left of all other samples, with more strongly negative values for both $\delta^{18}\text{O}$ and $\delta^2\text{H}$.

Blank and rinsate samples plot in the upper right of the figure, and have a distinct composition as compared to all other samples, which is appropriate given that the de-ionized water was supplied by the laboratory, and therefore bears no relation to local waters.

4.7 Drill Water Contamination of Groundwater Samples

As described in Section 3.2.11, calculations can be completed to determine the proportion of drill water that comprises a groundwater sample, and subsequently this result can be used to determine corrected parameter concentrations for groundwater samples.

During drilling and prior to collection of the sample, the fresh water source was mixed to a fluorescein concentration of 100 ppb. However, the elevated turbidity of the drill water return masked the fluorescein concentration measurements and was not considered reliable until the filtering of fluorescein samples was implemented from 77.3 m to the end of drilling.

Prior to the start of purging for sample IG_BH01_GW001, the borehole was circulated with clean drill water with a measured fluorescein concentration of 78.6 ppb. As the turbidity decreased during purging, the variability in fluorescein concentrations reduced providing a more reliable measurement at the time of sampling. The variability in measured fluorescein concentrations due to turbidity introduces uncertainty in the calculation of the percentage of drill water remaining in the groundwater sample. Sample IG_BH01_GW001 contained 4.06 ppb fluorescein. The percentage of drill fluid in sample IG_BH01_GW001 can be estimated from 4.1% to 5.2% based on an assumed fluorescein concentration in the drill fluid ranging between 78.6 ppb and 100 ppb. The corrected analyte values applying the more conservative 5.2% drill water composition are presented in Appendix B.

Sample IG_BH01_GW005 represents a turbid zone identified between approximately 408 and 420 mbgs, but collected at 545 mbgs as the target dropped in the borehole. A modified protocol to collect an opportunistic groundwater sample from this zone was developed by the NWMO and communicated to the Golder geophysics staff on site who collected the sample at a depth of 545 m. The borehole was drilled using 100ppb fluorescein water, while the fluorescein concentration of the drill fluid that had been circulated throughout the borehole prior to sample collection was 25 ppb. The fluorescein concentration of the sample was 30.72 ppb. The increase in fluorescein concentration may be due to fluctuations in drill fluid turbidity within the borehole or possibly inflow of water from the formation with elevated fluorescein concentrations used during drilling. The cause of the variation in fluorescein concentration cannot be determined with confidence; however, it is evident that the sample is primarily comprised of drill fluid.

The intervals from samples IG_BH01_GW006 and IG_BH01_GW009 were not able to sustain a pumping rate that allowed the system to be purged to the criteria listed in Table 3 within a reasonable time period (72 hours). A full OGW sample was not collected from the flow-through cell on surface; the in-situ sample probe was instead used to collect a limited sample volume (1 liter) from just above the interval. Based on the fluorescein concentrations in the samples and the corresponding drill water samples, samples IG_BH01_GW006 and IG_BH01_GW009 were comprised of 61% drill water and 98% drill water, respectively. The low proportion of groundwater in these samples (particularly for IG_BH01_GW009) presents a concern with regard to accurate calculation of corrected values when formation water comprises a minority of the water in the sample. Correction of metals parameters is not possible as only total metals analysis could be completed with the limited sample volume, whereas drill water samples were analysed for dissolved metals. Additionally, several parameters were not analysed due to low sample volume, and several other parameters are below detection limit. Based on the very low proportion of formation water present (2%), it is Golder's opinion that there is insufficient confidence in the accuracy of the corrections to present calculated values for IG_BH01_GW009. For sample IG_BH01_GW006, it is possible to calculate corrected values for two parameters; all other parameters cannot be corrected due to an incomplete

parameter pair between the OGW and drill water samples, or results below the method detection limit. The corrected values are presented in Table B-1 in Appendix B.

5.0 REFERENCES

- Fritz, P., Drimmie, R.J., Frape, S.K., & O'Shea, K. (1987). The isotopic composition of precipitation and groundwater in Canada. International Atomic Energy Agency (IAEA).
- Golder (Golder Associates Ltd.), 2017. Phase 2 Initial Borehole Drilling and Testing - Ignace Area - Initial Borehole Characterization Plan for IG_BH01.
- Golder (Golder Associates Ltd.), 2018a. Phase 2 Initial Borehole Drilling and Testing – Ignace Area – WP2 Data Report – Drilling and Coring for IG_BH01. NWMO Report Number: APM-REP-01332-0229.
- Golder (Golder Associates Ltd.), 2018b. Phase 2 Initial Borehole Drilling and Testing – Ignace Area – WP6 Data Report – Hydraulic Testing for IG_BH01. NWMO Report Number: APM-REP-01332-0235.
- Golder (Golder Associates Ltd.) and PGW (Paterson Grant and Watson Ltd.), 2017. Phase 2 Geoscientific Preliminary Assessment, Geological Mapping, Township of Ignace and Area, Ontario: APM-REP-01332-0225.
- SGL (Sander Geophysics Limited), 2015. Phase 2 Geoscientific Preliminary Assessment, Acquisition, Processing and Interpretation of High-Resolution Airborne Geophysical Data, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06145-0002.

APPENDIX A

Table A-1: Sample Summary Description for IG_BH01 Fluid Samples

Table A-2: Summary of Analyses for Groundwater, Drill Water and Water Source Samples Collected for IG_BH01

Table A-3: Laboratory Analytical Methodology

Table A-4: Water Source and Drill Water Sample Results

Table A-5: QA/QC Water Quality Results

Sample ID	Work Package	From (m)	To (m)	Date Sampled	Comments
IG_BH01_GW001	7	39.55	44.27	13-Nov-17	OGW sample
IG_BH01_GW002	7	39.55	44.27	13-Nov-17	Duplicate OGW sample for IG_BH01_GW001
IG_BH01_GW003	7	39.55	44.27	13-Nov-17	Rinsate OGW sample for IG_BH01_GW001
IG_BH01_GW004	7	39.55	44.27	13-Nov-17	Field blank OGW sample for IG_BH01_GW001
IG_BH01_GW005	7	545.00	545.00	31-Jan-18	OGW sample of "cloudy" water identified during geophysics; collected with Mt Sopris probe
IG_BH01_GW006	7	538.00	557.78	16-Feb-18	OGW sample collected with Mt Sopris probe from HT008
IG_BH01_GW007	7	625.16	644.94	20-Feb-18	Field blank
IG_BH01_GW008	7	625.16	644.94	21-Feb-18	Field rinsate blank
IG_BH01_GW009	7	625.16	644.94	22-Feb-18	OGW sample collected with Mt Sopris probe from HT009
IG_BH01_GW010	7	39.55	44.27	27-Jul-18	Purge water sample from IG_BH01_GW001 after 1 system volume purged. Purged on 12-Nov-17.
IG_BH01_GW011	7	39.55	44.27	27-Jul-18	Purge water sample from IG_BH01_GW001 after 2 system volumes purged. Purged on 12-Nov-17.
IG_BH01_GW012	7	39.55	44.27	27-Jul-18	Purge water sample from IG_BH01_GW001 after 10 system volumes purged. Purged on 13-Nov-17.
IG_BH01_DW001	2	41.26	44.27	11-Nov-17	Drill water collected for IG_BH01_GW001
IG_BH01_DW002	7	98.26	101.27	16-Nov-17	Microbiology sample depth
IG_BH01_DW003	2	98.26	101.27	16-Nov-17	Archive @ 100 m
IG_BH01_DW004	2	149.26	152.27	23-Nov-17	Archive @ 150 m
IG_BH01_DW005	2	200.26	203.26	25-Nov-17	Archive @ 200 m
IG_BH01_DW006	7	218.28	221.30	26-Nov-17	Microbiology sample depth
IG_BH01_DW007	2	248.28	251.28	27-Nov-17	Archive @ 250 m
IG_BH01_DW008	2	299.28	302.33	28-Nov-17	Archive @ 300 m
IG_BH01_DW009	2	347.28	350.32	1-Dec-17	Archive @ 350 m
IG_BH01_DW010	2	398.29	401.28	2-Dec-17	Archive @ 400 m
IG_BH01_DW011	2	449.28	452.30	4-Dec-17	Archive @ 450 m
IG_BH01_DW012	2	497.25	500.26	8-Dec-17	Archive @ 500 m
IG_BH01_DW013	7	512.29	515.30	8-Dec-17	Microbiology sample depth
IG_BH01_DW014	2	548.29	551.28	10-Dec-17	Archive @ 550 m
IG_BH01_DW015	2	599.29	602.29	12-Dec-17	Archive @ 600 m
IG_BH01_DW016	2	647.28	650.27	14-Dec-17	Archive @ 650 m
IG_BH01_DW017	2	698.27	701.21	17-Dec-17	Archive @ 700 m
IG_BH01_DW018	2	749.26	752.28	19-Dec-17	Archive @ 750 m
IG_BH01_DW019	2	797.26	800.25	7-Jan-18	Archive @ 800 m
IG_BH01_DW020	2	848.28	851.12	9-Jan-18	Archive @ 850 m
IG_BH01_DW021	2	899.28	902.28	11-Jan-18	Archive @ 900 m
IG_BH01_DW022	2	947.27	950.28	14-Jan-18	Archive @ 950 m
IG_BH01_DW023	2	998.27	1001.27	16-Jan-18	Archive @ 1000 m
IG_BH01_DW024	7	538.00	557.78	16-Feb-18	Drill water collected for IG_BH01_GW006
IG_BH01_DW025	7	625.16	644.94	20-Feb-18	Drill water collected for IG_BH01_GW009
IG_BH01_DW026	2	-	-	10-Dec-17	Drill water additive sample
IG_BH01_WS001	2	-	-	5-Nov-17	Water source sample for drilling
IG_BH01_WS002	2	-	-	7-Nov-17	Water source sample for drilling
IG_BH01_WS003	2	-	-	11-Nov-17	Water source sample for drilling
IG_BH01_WS004	2	-	-	16-Nov-17	Water source sample for drilling
IG_BH01_WS005	2	-	-	17-Nov-17	Water source sample for drilling
IG_BH01_WS006	2	-	-	18-Nov-17	Water source sample for drilling
IG_BH01_WS007	2	-	-	20-Nov-17	Water source sample for drilling; IT2 bottled Nov 24, 2017
IG_BH01_WS008	2	-	-	21-Nov-17	Water source sample for drilling; IT2 bottled Nov 24, 2017
IG_BH01_WS009	2	-	-	25-Nov-17	Water source sample for drilling
IG_BH01_WS010	2	-	-	26-Nov-17	Water source sample for drilling
IG_BH01_WS011	2	-	-	29-Nov-17	Water source sample for drilling
IG_BH01_WS012	2	-	-	3-Dec-17	Water source sample for drilling
IG_BH01_WS013	2	-	-	6-Dec-17	Water source sample for drilling; IT2 bottled Jan 11, 2018
IG_BH01_WS014	2	-	-	15-Dec-17	Water source sample for drilling; IT2 bottled Jan 11, 2018
IG_BH01_WS015	2	-	-	5-Jan-18	Water source sample for drilling; IT2 bottled Jan 11, 2018
IG_BH01_WS016	2	-	-	17-Jan-18	Water supply for post drilling BH flushing
IG_BH01_WS017	2	-	-	18-Jan-18	Water supply for post drilling BH flushing
IG_BH01_WS018	6	-	-	31-Jan-18	Water supply for WP06
IG_BH01_WS019	6	-	-	16-Feb-18	Water supply for WP06

Notes:

IG_BH01_GWxxx indicates a groundwater sample
 IG_BH01_DWAddxx indicates a drill water additive sample
 IG_BH01_DWxxx indicates a drill water sample
 IG_BH01_WSxxx indicates a water source (fresh water supply) sample

Prepared By: NS

Checked By: MG

Reviewed By: ML

Sample ID	Date Collected	Time Collected	Depth		Volume Purged Prior to Sample Collection	Bottle Sets for Laboratory Analysis												In-Field Geochemistry					In-Field Measurements ¹	Microbiology			Purpose of Sample
			From (mbgs)	To (mbgs)		Major Elements & Metals ⁴			Anions & Nutrients ⁴		Stable Isotopes ⁵			Radioisotopes ⁵		Fluorescein	Sulphide	Dissolved Oxygen	Ferrous Iron	Alkalinity	PLFA	DNA		Cell Count			
						Na, K, Ca, Mg, Sr, Li, Si, S _{Total} , Fe _{Total}	SiO ₂	S ²⁻ _{Total}	Br, F, Cl, I, SO ₄ , PO ₄ , NO ₃ , NO ₂	NH ₄ +NH ₃ , N _{Total} , P _{Total}	δ ¹⁸ O, δ ² H	⁸⁷ Sr/ ⁸⁶ Sr	δ ¹³ C DIC	¹⁴ C-DIC	³ H												
IG_BH01_GW001	13-Nov-17	12:00	39.55	44.27	1835 litres ³	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Opportunistic groundwater sample		
IG_BH01_GW002	13-Nov-17	12:00	39.55	44.27	1835 litres ³	✓ ²	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓					Duplicate associated with IG_BH01_GW001		
IG_BH01_GW003	12-Nov-17	19:00	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓										Rinsate blank associated with IG_BH01_GW001		
IG_BH01_GW004	12-Nov-17	12:30	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓										Field blank associated with IG_BH01_GW001		
IG_BH01_GW005	31-Jan-18	6:45	545	545	-	✓ ²		✓	✓		✓											✓			Turbid zone during OTV logging		
IG_BH01_GW006	16-Feb-18	16:20	538	557.78		✓		✓	✓						✓						✓				Opportunistic groundwater sample		
IG_BH01_GW007	20-Feb-18	13:55	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										Field blank associated with IG_BH01_GW009		
IG_BH01_GW008	21-Feb-18	9:00	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										Rinsate blank associated with IG_BH01_GW009		
IG_BH01_GW009	22-Feb-18	13:55	625.16	644.94	747 litres ³	✓		✓	✓		✓				✓						✓				Opportunistic groundwater sample		
IG_BH01_GW010	27-Jul-18 (Purged on 12-Nov-17)	14:00	39.55	44.27	171 litres ⁶	✓			✓		✓										✓				Purge water associated with IG_BH01_GW001		
IG_BH01_GW011	27-Jul-18 (Purged on 12-Nov-17)	14:10	39.55	44.27	342 litres ⁶	✓			✓		✓										✓				Purge water associated with IG_BH01_GW001		
IG_BH01_GW012	27-Jul-18 (Purged on 13-Nov-17)	14:20	39.55	44.27	1835 litres ⁶	✓			✓		✓										✓				Purge water associated with IG_BH01_GW001		
IG_BH01_DW001	11-Nov-17	6:45	41.26	44.27	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Drill water sample associated with IG_BH01_GW001		
IG_BH01_DW002	16-Nov-17	16:00	98.26	101.27	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Microbiology sampling depth		
IG_BH01_DW003	16-Nov-17	3:35	98.26	101.27	-																				Archive		
IG_BH01_DW004	23-Nov-17	4:45	149.26	152.27	-																				Archive		
IG_BH01_DW005	24-Nov-17	20:20	200.26	203.26	-																				Archive		
IG_BH01_DW006	26-Nov-17	14:00	218.28	221.3	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓	Microbiology sampling depth		
IG_BH01_DW007	27-Nov-17	10:45	248.28	251.28	-																				Archive		
IG_BH01_DW008	28-Nov-17	20:20	299.28	302.33	-																				Archive		
IG_BH01_DW009	1-Dec-17	4:27	347.28	350.32	-																				Archive		
IG_BH01_DW010	2-Dec-17	20:30	398.29	401.28	-																				Archive		
IG_BH01_DW011	4-Dec-17	11:35	449.28	452.3	-																				Archive		
IG_BH01_DW012	8-Dec-17	5:30	497.25	500.26	-																				Archive		
IG_BH01_DW013	8-Dec-17	15:40	512.29	515.3	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓	Microbiology sampling depth		
IG_BH01_DW014	10-Dec-17	4:30	548.29	551.28	-																				Archive		
IG_BH01_DW015	12-Dec-17	0:25	599.29	602.29	-																				Archive		
IG_BH01_DW016	14-Dec-17	9:10	647.28	650.27	-																				Archive		
IG_BH01_DW017	17-Dec-17	11:25	698.27	701.21	-																				Archive		
IG_BH01_DW018	19-Dec-17	20:20	749.26	752.28	-																				Archive		
IG_BH01_DW019	7-Jan-18	12:30	797.26	800.25	-																				Archive		
IG_BH01_DW020	9-Jan-18	11:40	848.28	851.12	-																				Archive		
IG_BH01_DW021	11-Jan-18	11:45	899.28	902.28	-																				Archive		
IG_BH01_DW022	14-Jan-18	14:50	947.27	950.28	-																				Archive		
IG_BH01_DW023	16-Jan-18	10:45	998.27	1001.27	-																				Archive		
IG_BH01_DW024	16-Feb-18	11:45	538.00	557.78	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓						✓				Purge water associated with IG_BH01_GW006		
IG_BH01_DW025	20-Feb-18	14:35	625.16	644.94	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Purge water associated with IG_BH01_GW009		
IG_BH01_DW026	10-Dec-17	17:00	-	-	-	✓		✓	✓												✓				Drill water additive		
IG_BH01_WS001	5-Nov-17	10:30	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS002	7-Nov-17	12:00	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS003	11-Nov-17	22:00	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS004	16-Nov-17	16:00	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS005	17-Nov-17	11:30	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS006	18-Nov-17	10:45	-	-	-	✓ ²	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS007	20-Nov-17	13:20	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS008	21-Nov-17	3:45	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS009	25-Nov-17	1:30	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS010	26-Nov-17	17:40	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS011	29-Nov-17	16:00	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS012	2-Dec-17	22:55	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				Water source sample for drilling		
IG_BH01_WS013	6-Dec-17	0:00	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		
IG_BH01_WS014	15-Dec-17	22:15	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		
IG_BH01_WS015	5-Jan-18	14:00	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		
IG_BH01_WS016	17-Jan-18	5:00	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		
IG_BH01_WS017	18-Jan-18	20:45	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		
IG_BH01_WS018	31-Jan-18	11:30	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		
IG_BH01_WS019	16-Feb-18	11:30	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓			Water source sample for drilling		

Notes

IG_BH01_GWxxx indicates a groundwater sample

IG_BH01_DWxxx indicates a drill water sample

IG_BH01_WSxxx indicates a water source (fresh water supply) sample

¹In-field measurements include the fluorescein concentration measured with an Aqualuor Fluorimeter, and the following parameters measured with a Horiba U52-2 Multiprobe: temperature, pH, electrical conductivity, ORP, turbidity and dissolved oxygen

²Analyses include total metals and dissolved metals

³For IG_BH01_GW001, 1835 litres represents 10.75 system volumes; for IG_BH01_GW009, 747 litres represents 1 modified system volume (i.e. the volume of the interval contained by the straddle packers)

⁴Laboratory analyses completed at Maxxam Analytics (Maxxam)

⁵Laboratory analyses completed at Isotope Tracer Technologies (IT2)

⁶Volume listed is approximate



Parameter	Units	Method	Method Detection Limit (conventional parameters) Standard Deviation (isotopes)
ANIONS & NUTRIENTS			
Bromide	mg/L	Ion Chromatography	1
Chloride	mg/L	Ion Chromatography	1
Iodide	mg/L	Ion Chromatography	0.1
Fluoride	mg/L	Potentiometry - ISE	0.1
Nitrite	as N mg/L	Colourimetry	0.01
Nitrate	as N mg/L	Colourimetry	0.1
Total Ammonia	as N mg/L	Colourimetry	0.05
Total Kjeldahl Nitrogen	as N mg/L	SKAL	0.1
Orthophosphate	mg/L	KONE	0.01
Total Phosphorus	mg/L	Colourimetry	0.02
Sulphate	mg/L	Automated Colourimetry	1
Sulphide	mg/L	ISE	0.02
TOTAL AND DISSOLVED METALS			
Calcium	mg/L	ICP/MS	0.2
Iron	mg/L	ICP/MS	0.1
Lithium	mg/L	ICP/MS	0.005
Magnesium	mg/L	ICP/MS	0.05
Potassium	mg/L	ICP/MS	0.2
Silicon	mg/L	ICP/MS	0.05
Sodium	mg/L	ICP/MS	0.1
Strontium	mg/L	ICP/MS	0.001
Silica	mg/L	KONE	0.05
Sulphur	mg/L	ICP/MS	0.05
STABLE ISOTOPES			
$\delta^{18}\text{O}$	VSMOW	Cavity Ring Down Spectroscopy	$\pm 0.1\text{‰}$
$\delta^2\text{H}$	VSMOW	Cavity Ring Down Spectroscopy	$\pm 1\text{‰}$
$^{87}\text{Sr}/^{86}\text{Sr}$	ratio	Thermal Ionization Mass Spectrometry	± 0.0001
$\delta^{13}\text{C}$ DIC	PDB	Finnigan MAT, DeltaPlus XL IRMS	$\pm 0.2\text{‰}$
RADIOISOTOPES			
^{14}C -DIC	% Modern Carbon	Accelerator Mass Spectrometry	5 to 10%
^3H	TU	Liquid Scintillation Counting	± 1

Notes:

Detection limits are not applicable to isotopes as measurement is relative to a standard rather than absolute.

Prepared By: BT

Checked By: MG

Reviewed By: ML

Notes:	Prepared By: BT
¹ Hach model DR2800 Spectrophotometer used for field readings.	Checked By: NAS
² Alkalinity kit model 10-400 mg/L Model AL-DT used for field titration.	Reviewed By: MG
³ Not analyzed due to insufficient sample volume.	
⁴ Not analyzed due to revised parameter set at request of NWMO.	
⁵ Analysis not possible due to excess turbidity.	
⁶ Calculation not possible due to at least one input either below detection limit or not reported.	
⁷ Lack of alkalinity values produces erroneous result.	
⁸ Reading masked by high turbidity.	
⁹ Not measured.	
NA: Parameter not applicable to this sample type.	
BDL: Result below method detection limit.	

Sample Type		Opportunistic Groundwater Samples				Blank		Rinsate		Duplicate		Purge Water		
Sample Date		2017-11-13	2018-01-31	2018-02-16	2018-02-22	2017-11-12	2018-02-20	2017-11-12	2018-02-21	2017-11-13	Relative Percent Difference (%)	2018-07-27 (2017-11-12) ¹⁰	2018-07-27 (2017-11-12) ¹⁰	2018-07-27 (2017-11-13) ¹⁰
Sample ID		IG_BH01_GW001	IG_BH01_GW005	IG_BH01_GW006	IG_BH01_GW009	IG_BH01_GW004	IG_BH01_GW007	IG_BH01_GW003	IG_BH01_GW008	IG_BH01_GW002		IG_BH01_GW010	IG_BH01_GW011	IG_BH01_GW012
Associated OGW Sample						IG_BH01_GW001	IG_BH01_GW009	IG_BH01_GW001	IG_BH01_GW009	IG_BH01_GW001		IG_BH01_GW001		
Sample Interval (m)		39.55 – 44.27	408 – 420	538.00 – 557.78	625.16-644.94							39.55 - 44.27		
GENERAL PARAMETERS														
pH	--	6.27	7.94	7.20	7.51	7.0	-	7.0	-	.11	-	7.07	6.60	6.27
Temperature	°C	6.65	14.27	16.55	11.76	10.0	-	10.0	-	-	-	5.42	6.71	6.65
ORP	mV	-108	342	97	-104	-	-	-	-	-	-	125	-	-108
EC	mS/cm	0.078	2.81	0.44	1.52	-	-	-	-	-	-	0.105	0.095	0.078
DO	mg/L	0	10.37	8.74	8.99	-	-	-	-	-	-	9.0	0.0	0.0
Turbidity	NTU	0	199	402	663	-	-	-	-	-	-	223	65.2	<0.1
Fluorescein	ppb	4.06	30.72	15.92	20.27	-	-	-	-	-	-	45.7	23	4.06
Dissolved Oxygen ¹	mg/L	0.479	-	-	-	-	-	-	-	-	-	-	-	-
Total Alkalinity ²	mg/L CaCO ₃	49.7	. ³	. ³	. ³	. ⁴	. ⁴	. ⁴	. ⁴	47.7	4.1	55 ⁹	55 ⁹	49 ⁹
Hydroxide Alkalinity (calculated)	mg/L CaCO ₃	0.0	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	0.0	-	<1.0 ⁹	<1.0 ⁹	<1.0 ⁹
Carbonate Alkalinity (calculated)	mg/L CaCO ₃	0.0	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	0.0	-	<1.0 ⁹	<1.0 ⁹	<1.0 ⁹
Bicarbonate Alkalinity (calculated)	mg/L CaCO ₃	49.7	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	. ⁶	47.7	4.1	55 ⁹	55 ⁹	49 ⁹
Charge Balance	-	-3.0%	. ⁷	. ⁷	. ⁷	. ⁷	. ⁷	. ⁷	. ⁷	-3.5%	-	-	-	-
ANIONS & NUTRIENTS														
Bromide	mg/L	<1.0	16	2.3	6.6	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	<1.0
Chloride	mg/L	<1.0	880	170	510	<1.0	<1.0	<1.0	<1.0	<1.0	-	5.8	3.2	<1.0
Iodide	mg/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	-	<0.10	<0.10	<0.10
Fluoride	mg/L	0.13	0.28	<0.10	0.11	<0.10	<0.10	<0.10	<0.10	0.12	8.0	0.17	0.13	0.13
Nitrite	as N mg/L	<0.010	<0.010	<0.010	<0.050	<0.010	<0.010	<0.010	<0.010	<0.010	-	<0.010	<0.010	<0.010
Nitrate	as N mg/L	<0.10	<0.10	<0.10	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	-	<0.10	<0.10	<0.10
Nitrite + Nitrate	as N mg/L	<0.10	<0.10	<0.10	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	-	<0.10	<0.10	<0.10
Ammonium	as N mg/L	<0.05	. ³	. ³	. ³	<0.05	<0.05	<0.05	0.1	<0.05	-	-	-	-
Total Ammonia	as N mg/L	<0.050	. ³	. ³	. ³	<0.050	<0.050	<0.050	0.079	<0.050	-	-	-	-
Total Kjeldahl Nitrogen	as N mg/L	-	-	-	-	-	<0.10	-	<0.10	-	-	-	-	-
Orthophosphate	mg/L	0.014	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.014	0.0	<0.010	<0.010	<0.010
Total Phosphorus	mg/L	0.021	. ³	. ³	. ³	<0.020	<0.020	<0.020	0.021	0.023	-9.1	-	-	-
Sulphate	mg/L	1.1	21	6.5	13	<1.0	<1.0	<1.0	<1.0	1.1	0.0	1.5	1.4	<1.0
Sulphide	mg/L	<0.020	. ⁴	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	. ³	-	-	-	-
Sulphide (field) ¹	mg/L	<0.005	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL METALS														
Calcium	mg/L	7.5	430	70	210	<0.2	-	<0.2	-	8.0	-6.5	-	-	-
Iron	mg/L	0.7	6.1	31	36	<0.1	-	<0.1	-	0.74	-1.4	-	-	-
Lithium	mg/L	0.036	0.025	0.019	0.048	<0.005	-	<0.005	-	0.037	-2.7	-	-	-
Magnesium	mg/L	1.8	2.0	2.3	2.8	<0.05	-	<0.05	-	1.9	-5.4	-	-	-
Potassium	mg/L	2.3	8.6	4.8	8.2	<0.2	-	<0.2	-	2.4	-4.3	-	-	-
Silicon	mg/L	11	3.5	2.1	3.0	<0.05	-	<0.05	-	12	-8.7	-	-	-
Sodium	mg/L	8.9	96	28	62	<0.1	-	<0.1	-	9.6	-7.6	-	-	-
Strontium	mg/L	0.054	4.8	0.710	2.5	<0.001	-	<0.001	-	0.055	-1.8	-	-	-
DISSOLVED METALS														
Calcium	mg/L	7.8	410	. ³	. ³	<0.2	<0.2	<0.2	<0.2	7.6	2.6	7.4	7.7	7.4
Iron	mg/L	0.52	<0.1	. ³	. ³	<0.1	<0.1	<0.1	<0.1	0.53	-1.9	<0.1	<0.1	<0.1
Ferrous Iron ¹	mg/L	2.5	-	-	-	-	-	-	-	-	-	-	-	-
Lithium	mg/L	0.032	0.025	. ³	. ³	<0.005	<0.005	<0.005	<0.005	0.032	0.0	0.043	0.040	0.033
Magnesium	mg/L	1.8	1.6	. ³	. ³	<0.05	<0.05	<0.05	<0.05	1.7	5.7	1.6	1.7	1.7
Potassium	mg/L	2.3	8.1	. ³	. ³	<0.2	<0.2	<0.2	<0.2	2.2	4.4	3.7	3.4	2.3
Silicon	mg/L	12	1.7	. ³	. ³	<0.05	<0.05	<0.05	<0.05	12	0.0	9.2	11.0	11.0
Sodium	mg/L	8.9	94	. ³	. ³	<0.1	<0.1	<0.1	<0.1	8.3	7.0	15.0	12.0	8.5
Strontium	mg/L	0.051	4.9	. ³	. ³	<0.001	<0.001	<0.001	<0.001	0.047	8.2	0.05	0.049	0.049
Silica	mg/L	23	. ⁴	. ³	. ³	<0.050	<0.050	<0.050	<0.050	23	0.0	-	-	-
Sulphur	mg/L	0.52	7.7	. ³	. ³	<0.05	<0.05	<0.05	<0.05	0.53	-1.9	0.79	0.65	0.56
STABLE ISOTOPES														
δ ¹⁸ O	VSMOW	-13.50	-9.05	. ³	-8.82	-7.11	-7.25	-6.90	-7.17	-13.75	-1.8	-11.3	-12.5	-13.7
δ ² H	VSMOW	-96.6	-71.5	. ³	-70.8	-50.4	-50.7	-49.7	-50.2	-97.6	-1.1	-84.8	-91.3	-97.7
⁸⁷ Sr/ ⁸⁶ Sr	ratio	0.731	. ³	. ³	. ³	BDL	0.710	BDL	0.711	0.731	-	-	-	-
δ ¹³ C DIC	PDB	-21.8	. ³	. ³	. ³	-21.1	-19.6	-18.8	-18.4	-20.4	6.7	-	-	-
RADIOISOTOPES														
¹⁴ C-DIC	% Modern Carbon	75%	. ³	. ³	. ³	. ⁸	. ⁸	. ⁸	. ⁸	78%	-3.0	-	-	-
³ H	TU	6.9	. ³	8.1	8.1	35	34	33	31	6.4	7.1	-	-	-

Notes:

¹Hach model DR2800 Spectrophotometer used for field readings

²Alkalinity kit model 10-400 mg/L Model AL-DT used for field titration

³Not analyzed due to insufficient sample volume

⁴Not analyzed due to revised parameter set at request of NWMO

⁵Analysis not possible due to excess turbidity

⁶Calculation not possible due to at least one input either below detection limit or not reported

⁷Lack of alkalinity values produces erroneous result

⁸No gas in sample to permit analysis

⁹Parameters measured / calculated by Maxxam Analytics laboratory

¹⁰Parentheses indicate date of purge water sample collection

¹¹pH of 6.27 (from IG_BH01_GW001) assumed for alkalinity calculation

NA: Parameter not applicable to this sample type

BDL: Result below method detection limit

Prepared By: BT

Checked By: NS

Reviewed By: MG



APPENDIX B

Table B-1: Drill Water Contamination Correction Values

Sample Type	OGW Sample	Corrected Result	OGW Sample	Corrected Result
Sample Date	11/13/2017	11/13/2017	2/16/2018	2/16/2018
Sample ID	IG_BH01_GW001	IG_BH01_GW001	IG_BH01_GW006	IG_BH01_GW006
Sample Interval	39.55 – 44.27 m	39.55 – 44.27 m	538.00 – 557.78 m	538.00 – 557.78 m
GENERAL PARAMETERS				
Total Alkalinity	mg/L CaCO ₃	49.7	42.3	-
Hydroxide Alkalinity (calculated)	mg/L CaCO ₃	0	0.0	-
Carbonate Alkalinity (calculated)	mg/L CaCO ₃	0.0	0.0	-
Bicarbonate Alkalinity (calculated)	mg/L CaCO ₃	49.7	42.3	-
ANIONS & NUTRIENTS				
Bromide	mg/L	<1.0	2.3	- ³
Chloride	mg/L	<1.0	170	327
Iodide	mg/L	<0.10	<0.10	- ³
Fluoride	mg/L	0.13	0.11	<0.10
Nitrite	as N mg/L	<0.010	<0.010	- ³
Nitrate	as N mg/L	<0.10	<0.10	- ³
Nitrite + Nitrate	as N mg/L	<0.10	<0.10	- ³
Ammonium	as N mg/L	<0.05	-	- ³
Total Ammonia	as N mg/L	<0.050	-	- ³
Total Kjeldahl Nitrogen	as N mg/L	-	-	- ³
Orthophosphate	mg/L	0.014	<0.010	- ³
Total Phosphorus	mg/L	0.021	0.011	- ³
Sulphate	mg/L	1.1	1.0	6.5
Sulphide	mg/L	<0.020	<0.020	- ³
Sulphide (field) ¹	mg/L	<0.005	-	- ³
TOTAL METALS				
Calcium	mg/L	8	4	70
Iron	mg/L	0.7	0	31.0
Lithium	mg/L	0.036	0.003	0.019
Magnesium	mg/L	1.8	0	2.3
Potassium	mg/L	2	0	5
Silicon	mg/L	11	0.7	2.1
Sodium	mg/L	9	4	28
Strontium	mg/L	0.054	0.010	0.71
DISSOLVED METALS				
Calcium	mg/L	8	8	-
Iron	mg/L	0.5	0.4	-
Ferrous Iron ²	mg/L	2.5	- ³	-
Lithium	mg/L	0.032	0.030	-
Magnesium	mg/L	1.8	1.9	-
Potassium	mg/L	2.3	1.9	-
Silicon	mg/L	12	12	-
Sodium	mg/L	8.9	7.2	-
Strontium	mg/L	0.051	0.053	-
Silica	mg/L	23	23	-
Sulphur	mg/L	0.52	0.48	-
STABLE ISOTOPES				
$\delta^{18}\text{O}$	VSMOW	-13.50	-13.80	-
$\delta^2\text{H}$	VSMOW	-96.6	-98.2	-
$^{87}\text{Sr}/^{86}\text{Sr}$	ratio	0.731	0.730	-
$\delta^{13}\text{C DIC}$	PDB	-21.8	-22.4	-
RADIOISOTOPES				
$^{14}\text{C-DIC}$	Years Before Present	75%	76%	-
^3H	TU	6.9	6.7	8.1

Notes:¹Hach model DR2800 Spectrophotometer used for field readings²Alkalinity kit model 10-400 mg/L Model AL-DT used for field titration³Calculation not possible due to at least one input either below detection limit or not reported

Prepared By: BT

Checked By: NS

Reviewed By: MG

APPENDIX C

Analytical In-field Analysis Procedures

1.0 ANALYTICAL IN-FIELD PARAMETER MEASUREMENTS

The samples analyses for alkalinity, total sulfide, dissolved oxygen and ferrous iron can be impacted by contact with the atmosphere. In order to collect, prepare and analyze samples while preventing contact to the atmosphere, the samples were collected using an in-situ fluid sampler probe to collect groundwater from directly above the packers. The in-situ fluid sampler probe that was used is the 2FSA-1000 1L Fluid Sampler Probe manufactured by Mount Sopris Instrument Company (MSI). The sampler probe operates from the MSI 4MXA-1000 1000m wireline winch.

The fluid sampler was lowered on the wireline winch with the 1L sample chamber closed. Once the fluid sampler was positioned approximately 1 meter above the inflated packers, the chamber was opened using the MSI control system, allowing fluid to enter the chamber. The chamber was then closed and retrieved to surface.

Once the filled chamber was at the surface, the fluid sampler valve cap was removed, exposing the inlet port. A rubber sleeve was slid over the inlet port. Pressurized nitrogen was directed through the port to flush any trapped atmospheric air above the water sample and to extrude the OGW water into the sampling tube.

If additional sample volume was required for analyses, the chamber was decontaminated following Section 3.1 and lowered downhole to collect additional volume. This process can be repeated as often as required.

Alkalinity

Alkalinity of the OGW sample was measured in the field using a titration method that determines the phenolphthalein and total alkalinities. The titration method consists of incremental addition of sulphuric acid (H_2SO_4), while using phenolphthalein and bromcresol green-methyl red indicators to visually identify key endpoints in the titration. Once the phenolphthalein and total alkalinities were determined, the proportion of the phenolphthalein alkalinity relative to the total alkalinity was used to estimate the hydroxide, carbonate and bicarbonate alkalinities.

The OGW sample for alkalinity analysis was first collected by passing the sample through a $0.45\ \mu\text{m}$ groundwater filter and into a clean flask (rinsed with nanopure deionized water). Next, a Hach kit and digital titrator was used to complete alkalinity measurements.

Sulphide

Total sulphide ($\text{S}^{2-}_{\text{Total}}$) was measured in the field immediately after sample collection using the Methylene Blue Method. Hach sulphide reagents and spectrophotometer was used to carry out the analysis in the field. First, two standard Hach reagents, referred to as Sulphide 1 Reagent and Sulphide 2 Reagent, were readied by loading two separate 1 mL syringes (fitted with a hypodermic needle) with each reagent with no headspace. A blank was prepared with 25 mL deionized water in a Hach spectrophotometer sample cell; the blank was used to zero the Hach spectrophotometer before reading the OGW sample. The Hach spectrophotometer was turned on and readied, as it needs time to warm-up prior to use. These steps were completed first in order to minimize the time between the OGW sample collection and the analysis.

Next, a glass syringe was connected to the sample tubing and an OGW sample was extruded into the glass syringe with compressed nitrogen. A glass syringe is needed (rather than plastic) to mitigate the ingress or egress of gases through the syringe wall. About 10 mL of sample was extruded into the glass syringe and then the syringe was disconnected to bleed out any air and some of the sample; this was to ensure there is no headspace. The syringe was then reconnected to the sample tubing and the full OGW sample volume (25 mL) was collected

with no air bubbles. A steady flow from the sample tube was maintained at a slow rate upon reconnection of the syringe to assist with mitigating the entry of air bubbles. Once the 25 mL sample was attained, the syringe was disconnected and the tip capped with a rubber septum. If there are air bubbles present after attaching the rubber septum, the OGW sample was discarded and the sample collection steps repeated until an OGW sample was attained with no air bubbles. The syringe with 1 mL of Sulphide 1 Reagent was then immediately inserted through the rubber septum into the glass syringe and the first reagent was then injected into the OGW sample. The syringe with 1 mL of Sulphide 2 Reagent was then immediately inserted through the rubber septum into the glass syringe and the second reagent was then injected into the OGW sample. The reagents also need to be added to the blank in the same sequence immediately after adding to the OGW sample: 1 mL of Sulphide 1 Reagent, then 1 mL of Sulphide 2 Reagent. The timer on the Hach spectrophotometer was then started for a 5 minimum reaction time. Once the 5 minute reaction time was complete, the blank was inserted into the Hach spectrophotometer to zero the instrument. The sample in the glass syringe was then injected into a sample cell and inserted into the Hach spectrophotometer for an immediate sample reading; the reading value was recorded directly into the AcQuire groundwater sampling data entry object. If there is dissolved sulphide in the OGW sample, the sample will turn a blue colour during the reaction time; therefore, the colour of the OGW sample was recorded in field notes as a qualitative indicator of presence/absence of sulphide. Given the importance of the potential presence of dissolved sulphide on the long-term chemical stability of some of the barrier components associated with the deep geological repository, this procedure was repeated twice to attain a duplicate in-field measurement of total sulphide (S^{2-}_{Total}).

Prior to collecting the OGW sample, a series of five sulphide standards was prepared using a sulphide stock standard solution (Radiello™ Methylene Blue Calibration Standard). Using the stock standard solution, five standards were prepared at different concentrations that are expected to encompass the range of sulphide concentrations in the OGW sample (0.01 mg/L to 1 mg/L). The known concentrations of the standards can be compared to the values measured using the Hach spectrophotometer to determine a sample-specific correction factor. Preparation and analysis of standards were completed prior to the start of, and during, field work as a QA check on the operation of the Hach spectrophotometer and recorded in the Data Quality Confirmation Workbook.

The concentrations of hydrogen sulphide (H_2S) and unionized hydrogen sulphide (or bisulphide ion, HS^-) were calculated using the total sulphide (S^{2-}_{total}) concentration and pH. Concentration of S^{2-} ions will not be measured or calculated, given that the concentrations of S^{2-} ions under natural conditions are negligible.

Dissolved Oxygen

Dissolved oxygen (DO) was measured in the field immediately after sample collection using the Indigo Carmine Method. Hach AccuVac Ampuls and spectrophotometer were used to carry out the analysis in the field. The Hach AccuVac Ampuls are glass cells pre-loaded with reagent and under a vacuum so that the sample is sucked into the ampul without exposure to atmospheric conditions. The DO results were compared to the DO measured using the multiprobe; all values were recorded in the Data Quality Confirmation Workbook.

Ferrous Iron

Ferrous iron (Fe^{2+}) was measured in the field after sample collection using the 1-10 Phenanthroline Method. Hach AccuVac Ampuls and spectrophotometer was used to carry out the analysis in the field. As with the Hach DO AccuVac Ampuls, the Hach Ferrous Iron AccuVac Ampuls are glass cells that are pre-loaded with reagent and under a vacuum so that the sample is sucked into the ampul without exposure to atmospheric conditions. This method is only applicable for concentrations up to 3 mg/L; in the case when samples contain concentrations of ferrous iron greater than 3 mg/L, the sample would need to be diluted with nanopure water (attained from a

laboratory) to bring the concentration within the detection range of the method. The concentration would then be corrected by the dilution factor.

Ferrous iron oxidizes very rapidly at neutral pH conditions, but oxidizes at a much slower rate under acidic conditions. As such, an alternative to completing the analysis immediately in the field during the collection of the OGW samples is to preserve a filtered OGW sample with trace grade nitric acid (HNO₃). The Hach method can then be completed later in the day or within a 24 hour period. This would provide some additional time to complete the analysis, which is particularly useful if the concentrations in the OGW sample are greater than 3 mg/L and sample dilution is necessary to complete the analysis.

Similar to the hydrogen sulphide analysis, a series of five ferrous iron standards were prepared using ferrous ammonium sulfate, hexahydrate (Fe(NH₄)₂(SO₄)₂·6H₂O). These standards were prepared at different concentrations, which are expected to encompass the range of ferrous iron concentrations in the OGW sample; in this case, it is expected that the concentrations will be relatively low (<1 mg/L). The standards will be analysed using the 1-10 Phenanthroline Method and the known concentrations of the standards were compared to the values measured using the Hach spectrophotometer to determine a sample-specific correction factor. Preparation and analysis of standards were completed prior to the start of, and during, field work as a QA check on the operation of the Hach spectrophotometer and recorded in the Data Quality Confirmation Workbook.

2.0 SAMPLE COLLECTION FOR MICROBIOLOGY RESEARCH AND DEVELOPMENT

University of Waterloo will order and ship required sampling equipment to the Ignace office for Golder to use during sampling. For each opportunistic sampling event, take water samples for deoxyribonucleic acid (DNA), phospholipid fatty acid (PLFA) and cell count analysis, as described in this section.

It is recognized that the microbiology samples are lower priority than the geochemical analyses in the previous sections. The overall goal is to prepare for future site characterization activities, by assessing detection limits and contamination sources. The water volumes requested are best case scenario. If less water is available, please note the volume of the sample. Duplicates samples for DNA, PLFA and cell count will be taken if water is available. Always sample one replicate for DNA, PLFA and cell count first, before collecting the duplicate samples. This way we ensure at least one replicate for each analysis.

Important: Use Sterivex filter with PVDF (SVG010RS) and not PES membrane (SVG01050) for DNA and PLFA sampling! Sampling procedure and equipment for DNA and PLFA is now the same.

Note: Only take a field blank for DNA and PLFA (one each) when sampling OGW. No need to take a field blank for DNA and PLFA when taking the drill water return immediately following opportunistic groundwater. Do take a field blank for DNA and PLFA (one each) when sampling the drill water return following core sampling.

Opportunistic water samples for DNA analysis

- For DNA samples, filter opportunistic water via syringe filtration as described below. Although a specific syringe filter is noted, any syringe filter rated for DNA extraction with at least a 0.45 micron pore size and ideally a 0.22 pore size to capture smaller organisms can be used.

-
- For DNA analysis water volumes should be the minimum required to clog the filter such that no further water can pass to a maximum of 1200 mL.
 - DNA filtering is carried out by filling a syringe (Fisher, BD 60 mL Luer Lok syringe, catalogue number B309653) with ground water (by removing the plunger) and after replacing the plunger passing the water through Sterivex filters (Fisher Scientific, Millipore SVGV010RS, Sterivex-GV 0.22 µm, PVDF).
 - Water must be passed through the filter until the filter is clogged. When the filter clogs, record the volume of water passed through the filter. If clogging does not occur, stop filtering at 1200 ml. The easiest way to refill the syringe is to unscrew the Sterivex filter, withdraw the plunger from the syringe (being sure to keep it clean and handle only with clean sterile surgical gloves; you can store the plunger in the clean wrapper from the syringe), then reattach the filter, pour more groundwater sample into the syringe. Fill the syringe all the way until the water bulges before placing the plunger back in. This way, no air will be introduced into the syringe (once wetted, the membrane is not air permeable and any air would reduce the filtration area in the filter unit). Then push the sample through and repeat. If the syringe is filled all the way, it holds 72 ml liquid (16.5 syringe volumes = 1,200 ml). Once the filter plugs, follow-up with a final slug of air to force the water on the upstream side of the filter through and out (e.g. this dewatering step ensures freezing occurs without a lot of water to prevent expansion and casing cracking).
 - Once the DNA filter is clogged and dewatering is complete, place the DNA filter in a 50 cc plastic centrifuge tube (Fisher, Tube screw cap grad 50 mL, catalogue number C352070), place the tube in a Ziploc bag and store in freezer. Once frozen, try not to thaw and refreeze. Sample should remain frozen and be shipped on dry ice.
 - Along with each sample, collect a field blank by setting up the filter and syringe in preparation to sample and then placing the filter in the 50 cc tube and treating as a sample.

Opportunistic water samples for PLFA analysis

- For PLFA samples, filter opportunistic water via syringe filtration as described below. In the case of PLFA sampling, only solvent extractable filter material can be used, therefore make sure to use SVGV010RS, Sterivex-GV 0.22 µm, PVDF.
- For PLFA analysis water volumes should be the minimum required to clog the filter such that no further water can pass through, to a maximum of 1200 mL.
- PLFA filtering is carried out by filling a syringe (Fisher, BD 60 mL Luer Lok syringe, catalogue number B309653) with groundwater (by removing the plunger) and after replacing the plunger passing the water through Sterivex filters (Fisher Scientific, Millipore SVGV010RS, Sterivex-GV 0.22 µm, PVDF).
- Water must be passed through the filter until the filter is clogged. When the filter clogs, record the volume of water passed through the filter. If clogging does not occur, stop filtering at 1200 ml. The easiest way to refill the syringe is to unscrew the Sterivex filter, withdraw the plunger from the syringe (being sure to keep it clean and handle only with clean sterile surgical gloves; you can store the plunger in the clean wrapper from the syringe), then reattach the filter, pour more groundwater sample into the syringe. Fill the syringe all the way until the water bulges before placing the plunger back in. This way, no air will be introduced into the syringe (once wetted, the membrane is not air permeable and any air would reduce the filtration area in the filter unit). Then push the sample through and repeat. If the syringe is filled all the way, it holds 72 ml liquid (16.5 syringe volumes = 1,200 ml). Once the filter plugs, follow-up with a final slug of air to force the water on the upstream

side of the filter through and out (e.g. this dewatering step ensures freezing occurs without a lot of water to prevent expansion and casing cracking).

- Once the PLFA filter is clogged and dewatering is complete, place the PLFA filter in a 50 cc plastic centrifuge tube (Fisher, Tube screw cap grad 50 mL, catalogue number C352070), place the tube in a Ziploc bag and store in freezer. Once frozen, try not to thaw and refreeze. Sample should remain frozen and be shipped on dry ice.
- Along with each sample collect a field blank by preparing the syringe and filter as for collection of sample, then without filtering water, collect the filter and treat as a sample.

Cell count sample

- The cell count samples are collected by adding opportunistic water to the 50 cc tubes preloaded with 2% glutaraldehyde. Store **refrigerated but do not freeze** the samples before they are picked up by NWMO.
- Collect a field blank by opening a 50 cc tube, reclosing and treating as a sample.

2.1 Drill water samples for assessing contamination

A grab sample of the drill water return (DWR) immediately **following both opportunistic groundwater and core sampling**. The grab sample can be obtained by collecting a bucket sample of the drill water return.

Please coordinate with the core sampler to make sure that drill water samples are taken at the same time.

Core samples will be taken at the following approximate intervals (summarized in WP3):

- Approximately 100m depth
- Following the first opportunistic water sampling below 200m
- Approximately 534m depth

When core or opportunistic groundwater samples are collected, the drill water return can be sampled by the following method:

- Wear disposable surgical gloves when sampling drill water return.
- Collect drill water return in a bucket.
- pH, Eh (redox), electrical conductivity, temperature, and alkalinity should be measured, as per above.
- Samples of drill water should be taken for commercial laboratory analysis, as per above.
- Sampling for DNA analysis, PLFA analysis and total cell counts as described below.

The on-site geochemical measurements will be logged in the Data Quality Confirmation workbook and will be identified by DWR-XXXX-YYY, where XXXX is the borehole identifier and YYY is the consecutive index number of the sample unique to the borehole. The core run number, date and depth associated with the sample should also be noted in the Data Quality Confirmation workbook. The sample identifier will be used to label the filters and water samples described below.

Drill fluid samples for DNA analysis

- For DNA samples, filter drill water return via syringe filtration as described below. Although a specific syringe filter is noted, any syringe filter rated for DNA extraction with at least a 0.45 micron pore size and even better a 0.22 pore size to capture smaller organisms can be used.
- For DNA analysis water volumes should be the minimum required to clog the filter such that no further water can pass to a maximum of 1200 mL.
- DNA filtering is carried out by filling a syringe (Fisher, BD 60 mL Luer Lok syringe, catalogue number B309653) with drill water return (by removing the plunger) and after replacing the plunger passing the water through Sterivex filters (Fisher Scientific, Millipore SVGV010RS, Sterivex-GV 0.22 µm, PVDF).
- Water must be passed through the filter until the filter is clogged. When the filter clogs, record the volume of water passed through the filter. If clogging does not occur, stop filtering at 1200 ml. The easiest way to refill the syringe is to unscrew the Sterivex filter, withdraw the plunger from the syringe (being sure to keep it clean and handle only with clean sterile surgical gloves; you can store the plunger in the clean wrapper from the syringe), then reattach the filter, pour more sample into the syringe. Fill the syringe all the way until the water bulges before placing the plunger back in. This way, no air will be introduced into the syringe (once wetted, the membrane is not air permeable and any air would reduce the filtration area in the filter unit). Then push the sample through and repeat. If the syringe is filled all the way, it holds 72 ml liquid (16.5 syringe volumes = 1,200 ml). Once the filter plugs, follow-up with a final slug of air to force the water on the upstream side of the filter through and out (e.g. this dewatering step ensures freezing occurs without a lot of water to prevent expansion and casing cracking).
- Once the DNA filter is clogged and dewatering is complete, place the DNA filter in a 50 cc plastic centrifuge tube (Fisher, Tube screw cap grad 50 mL, catalogue number C352070), place the tube in a Ziploc bag and store in freezer. Once frozen, try not to thaw and refreeze. Sample should remain frozen and be shipped on dry ice.

Drill fluid samples for PLFA analysis

- For PLFA samples, filter drill return water via syringe filtration as described below. In the case of PLFA sampling, only solvent extractable filter material can be used, therefore make sure to use SVGV010RS, Sterivex-GV 0.22 µm, PVDF
- For PLFA analysis water volumes should be the minimum required to clog the filter such that no further water can pass through, to a maximum of 1200 mL.
- PLFA filtering is carried out by filling a syringe (Fisher, BD 60 mL Luer Lok syringe, catalogue number B309653) with drill water (by removing the plunger) and after replacing the plunger passing the water through Sterivex filters (Fisher Scientific, Millipore SVGV010RS, Sterivex-GV 0.22 µm, PVDF).
- Water must be passed through the filter until the filter is clogged. When the filter clogs, record the volume of water passed through the filter. If clogging does not occur, stop filtering at 1200 ml. The easiest way to refill the syringe is to unscrew the Sterivex filter, withdraw the plunger from the syringe (being sure to keep it clean and handle only with clean sterile surgical gloves; you can store the plunger in the clean wrapper from the syringe), then reattach the filter, pour more sample into the syringe. Fill the syringe all the way until the water bulges before placing the plunger back in. This way, no air will be introduced into the syringe (once wetted,

the membrane is not air permeable and any air would reduce the filtration area in the filter unit). Then push the sample through and repeat. If the syringe is filled all the way, it holds 72 ml liquid (16.5 syringe volumes = 1,200 ml). Once the filter plugs, follow-up with a final slug of air to force the water on the upstream side of the filter through and out (e.g. this dewatering step ensures freezing occurs without a lot of water to prevent expansion and casing cracking).

- Once the PLFA filter is clogged and dewatering is complete, place the PLFA filter in a 50 cc plastic centrifuge tube (Fisher, Tube screw cap grad 50 mL, catalogue number C352070), place the tube in a Ziploc bag and store in freezer. Once frozen, try not to thaw and refreeze. Sample should remain frozen and be shipped on dry ice.
- Along with each sample collect a field blank by preparing the syringe and filter as for collection of sample, then without filtering water, collect the filter and treat as a sample.
- Once filtering is complete, remove filter and put the filter into its own Ziploc bag store in a freezer. Once frozen, try not to thaw and refreeze. Sample should remain frozen and be shipped on dry ice. Dewatering is not necessary in this case.

Cell count sample

- The cell count samples are collected by adding drill water return to the 50 cc tubes preloaded with 2% glutaraldehyde. Store **refrigerated but do not freeze** the samples before they are picked up by NWMO.

2.2 Additional Sources of Contamination Sampling

- After the final core sampling (~534m), to complete the assessment of possible sources of contamination, collect one 50 cc tube of each of the drilling mud components (e.g. bentonite, detergents, oils, polymers). **Store refrigerated but do not freeze.**
- These are one-time samples. The samples will not be labelled according to the by DWR-XXXX-YYY convention. These sample labels will clearly identify the type of material and the date of collection.

2.3 Summary of sampling equipment for microbiology samples

Sampling equipment will be gathered and shipped by University of Waterloo. The following table summarizes the equipment.

Table 1: Microbiology sampling equipment

Quantity	Part number	Item description	Purpose
4 boxes	19-188-587 fishersci.com	Kimberly-Clark™ KC500 Purple Nitrile Sterile Exam Gloves (2x medium and 2x large)	Sampling
2 each	----	Red and black Sharpie markers	Labelling
60	82028-488 vwr.com	2000 mL Nalgene bottle, polypropylene	Container to hold water before filtering/ sampling
80	B309653 Fishersci.com	60 mL Luer Lok syringe	Microbiology (DNA and PLFA)

Quantity	Part number	Item description	Purpose
150	SVGV010RS Fishersci.com	Millipore SVGV010RS, Sterivex-GV 0.22 µm, PVDF	Microbiology (DNA and PLFA)
150	C352070 Fishersci.com	Centrifuge tube screw cap graduated 50 mL	Microbiology
60	O2957-1 fishersci.com	25% glutaraldehyde solution, certified	Microbiology (cell counts)
2 boxes		Ziploc heavy duty freezer bags (2x 28 Gallon size)	Microbiology (core samples)
1 box		Ziploc bags small (x40)	

2.4 Microbiology sample preservation summary and shipping

Microbiology samples are stored frozen or refrigerated, as outlined in Table 2. At the end of sampling, all samples will be transported on ice packs in coolers to the Ignace office and placed into refrigerator/freezer. NWMO will coordinate shipping all samples to McMaster/Waterloo University. Frozen samples should be shipped on dry ice. Refrigerated samples can be shipped with ice packs.

Table 2: Samples for microbiology research and development for opportunistic water and core sampling events

Sample Type	Analysis type	Sample storage	Sample type	Total number of samples
Opportunistic groundwater	DNA	Frozen	Filter	10 total (20 total with replicates) = one from each OGW sample interval
Opportunistic groundwater	PLFA	Frozen	Filter	10 total (20 total with replicates) = one from each OGW sample interval
Opportunistic groundwater	Cell count	Refrigerate	Water in tube with glutaraldehyde	10 total (20 total with replicates) = one from each OGW sample interval
Field blank	DNA	Frozen	Filter	13 total = one from each OGW sample interval + and one from each core sample interval
Field blank	PLFA	Frozen	Filter	13 total = one from each OGW sample interval (10) + and one from each core sample interval (3)
Field blank	Cell count	Refrigerate	Water in tube with glutaraldehyde	13 total = one from each OGW sample interval (10)

Sample Type	Analysis type	Sample storage	Sample type	Total number of samples
				+ and one from each core sample interval (3)
Drill water	DNA	Frozen	Filter	13 total (26 total with replicates) = one from each OGW sample interval (10) + and one from each core sample interval (3)
Drill water	PLFA	Frozen	Filter	13 total (26 total with replicates) = one from each OGW sample interval (10) + and one from each core sample interval (3)
Drill water	Cell count	Refrigerate	Water in tube with glutaraldehyde	13 total (26 total with replicates) = one from each OGW sample interval (10) + and one from each core sample interval (3)
Core	DNA, PLFA	Frozen	Core	3 total (6 total with replicates)



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