PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING at IG_BH04/05/06 - IGNACE AREA

WP02 Data Report - Borehole Drilling and Flushing for IG_BH04

APM-REP-01332-0278 November 2022

Golder Associates Ltd.

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Nuclear Waste Management Organization
22 St. Clair Avenue East, 4th Floor
Toronto, Ontario
M4T 2S3
Canada

Tel: 416-934-9814
Web: www.nwmo.ca

REPORT

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WP02 Data Report - Borehole Drilling and Flushing for IG_BH04

Submitted to:

Nuclear Waste Management Organization

4th Floor
22 St. Clair Avenue East
Toronto, Ontario, M4T 2S3

Submitted by:

Golder Associates Ltd.

6925 Century Avenue, Suite #100, Mississauga, Ontario, L5N 7K2, Canada

+1 905 567 4444

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WP02 DATA REPORT
BOREHOLE DRILLING AND FLUSHING FOR IG_BH04

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Client:	Nuclear Waste Management Organization (NWMO)
Address:	22 St. Clair Avenue East, 4th Floor
City:	Toronto
Province:	Ontario
Postal Code:	M4T 2S3

Client Contact:	Martin Sykes	Warwick Watt	Natacha Lugo Bizarro
Telephone:	647-259-3021	437-972-3669	416-561-0920
Email:	msykes@nwmo.ca	wwatt@nwmo.ca	nlugo@nwmo.ca

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SIGNATURES

Prepared by:

Andrew Verok, P.Eng.
Geological Engineer

Reviewed by:

Joe Carvalho, Ph.D., P.Eng.
Mining & Rock Engineering – Principal

Approved by:

George Schneider, M.Sc., P.Geo.
Senior Geoscientist - Principal

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1.0 INTRODUCTION

The Phase 2 Initial Borehole Drilling and Testing at IG_BH04/05/06 project in the Ignace area of Ontario, is part of the Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's Adaptive Phased Management (APM) Site Selection Phase.

This project involves testing of deep borehole IG_BH04 and the drilling and testing of deep boreholes IG_BH05 and IG_BH06 in the Ignace area within the identified Potential Repository Area (PRA). The work comprises a total of seven work packages and will be carried out by a team led by Golder Associates Ltd. (Golder) on behalf of the NWMO. The IG_BH04 program is described in the Borehole Characterization Plan (BCP) for IG_BH04 (Golder 2021a).

This data report describes the methodology, activities and reporting for Work Package 2 (WP02): Borehole Drilling and Flushing, which includes: drilling of plugs and cemented intervals, and drilling fluid management and use of tracers.

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 km^2. Based on geophysical modelling, the batholith is approximately 2 km to 3 km thick through the center of the northern portion (SGL 2015). The batholith is surrounded by supracrustal rocks of the Raleigh Lake (to the north and east) and Bending Lake (to the southwest) greenstone belts (Figure 2).

IG_BH04 is located within an investigation area of approximately 19 km^2 in size, situated in the northern portion of the Revell batholith. Bedrock exposure in the area is generally 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. Local water courses tend to flow to the southwest towards Mennin Lake (Figure 1).

Four main rock units are identified in the supracrustal rock group: mafic metavolcanic rocks, intermediate to felsic metavolcanic rocks, metasedimentary rocks, and mafic intrusive rocks (Figure 2). Sedimentation within the supracrustal rock assemblage was largely synvolcanic, although sediment deposition in the Bending Lake area may have continued past the volcanic period (Stone 2009; Stone 2010a; Stone 2010b). All supracrustal rocks are affected, to varying degrees, by penetrative brittle-ductile to ductile deformation under greenschist- to amphibolite-facies metamorphic conditions (Blackburn and Hinz 1996; Stone et al. 1998). In some locations, primary features, such as pillow basalt or bedding in sedimentary rocks are preserved, in other locations, primary relationships are completely masked by penetrative deformation. Uranium-lead (U-Pb) geochronological analysis of the supracrustal rocks produced ages that range between 2734.6 +/-1.1 Ma and 2725 +/-5 Ma (Stone et al. 2010).

Three main suites of plutonic rock are recognized in the Revell batholith, including, from oldest to youngest: a Biotite Tonalite to Granodiorite suite, a Hornblende Tonalite to Granodiorite suite, and a Biotite Granite to Granodiorite suite (Figure 2). Plutonic rocks of the Biotite Tonalite to Granodiorite suite occur along the southwestern and northeastern margins of the Revell batholith. The principal type of rock within this suite is a white to grey, medium-grained, variably massive to foliated or weakly gneissic, biotite tonalite to granodiorite. One sample of foliated and medium-grained biotite tonalite produced a U-Pb age of 2734.2+/-0.8 Ma (Stone et al. 2010). The Hornblende Tonalite to Granodiorite suite occurs in two irregularly-shaped zones surrounding the central core of the Revell batholith. Rocks of the Hornblende Tonalite to Granodiorite suite range compositionally from tonalite through granodiorite to granite and also include significant proportions of quartz diorite and quartz monzodiorite. One sample of coarse-grained grey mesocratic hornblende tonalite produced a U-Pb age of 2732.3+/-0.8 Ma (Stone et al. 2010). Rocks of the Biotite Granite to Granodiorite suite underlie most of the northern, central and southern portions of the Revell batholith. Rocks of this suite are typically coarse-grained, massive to weakly foliated, and white to pink in colour. The Biotite Granite to Granodiorite suite ranges compositionally from granite through granodiorite to tonalite. A distinct potassium (K)-Feldspar Megacrystic Granite phase of the Biotite Granite to Granodiorite suite occurs as an oval-shaped body in the central portion of the Revell batholith (Figure 2). One sample of coarse-grained, pink, massive K-feldspar megacrystic biotite granite produced a U-Pb age of 2694.0+/-0.9 Ma (Stone et al. 2010).

The bedrock surrounding IG_BH04 is composed mainly of massive to weakly foliated felsic intrusive rocks that vary in composition between granodiorite and tonalite, and together form a relatively homogeneous intrusive complex. Bedrock identified as tonalite transitions gradationally into granodiorite and no distinct contact relationships between these two rock types are typically observed (SRK and Golder 2015; Golder and PGW 2017). Massive to weakly foliated granite is identified at the ground surface to the northwest of the feldspar-megacrystic granite. The granite is observed to intrude into the granodiorite-tonalite bedrock, indicating it is distinct from, and younger than, the intrusive complex (Golder and PGW 2017).

West-northwest trending mafic dykes interpreted from aeromagnetic data extend across the northern portion of the Revell batholith and into the surrounding greenstone belts. One mafic dyke occurrence, located to the northwest of IG_BH01, is approximately 15-20 m wide (Figure 2). All of these mafic dykes have a similar character and are interpreted to be part of the Wabigoon dyke swarm. One sample from the same Wabigoon swarm produced a U-Pb age of 1887+/-13 Ma (Stone et al. 2010), indicating that these mafic dykes are Proterozoic in age. 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.

Regional observations from mapping have indicated that structural features are widely spaced (typical 30 to 500 cm spacing range) and dominantly comprised of sub-vertical joints with two dominant orientations, northeast and northwest trending (Golder and PGW 2017). Interpreted bedrock lineaments generally follow these same dominant orientations in the northern portion of the Revell batholith (Figure 2; DesRoches et al. 2018). Minor sub-horizontal joints have been observed with minimal alteration, suggesting they are younger and perhaps related to glacial unloading. One mapped regional-scale fault, the Washeibemaga Lake fault, trends east and is located to the west of the Revell batholith (Figure 2). Ductile lineaments, also shown on Figure 2, follow the trend of foliation mapped in the surrounding greenstone belts. Additional details of the lithological units and structures found at surface within the investigation area are reported in Golder and PGW (2017).

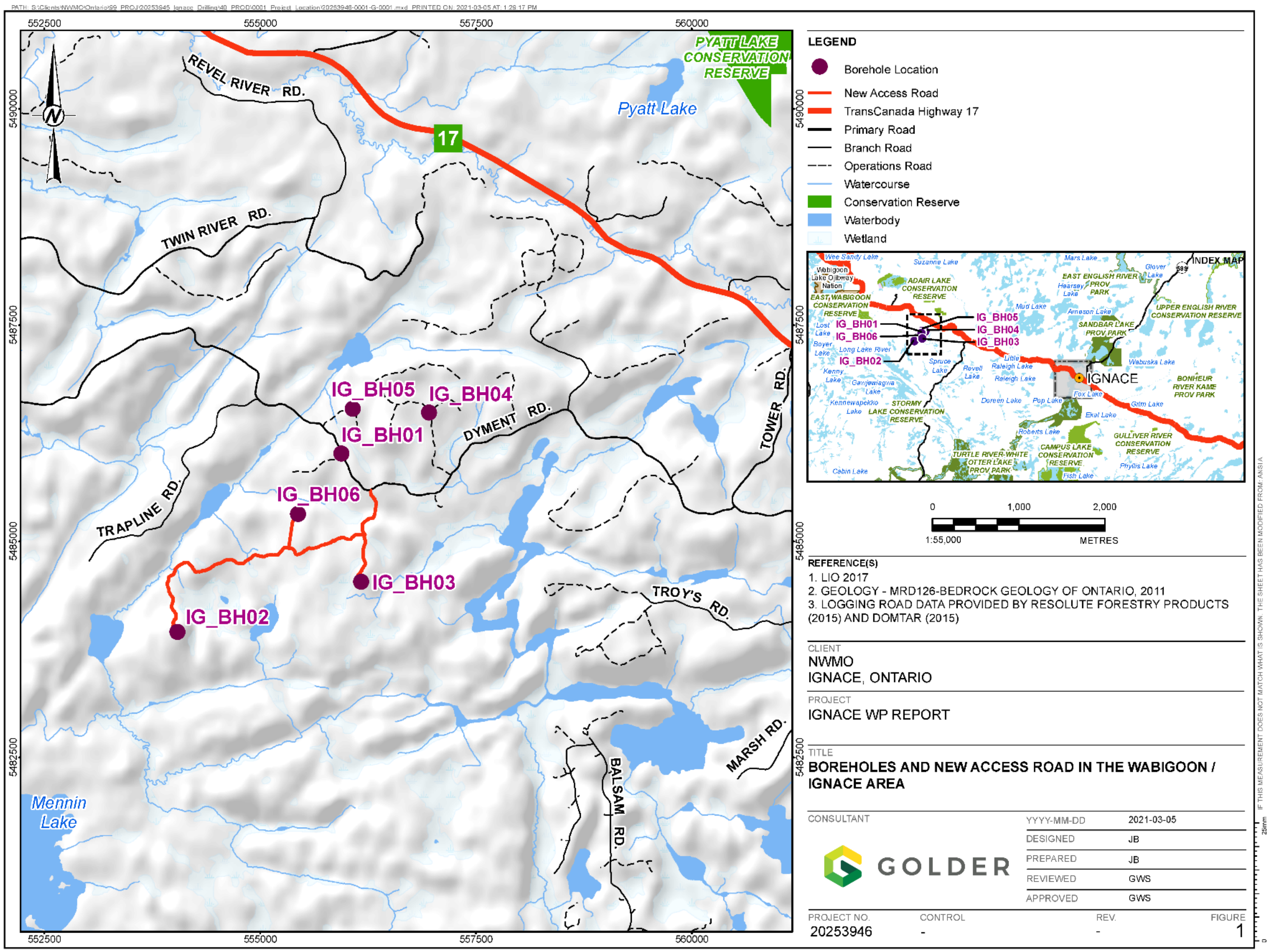

Figure 1: Location of IG_BH04 in Relation to the Ignace Area

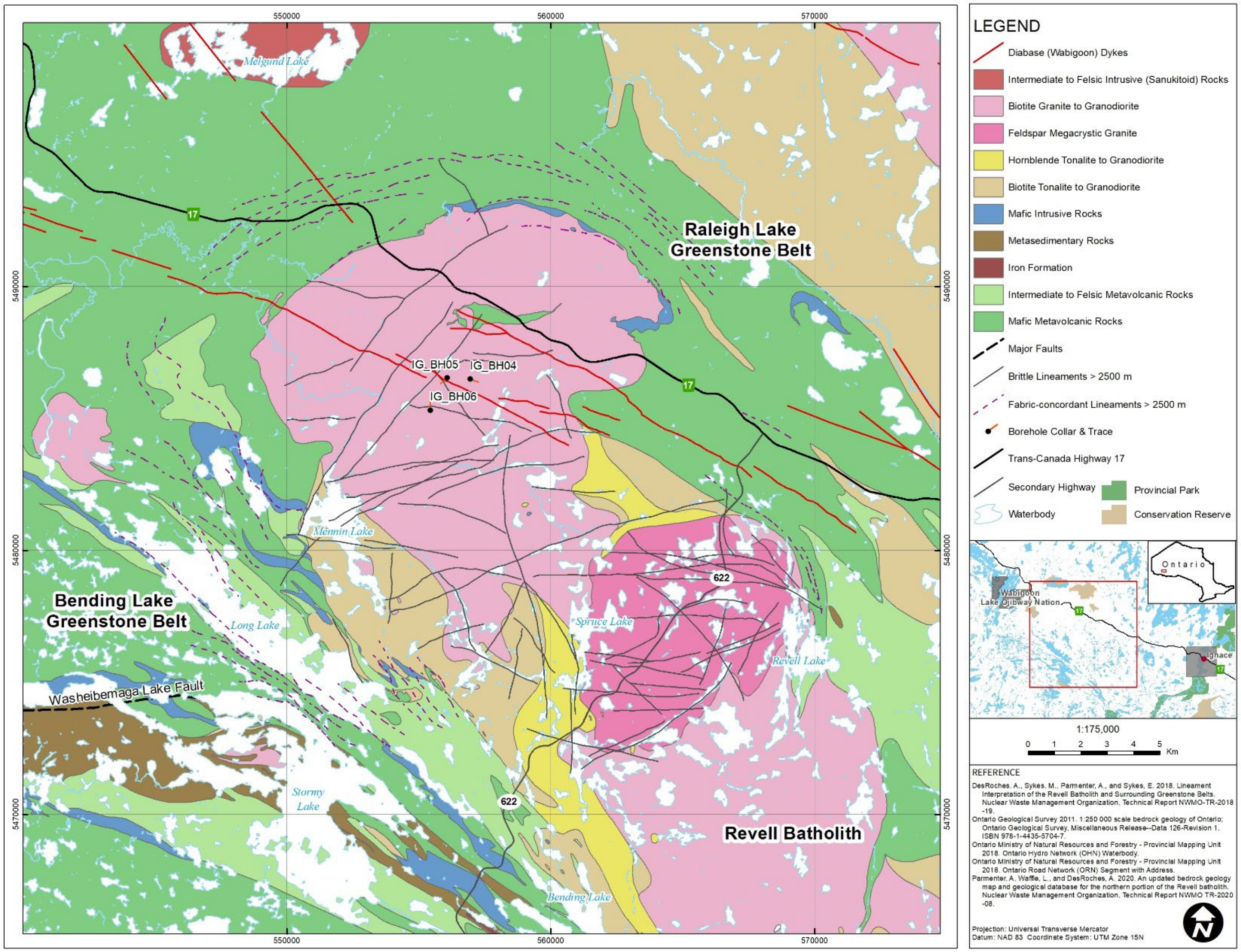

Figure 2: Geological Setting and Location of Boreholes IG_BH04, IG_BH05, and IG_BH06 in the Northern Portion of the Revell Batholith

2.2 Technical Objectives

The technical objectives of the borehole drilling and flushing activities are:

- To provide opportunity to complete supplementary studies such as borehole geophysical logging, hydraulic testing and opportunistic groundwater sampling; and
- To provide stable borehole walls to allow for future testing and monitoring.

The main objectives of the Drilling Fluid Management and Use of Tracers are:

- Optimize drilling to minimize borehole deterioration;
- Effectively remove any cuttings to maintain efficient drilling; and
- Trace the drilling fluids using a fluorescein tracer and measure fluid parameters (e.g., temperature, density and electric conductivity) in order to recognize drilling fluid contamination of groundwater (to be discussed in the WP07 Report – Opportunistic Groundwater Sampling for IG_BH04, Golder 2021b).

3.0 DESCRIPTION OF ACTIVITIES

Activities were overseen by Lead Contractor Golder Associates with Rodren Drilling Ltd. (Rodren), based in Winnipeg, Manitoba, contracted by Golder to carry out the drilling and flushing for IG_BH04.

Permission to drill was obtained from the Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF) on September 24th, 2019 and formal notification given to Golder from the NWMO on February 11th, 2021 with the understanding that drilling and flushing would begin in April 2021. Drilling of the plugs and cemented intervals and flushing of IG_BH04 commenced immediately following completion of WP01 activities at IG_BH04.

Drilling was carried out on a 24 hour, 7 days per week basis. Day shifts ran from 7 am to 7 pm, with night shifts from 7 pm to 7 am. A driller and helper were on site for each day and night shift, and a drilling foreman was typically present during the day shifts, or as required. A Golder drilling supervisor was present on site for all drilling activities. When the Golder site supervisor was not on site, the drilling supervisor took over this role. This was documented in the daily tail gate sign-in sheet located in the Golder trailer at the site entrance.

The Golder drilling supervisor’s responsibilities were divided between two main activities: (1) Drilling and Flushing (2) Drilling Fluid Management and Use of Tracers. These activities included the following actions:

Drilling and Flushing

- Verifying drill rig setup;
- Tracking the depth of the borehole;
- Monitoring drilling parameters during drilling; and
- Managing drill cutting collection and disposal.

Drilling Fluid Management and Use of Tracers

- Testing all fresh source water added to the drill fluid system;

- Monitoring drill fluid parameters during drilling; and
- Supervising borehole flushing prior to geophysical survey (WP05)

3.1 Health and Safety

The Ignace drilling and testing program conformed to applicable health and safety standards for the duration of the program. A comprehensive “pre-drill” drill rig inspection was originally completed by Rodren prior to the start of drilling IG_BH04 on April 19th, 2021. This inspection included the following checks:

- Emergency switches are in working order;
- Equipment and protective guards are in place;
- Cables, chains, pulleys, cable winches, latches / lifting devices are in proper working order;
- Drill string (coring rods) are manufacturer recommended;
- Mast is unmodified from manufacturer and regularly inspected;
- Drill controls are appropriate and free from obstructions;
- Hydraulic lines are secure and not bent or pinched;
- Pump lines (water hoses) are in good condition with whip checks, where required;
- Fire prevention supplies are present;
- Exhaust piping is directed appropriately;
- Fuel is properly stored; and
- Other general items including maintenance logs to confirm inspections were available.

Rodren continued to complete daily rig inspections to ensure that rig safety was maintained throughout the drilling program.

Once drilling commenced, a Casella Sound Level Meter was used to establish zones where hearing protection was required, that is, all areas with an equivalent sound exposure level exceeding 83 dBA (O.Reg. 851/139) due to the prolonged exposure of 12-hour shifts. The area inside of the drill rig and surrounding support shacks was established as requiring hearing protection, as well as the area adjacent to the light tower close to site entrance.

An RKI Model GX-2012, 4-Gas Monitor was installed in the drill rig and used to monitor for levels of oxygen, carbon monoxide, hydrogen sulphide and combustible gases during drilling. The gas monitor was bump checked by the Golder site supervisor daily. One exceedance of safe limits of these gases was encountered during drilling of IG_BH04. This occurred from the location of the exhaust, and the direction of the wind. The drill was shut-off and the area vacated, leaving all the doors open for proper ventilation.

Health and safety toolbox meetings were held at the beginning of each shift (day and night), where attendance of all site personnel was mandatory. The meeting reviewed all activities to be completed during that shift, and identified the hazards and mitigation efforts to reduce risk of injury. Any visitors on site, who did not participate in the toolbox meetings, were required to review and acknowledge the toolbox report before allowed to perform work on site.

4.0 SUMMARY OF DRILLING AND FLUSHING

IG_BH04 was previously drilled in the fall and winter of 2019/2020 by a different contractor, Wood Plc (Wood). Prior to the de-mobilization of Wood from IG_BH04, two Van Ruth plugs were installed at a depth of 584.21 mbgs, with a cement plug from 560.21 – 584.21 mbgs. The plugs were installed to isolate the deep groundwater regime from the groundwater encountered closer to surface. Golder commenced the drilling of the IG_BH04 plugs on April 18th, 2021 and completed the flushing on April 29th, 2021. The overall drilling progress and key activities are shown on Figure 3.

The final drilled depth of IG_BH04, based on measurement of the length of retrieved core, was 1000.20 mbgs (along hole). During this campaign, the borehole was advanced to 1000.36 metres below ground surface (mbgs); this drilled depth (along hole) is based on the rod count and measured stickup of the drill rods on the final drill run. This discrepancy is associated with an unsuccessful attempt to drill a final core plug to retrieve the borehole plugs installed in the borehole. It is likely that some core was ground up at the bottom of the borehole, and not recovered. An updated borehole schematic is presented in Figure 4.

Once the activities associated with WP02 were carried out at IG_BH04, the equipment was retained on site as most of the sampling and monitoring supplies were required for continued monitoring of drilling fluid during WP05 and WP06 activities, as well as any potential WP07 opportunistic groundwater sample attempts that may have been carried out during WP06 – Hydraulic Testing.

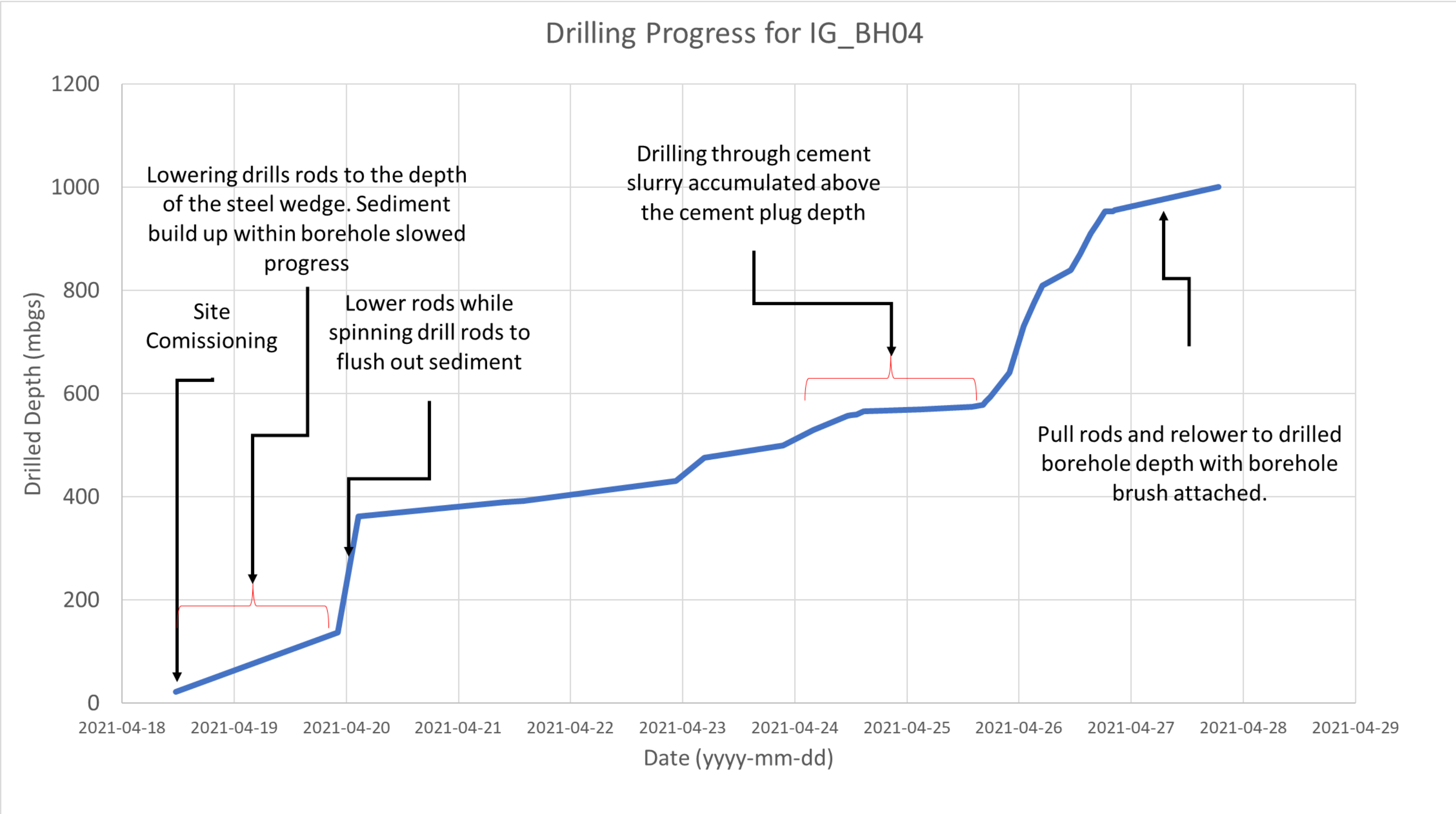

Figure 3: IG_BH04 Drilling Progress and Activities

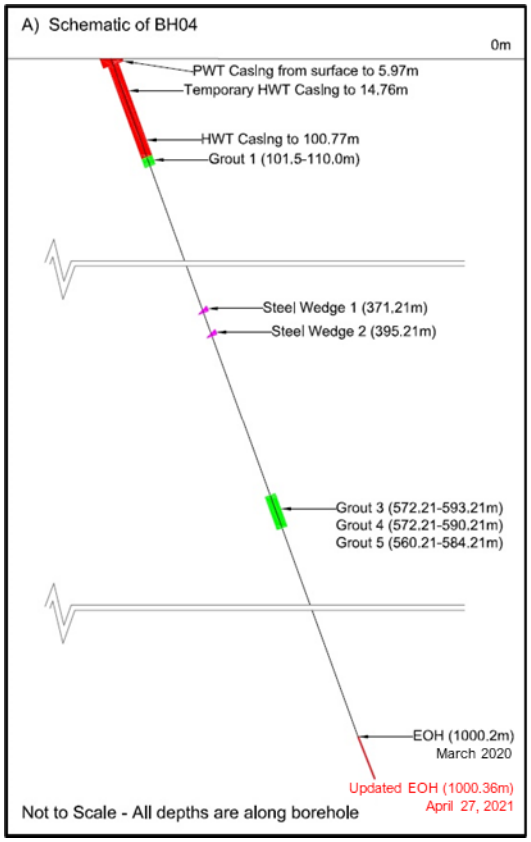

Figure 4: Updated IG_BH04 Schematic

4.1 Drilling Details

4.1.1 Drill Rig Setup

A skid mounted Discovery Diamond Drill model EF-75 12 HH was used for the program, set up with containment to minimize drill fluid entering the environment. Drilling was carried out with a constant water flush (as necessary), with the drill water (drill fluid) recycled initially using a Solids Removal System™ (SRU) from Australian Mud Company Pty Ltd. (AMC). This system utilized a centrifuge to remove cuttings from the return drill fluid and is shown in Figure 5.

Figure 5: Solids Removal Unit – Centrifuge Used to Remove Cuttings from Drill Fluid Return

Set-up of the drill rig commenced once the drill pad was prepared as described in the WP01 Commissioning Report (Golder 2021c). The construction of the drill pad included lining an area of approximately 200 m^2 to provide secondary containment beneath the drill and all support equipment including the centrifuge, the wastewater and fluorescein water tanks, as well as all connecting hoses and lines. The drill pad was prepared with a gentle slope towards the borehole collar, so that all fluid contained by the liner was directed to the borehole collar (i.e., the "lower sump"), where it was pumped to a wastewater tank via a submersible sump pump. Prior to the commencement of drilling, an "upper" metal sump box was welded to the outside of the PWT casing at the collar of the hole. The metal sump box is used to contain the return drill fluid from the casing during drilling and flushing activities.

The as-built collar azimuth and dip for IG_BH04 was 110˚/-70˚. Once the drill pad was constructed and the rig matting in place, the drill was moved into place using an excavator.

Golder WP02 staff mobilized to site around April 15th, 2021. During the initial days on site, Golder unpacked and set up the site trailers and carried out equipment calibrations, while Rodren prepared their support equipment. The overall view of the IG_BH04 site is shown in Figure 6, and an image of the drill rig shown in Figure 7.

Figure 6: View of IG_BH04 Drill Site Facing North

Figure 7: Photograph of the Inside of the Rodren Drill Rig and Rig Mast

4.1.2 Drill Rig and Equipment Maintenance

Throughout the drilling and advancement of IG_BH04 several operational issues were encountered, leading to extended delays. The issues encountered are detailed in Table 1.

Table 1: Operational Issues Encountering during the Advancement of IG_BH04

Delay Period	Operational Issues
April 19 – April 20	Centrifuge – A piece critical to the operation of the machine broke, preventing it from starting (this did not impact the advancement of lowering the drill rods)
April 20 – April 21	Accumulated Sediment / Steel Wedge – Pulled the drill rods to replace the HQ bit with a bevelled bit that is more suited to passing the steel wedges in the borehole due to encountered resistance. Discovered accumulated sediment in borehole had plugged the drill rods and contributed to resistance within the borehole.
April 21	Drill Bit – Pulled the drill rods to replace the bevelled drill bit after reaming the steel wedge was completed. An HQ bit with a graphite plug was used to help guide the drill rods past the steel wedge. The HQ bit was more suited to drilling the cement and Van Ruth plugs.
April 22	Chuck Jaws – While the drill rods were lowered with the HQ bit and graphite plug, the drill rods slipped. A new set of chuck jaws were delivered to site from the drillers warehouse to replace the jaws.
April 23	Graphite Plug – As the drill rods were lowered a significant amount of sediment was encountered above the cemented depth. An increased flushing rate was required to remove the material from the borehole. The drill rods were removed from the hole to remove the graphite plug. The core barrel and a 3 m rod were full of material once they were on surface.
April 24 – April 25	Cement Slurry – Accumulated material, approximately 90 m above the cement plug and Van Ruth plugs was encountered. The advancement rate decreased significantly throughout this interval.
April 27	Drill Rods – The threads of the drill rod 3 m below the ground surface sheared off. A rod tap was delivered to the site to retrieve the broken drill string from the borehole.

4.1.3 Tracking Borehole Depth

The depth of the borehole was monitored on a per run basis by the drilling supervisors. This was done by measuring the stickup of the drill rods from a fixed reference point at the completion of each run plus the fixed stick up of that reference point from the ground surface, which was subtracted from the length of the drill string (core barrel plus the drill rods). The chosen reference point was the top of the drill chuck, which was 2.07 m above ground surface (along hole). During drilling, the depth of the borehole was monitored as meters below ground surface along the hole and throughout this report depths are referred to as mbgs (along hole).

The core barrel assembly was measured as 4.14 m long and included the barrel, a reaming shell and the drill bit. All drill rods on site were confirmed as 3.0 m long (metric) HQ rods. No rod grease was used during the coring process; however thread lubricant was used on the rod threads as they were added to the drill string. As described above, the borehole depth was tracked by the number of rods added to the drill string.

A rod count was performed by WP02 supervisors during the final rod pull, where the total number of HQ coring rods used was verified as 333.

4.1.4 Drill Cuttings Management and Disposal

At the outset of the field program, the drill fluid recycling system was set up using the SRU™ (centrifuge). The drill fluid return containing cuttings from the borehole was pumped directly to the centrifuge, where the fine solids were separated from the water and directed to buckets that were emptied into plastic lined containment bags to await disposal. The centrifuge experienced difficulty at the beginning of the plug drilling and was used as a settlement tank prior to being repaired on April 20, 2021. The performance of the centrifuge was observed to be fairly consistent throughout the remainder of the plug drilling in IG_BH04.

These solid drill cuttings were sampled on April 28, 2021 and sent to Bureau Veritas Laboratories in Mississauga to be analyzed according to Ontario Regulation 558. The results indicated that the drill cuttings were safe for disposal and were accepted by the Ignace landfill.

4.2 Borehole Location and Orientation Details

The as-built borehole points were surveyed on October 28, 2021 by Rugged Geomatics Inc. Elevation data was measured for the top of the borehole casing as well as a ground surface point.

Given the as-built coordinates of the top of the surface casing (PQ), the along hole distance between the top of the PQ and the reference ground level as well as the casing orientation of 110° / -70°, the following relationships were used to translate the Northing, Easting and Elevation of the PQ casing to the reference ground level:

Northing: cos(70˚)*cos(110˚)

Easting: cos(70˚)*sin(110˚)

Elevation: -sin(70˚)

The calculated and provided as-built coordinates of IG_BH04 are presented in Table 2.

Table 2: IG_BH04 Final Surveyed Collar and Casing Coordinates

Point	Northing (m)	Easting (m)	Elevation (m)	Comment
Borehole Collar – Reference Ground Level	5486487.85	556957.93	444.25	Calculated E, N & Elev.
Top of Casing	5486487.88	556957.84	444.51	Provided E, N & Elev.

Note: Elevations are Geodetic and referred to the CGVD2013 Datum and coordinates are referred to UTM Zone 15, NAD 83 (CSRS). Borehole Collar – Reference Ground Level refers to the pre-drilling ground surface level and has since been regraded

4.3 Monitoring Drilling Parameters

Drilling supervisors were stationed at the rig during drilling, to observe the drilling parameters during drilling as well as any occurrences of drill fluid spills or maintenance related activities. The drill parameters included torque, thrust or down pressure, fluid injection pressure and downhole fluid flow. These parameters were observed from the gauges at the drill controls.

Results of the drilling parameters collected are presented in Table A-1 (Appendix A) and shown graphically in Figure B-1 (Appendix B). General observations are listed below.

- Bit Rotation Speed was observed to be consistent throughout the drilling.
- Torque and down pressure both increased at approximately 390 mbgs (along hole), the depth of the second steel wedge. The torque and down pressure were observed to be steady for the remainder of the borehole, with a generally increasing trend from approximately 390 mbgs (along hole) to the bottom of the borehole.
- Pump pressure increased while passing the second steel wedge at a depth of approximately 390 mbgs (along hole) and remained elevated until the cement slurry encountered above the cement plugs had been thoroughly flushed out of the borehole, approximately 565 mbgs (along hole).
- Fluid injection rate was 0 until the intersection of the cement plugs at approximately 565 mbgs (along hole).

It should be noted for that day shift and night shift drillers had different approaches to their drilling technique and fluctuations in all observed parameters are a reflection of those differences.

4.4 Borehole Brushing

Borehole brushing was completed after the cement plugs were successfully drilled through and recovered. Figure 8 shows the cement plug, two van ruth plugs, and a bottom plug installed in IG_BH04.

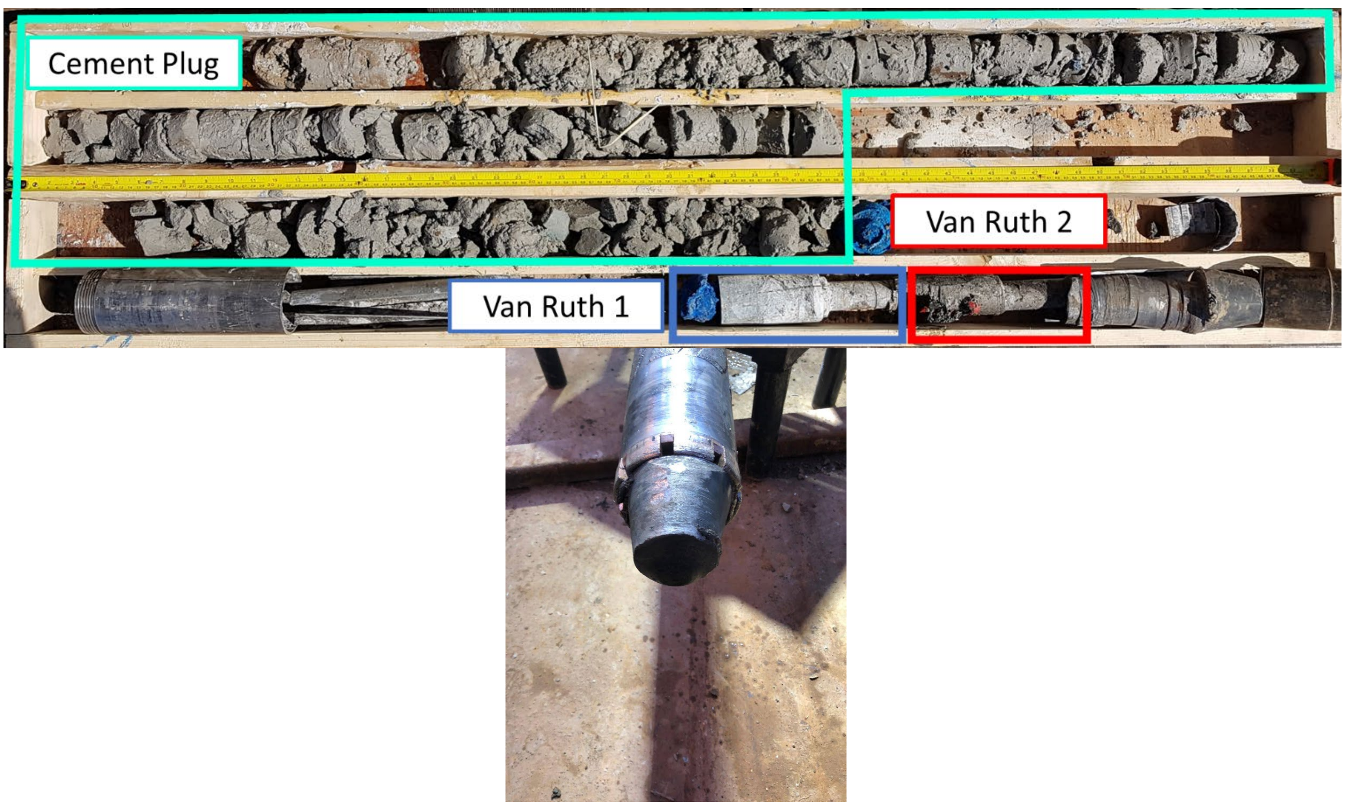

Figure 8: Borehole Plugs, Top: Cement Plug Overlaying Two Van Ruth Plugs and a Bottom Plug. Bottom: Bottom Plug Wedged in the Core Barrel.

Once the drill rods were removed from the hole, it was confirmed that the plugs installed in IG_BH04 after the completion of coring had been successfully retrieved from the borehole. It was determined that an additional drill core plug was not required to retrieve the borehole plugs. The borehole brush, shown in Figure 9, was then connected to the drill rods and lowered progressively down the borehole.

Figure 9: Borehole Brush Attached to Rods, Used to Remove Loose Cement from Grouted Intervals

At each cemented interval identified in Table 3, the borehole brush was raised and lowered approximately 10 times to remove any accumulated material from the borehole walls that may obscure imaging of the borehole walls during the geophysical surveys.

Table 3: Depths of Cemented Intervals

Cemented Zones	Depth in Borehole (mbgs (along hole))
Grout Plug 1 (permeable zone grouted during original coring of the borehole)	101.50 – 110.00
Grout Plug 3 (permeable zone grouted during original coring of the borehole)	572.21 – 593.21
Grout Plug 4 (permeable zone grouted during original coring of the borehole)	572.21 – 590.21
Grout Plug 5 (in place at the start of the work to temporarily seal the borehole)	560.21 – 584.21

4.5 Borehole Flushing

Borehole flushing was carried out on IG_BH04 with 100 ppb fluorescein traced fresh water prior to geophysical televiewer surveys.

Fresh water was circulated with a fluorescein tracer (target concentration of 100 ppb, the same used during coring) into the borehole through the drill rods until the return fluid was clear and had water quality indicator parameters that were targeted to be within 10% of the source water for turbidity, dissolved oxygen and electrical conductivity, within 20% of the source water fluorescein concentration and within 0.5 of pH of that of the fresh water used. After the parameters stabilized and authorization to terminate flushing was received from the NWMO, drill rods were withdrawn from the borehole for the immediate commencement of the time-sensitive geophysics.

The IG_BH04 flushing event was carried out over a single day period, from the evening of April 28th into the early afternoon of April 29th, 2021. Approximately 45,000 litres representing over 4 borehole volumes (borehole volume without HQ rods) were flushed through the borehole. Appendix C presents the water quality parameters for the final borehole flushing.

5.0 SUMMARY OF DRILL FLUID MANAGEMENT AND USE OF TRACERS

Monitoring of the drill fluid volume losses and gains during drilling was not required, since the main objective of the drilling and flushing activities was to prepare the borehole for the proceeding Work Packages. The drill fluid recycling system as well as the results of the drill fluid parameter are described in the subsequent sections.

5.1 Drill Fluid Closed System

The drill fluid system consisted of three components: a centrifuge (SRU™) tank, a plastic mixing tank in the rig and the borehole itself. The centrifuge tank (approximate capacity of 2.60 m^3) pumped water to the tank in the drill rig (approximate capacity of 0.65 m^3) using a submersible pump, from which water was pumped downhole using the rig's pump. The drill water returning to surface was pumped via a submersible pump, located in the steel sump box sealed at the collar of the hole to the centrifuge where the cuttings were removed, and the cleaned water fell back into the centrifuge tank. This provided a closed system where fresh water was only introduced after confirmation from the Golder drilling supervisor. A schematic representing this closed drill fluid system is shown in Figure 10.

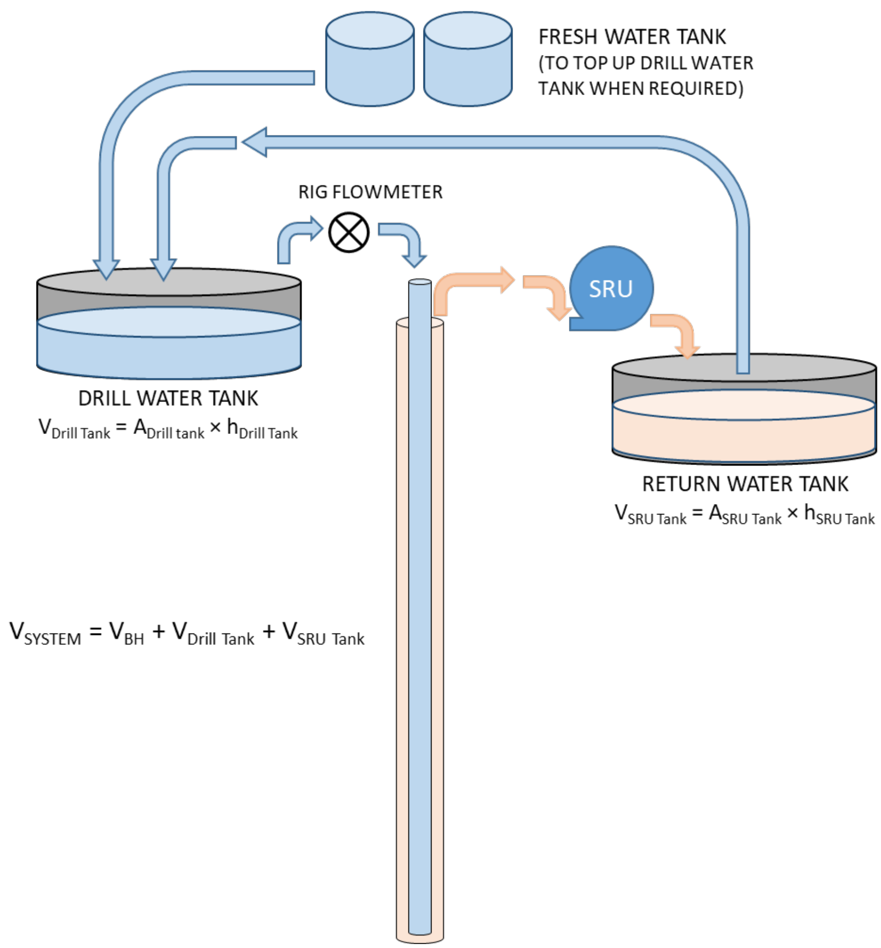

Figure 10: Diagram of IG_BH04 Drill Fluid System

5.2 Fresh Water Management and Sampling

Fresh water was stored in two 28,350 litre Baker tanks located on the west side of the site. Fresh water was collected from a municipal source in Ignace and transported to site via a local water truck service. Ignace has a water treatment plant, and municipal water is treated to adhere to Ontario drinking water standards. The municipal water is sourced from Lake Michel, which is located approximately 1 km north of Ignace, and undergoes filtration and chlorination at the water treatment plant. Where possible, two individual tanks of fresh water were circulated together using a submersible pump, in order to mix them into a single batch of fresh water for sampling. Each batch of fresh water was individually sampled before being introduced to the drill water system and entering the borehole. All fresh water batches were termed “water source” and designated for sample collection as IG_BH04_WSXXX, increasing consecutively from the previously designated water source sample, IG_BH04_WS015.

5.2.1 Water Source Samples and Testing

Water source samples were collected from all batches of fresh water delivered to site, prior to fluorescein addition and prior to introducing the water to the drill system. Water was collected from the storage tanks into a clean, triple rinsed 19 litre (5 gallon) bucket, and then transferred into labelled bottles using new syringes, or new tubing with a peristaltic pump. Samples were collected for submission to Bureau Veritas (BV), Isotope Tracer Technologies (IT2) and the University of Ottawa (UofO) as per Table 4, and in-field geochemistry analyses were carried out on the samples.

In-field geochemistry analyses methodologies are described in the WP07 Report – Opportunistic Groundwater Sampling for IG_BH04 (Golder 2021b) and include alkalinity, sulphide, ferrous iron and dissolved oxygen analyses.

Table 4: Sample Preservation Requirements for Bureau Veritas, Isotope Tracer Technologies and the University of Ottawa

Parameter Group	Parameter List	Bottle Type Requirement	Sample Volume Requirement	Head Space Requirement	Field Filtering Requirement	Preservative Requirement
Major Elements & Metals (BV)	Na, K, Ca, Mg, Sr, Li, Si, Al, B, STotal, FeTotalDiss (Dissolved Metals by ICPMS)	HDPE plastic bottles	120 mL	Fill Line	Yes, 0.45 µm filter	Trace grade nitric acid
Trace Elements, Anions & Nutrients (BV)	Cu, Ni, Zn, Pb, Cd, Al, As, Se, Bi, U, Cs, Rb, Ba, Cr, Co, Th, Zr					
	SiO2 & I	HDPE plastic bottles	250 mL	None	Yes, 0.45 µm filter	None

Parameter Group	Parameter List	Bottle Type Requirement	Sample Volume Requirement	Head Space Requirement	Field Filtering Requirement	Preservative Requirement
	S2-	HDPE plastic bottles	125 mL	Fill Line	Yes, 0.45 µm filter	Zinc acetate and sodium hydroxide solution
	NH4 (ammonium), NH3 + NH4 (total ammonia)	Clear glass vial	40 mL	Fill to neck	Yes, 0.45 µm filter	Trace grade sulphuric acid
	Ntotal, Ptotal, TOC	HDPE plastic bottles	120 mL	Fill Line	Yes, 0.45 µm filter	Trace grade sulphuric acid
	DOC	HDPE plastic bottles	120 mL	None	Yes, 0.45 µm filter	None
	Br, F, Cl, I, SO4, PO4, NO3, NO2, HCO3	HDPE plastic bottles	500 mL	None	Yes, 0.45 µm filter	None
Physical – Chemical (BV)	pH, Alkalinity, TIC					
Rare Earth Elements (BV)	Ce to Y	HDPE plastic bottles	2 X 1 L	None	Yes, 0.45 µm filter	None
Radioisotopes (BV)	238U, 234U, 40K, 222Rn, 223Ra, 224Ra, 226Ra, 228Ra, 227Th, 232Th, 230Th, Gross Alpha & Beta, 210Po, 210Pb, 90Sr		5 X 1 L	Fill Line	Yes, 0.45 µm filter	Trace grade nitric acid
Stable Isotopes (IT2)	δ18O, δ2H	HDPE plastic bottles	60 mL	No headspace	Yes, 0.45 µm filter	None
	87Sr/86Sr	HDPE plastic bottle	1000 mL	No headspace	Yes, 0.45 µm filter	None
	δ13C DIC	Amber glass vials, Teflon cap	2 x 40 mL glass vials with septa	No headspace	Yes, 0.45 µm filter	Zinc chloride

Parameter Group	Parameter List	Bottle Type Requirement	Sample Volume Requirement	Head Space Requirement	Field Filtering Requirement	Preservative Requirement
			caps (x2 per sample)			
	37Cl	HDPE plastic bottle	1000 mL	No headspace	Yes, 0.45 µm filter	None
Radioisotopes (IT2)	36Cl					
	129I	HDPE plastic bottle	500 mL	No headspace	Yes, 0.45 µm filter	None
	14C-DIC	Glass bottle	1000 mL	No headspace	Yes, 0.45 µm filter	Zinc chloride
	E3H	HDPE plastic bottle	500 mL	No headspace	Yes, 0.45 µm filter	None
Noble gas concentration & isotopic ratios (UofO)	He, Ar, Ne	Copper Tubing	-	-	None	None
	(3,4He, 20,22Ne, 21,22Ne, 40,36Ar)					

A total of 2 water source samples was collected during the drilling program as follows:

- IG_BH04_WS016 was collected and used during regular drilling and flushing activities.
- IG_BH04_WS017 and IG_BH04_WS018 were assigned to account for water source deliveries transferred from IG_BH05 for WP06 activities.

All water source data (including in-field parameters, in-field analyses and laboratory results) are included in the Opportunistic Groundwater Sampling WP07 report for IG_BH04 (Golder 2021b).

5.2.2 Fluorescein Addition

After a sample was collected from the fresh water tank or tanks, fluorescein was measured using an analytical scale (due to the small mass of powdered fluorescein required for each tank) and added to the tank or tanks. Each tank was circulated to mix in the fluorescein using a submersible pump with an attached hose placed inside the tank. Due to their large capacity, the tanks were generally left to circulate and mix for the majority of a 12-hour shift, or until consistent concentration readings were collected. The water was tested for fluorescein concentration using the AquaFluor fluorometer until the desired concentration was achieved. Once the fluorescein concentration was close to the specified target (100 ppb for all activities), the water was transferred to the drill system as required. Figure 11 below shows the tracer being added to the source water in one of the freshwater tanks used in the drilling of a previous borehole.

Figure 11: Fluorescein Tracer Being Added to the Source Water

5.3 Drill Fluid Field Parameters

At approximately 50 m intervals, while lowering the drill rods and progressively flushing, drilling supervisors communicated with the drillers to time the collection of drill fluid with the lowering of a full drill rod, pausing to allow for a rod stick-up measurement. Drillers and drill supervisors developed a workflow to communicate when the drillers could proceed to the next activity, that is, when measurements and sample collection were complete, and the drillers could add an additional drill rod and continue drilling.

Drill fluid field parameters were measured using a Horiba U52-2 multiparameter water quality meter. A baseline reading was taken prior to the start of drilling, and all subsequent occasions when fresh water was added to the system. At the end of each drill run, a sample of water for field parameters was collected from the return drill fluid from the outlet of the centrifuge that drained into the tank. This system allowed a sample of water directly from the borehole to be collected and tested, providing the most representative parameters possible for that run.

Fluorescein concentration was also measured from this sample. The presence of cuttings in the drill water was observed to mask the fluorescein concentration readings measured with the AquaFluor, and drill fluid samples were therefore filtered using an inline high volume 0.45 μm filter prior to collecting readings.

The field parameters of the drill fluid measured each run are presented in Table 5. These parameters were monitored at approximately 50 m intervals while drilling the borehole.

Table 5: Drill Fluid Monitoring Parameters

Field Parameter	Instrument	Target ranges for borehole flushing
Fluorescein dye (tracer)	Aquafluor Handheld Fluorometer/Turbidimeter	20% change in concentration from previous drill fluid source Note: Minimum detection limit of the fluorometer (0.4 ppb)

Field Parameter	Instrument	Target ranges for borehole flushing
Turbidity	Horiba U52-2 multiparameter water quality meter	10% change from the previous drill fluid source
Dissolved Oxygen		10% change from the previous drill fluid source
Electrical conductivity		10% change from the previous drill fluid source
pH		change of at least 0.5 from previous drill fluid source
Temperature		N/A
Density	Hydrometer	N/A

5.3.1 Drill Fluid Parameter Data

The drill fluid parameter data is presented in Table A-1 (Appendix A) and shown graphically on Figures B-2 and B-3 (Appendix B). General observations and comments are listed below.

- The initial borehole fluorescein concentration prior to drilling the borehole plugs and flushing was observed to be 1.728 ppb. As the drill fluid parameters were collected at deeper depths, the system fluorescein concentration was observed to progressively increase. The system concentration was observed to fluctuate between approximately 360 mbgs (along hole) and 590 mbgs (along hole) before continuing to increase to the 100 ppb target.
- Density of the drill fluid increased slightly as the cement was encountered and drill fluid additive was added to help remove cuttings from the borehole at approximately 470 mbgs (along hole).
- Turbidity remained above the Horiba's measurement range (1000 NTU) for the majority of the drilling as the cement was encountered and drilling additive were added to borehole at approximately 470 mbgs (along hole).
- There are a few notable changes in the drill fluid electrical conductivity and pH. The major spike in the electrical conductivity is at the approximate depth of the cement plug within the borehole, encountered at 470 mbgs (along hole). There is an increase in pH below the depth of the second steel wedge, where it is observed to stabilize for the remainder of the borehole.
- Dissolved oxygen (DO) fluctuated continuously in the sensor's range.
- The temperature of the drill fluid system was between 5 – 10 ˚C before a depth of 390 mbgs (along hole) and then was generally between 10-15 ˚C.

5.4 Drill Fluid Additives

At a depth of 470 mbgs (along hole), a bio-degradable polymer-based drilling additive, AMC Pure-Vis, was added to the drill fluid via the drill tank in the rig. This additive generally improves the ability of the fluid to lift cuttings from the drill bit and out of the borehole, helping to manage the drill bit binding with cuttings and causing spikes in the torque. No other drill fluid additives were used other than AMC Pure-Vis.

6.0 REFERENCES

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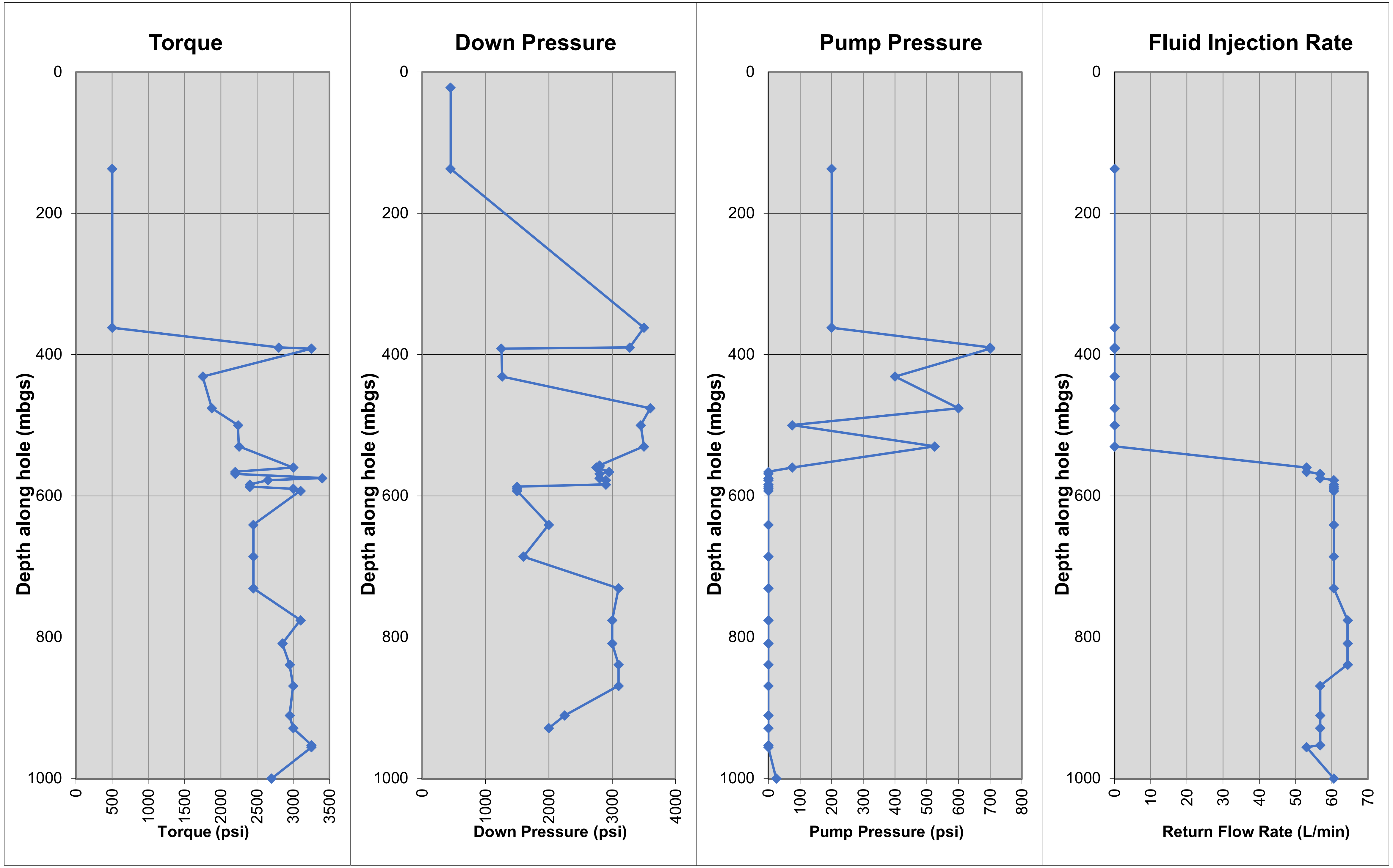
APPENDIX A

IG_BH04 Drilling and Drill Fluid Parameters

Date (End of Run)	Time	Depth	Drill Fluid Volume Change (L)	Fluorescein Concentration		Temp	Density		Elec. Cond.	pH	Dissolved Oxygen	Turbidity	ORP	ROP	Bit Rotation Speed	Torque	Thrust Pressure (Down-pressure)	Fluid Injection (pump) Pressure	Downhole Fluid Flow Rate	Comments
				Inlet	Outlet				Reading	Reading	Reading	Reading								
dd-mmm-yy	hh:mm	(mbgs)	>100 L	(ppb)	(ppb)	(°C)	API Gravity	SG	(mS/cm)	-	(mg/L)	(NTU)	(mV)	m/hr	RPM	psi	psi	psi	L/min	
18-Apr-21	11:35	22.00	-	-	1.728	8.12	9.6	1.00	7.39	10.71	5.42	1.7	161	-	-	0	0	0	0	
19-Apr-21	22:14	136.94	-	-	-	-	10	1.00	-	-	-	-	-	-	0	500	450	200	0	
20-Apr-21	02:36	361.96	-	-	10.1	4.77	10.1	1.00	0.230	10.29	13.18	1000	157		0	500	450	200	0	water from sump with sumbersible pump
21-Apr-21	09:40	390.02	-	-	76.13	9.21	9.8	1.00	4.350	12.49	14.68	281	-9	-	600	2800	3500	700	0	
21-Apr-21	14:00	391.66	-	-	71.64	11.76	9.9	1.00	4.240	12.47	11.06	1000	-32	-	600	3250	3275	700	0	
22-Apr-21	22:30	431.00	-	-	72.5	14.40	10	1.00	4.620	12.50	5.95	370	-57	-	100	1750	1250	400	0	
23-Apr-21	04:35	475.97	-	-	67.3	15.22	9.7	1.00	7.480	12.65	4.42	431	-43	-	300	1875	1263	600	0	
24-Apr-21	21:30	499.97	-	-	67.55	12.55	9.8	1.00	8.390	12.75	9.50	1000	-40	-	595	2238	3600	75	0	18:30 1.5L Pure-Vis added 21:00 6L of Pure-Vis added
24-Apr-21	04:00	529.97	-	-	22.33	11.92	9.7	1.00		12.84	12.35	1000	-22	-	500	2250	3450	525	0	04:00 6L of Pure-Vis added 04:30 5.5L of Pure-Vis added
25-Apr-21	11:20	556.97	-	-	37.51	12.16	9.7	1.00	9.860	12.82	11.64	1000	-41	-	-	-	-	-	-	initial reading while circulating
25-Apr-21	11:55	558.73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	While flushing borehole, resistance at 558.73 mbgs, assumed beginning of cement plug
25-Apr-21	13:10	559.88	-	-	67.3	15.22	9.7	1.00	7.480	12.65	4.42	431	-43	0.92	600	3000	3500	75	53	
25-Apr-21	14:41	565.99	-	-	-	-	-	-	-	-	-	-	-	19.87	625	2200	2800	0	57	
25-Apr-21	14:58	568.99	-	-	35.12	14.92	9.7	1.00	7.820	12.68	10.29	1000	-69	15.00	600	2200	2800	0	57	
25-Apr-21	13:58	574.99	-	-	-	-	-	-	-	-	-	-	-	5.45	600	3400	2750	0	61	
25-Apr-21	16:15	577.94	-	-	26.31	15.23	9.8	1.00	4.690	12.44	10.46	1000	-49	17.70	600	2650	2950	0	61	Bottom of Van Ruth assumed to have been encountered at a depth of 577.00 m.
25-Apr-21	16:50	583.97	-	-	-	-	-	-	-	-	-	-	-	18.00	600	2400	2800	0	61	
25-Apr-21	17:05	586.97	-	-	-	-	-	-	-	-	-	-	-	18.00	600	2400	2800	0	61	
25-Apr-21	17:25	589.97	-	-	-	-	-	-	-	-	-	-	-	-	600	3000	2900	0	61	
25-Apr-21	17:45	592.94	-	-	43.43	15.63	9.8	1.00	4.710	12.44	10.29	1000	-46	-	600	3100	2900	0	61	Added 1L of Pure-Vis
25-Apr-21	21:45	640.96	-	-	19.87	14.90	9.9	1.00	5.250	12.51	10.35	1000	-46	-	500	2450	1500	0	61	19:59 Add 10 mL fluorescein (5g/L) to centrifuge
25-Apr-21	23:25	686.00	-	-	58.73	13.16	9.8	1.00	4.930	12.50	13.55	1000	-43	-	500	2450	1500	0	61	
26-Apr-21	01:00	731.00	-	-	64.33	12.91	10	1.00	3.260	12.34	10.53	1000	-32	-	495	2450	1500	0	64	
26-Apr-21	03:10	775.97	-	-	61.73	12.46	9.9	1.00	2.960	12.30	13.07	1000	-25	-	500	3100	2000	0	64	
26-Apr-21	05:00	809.07	-	-	61.85	12.68	10	1.00	2.910	12.26	10.75	1000	-32	-	500	2850	1600	0	64	
26-Apr-21	11:00	838.97	-	-	54.83	12.55	9.7	1.00	4.050	12.44	11.92	1000	-34	-	400	2950	3100	0	57	
26-Apr-21	13:00	868.97	-	-	51.98	13.05	9.8	1.00	2.990	12.28	10.97	1000	-29	-	350	3000	3000	0	57	11:50 Add 25 mL fluorescein (5g/L) to centrifuge, 13:20 Add 1L Pure-Vis to drill tank
26-Apr-21	15:21	910.97	-	-	58.41	13.40	9.8	1.00	2.410	12.18	11.20	1000	-25	-	400	2950	3000	0	57	
26-Apr-21	16:45	928.97	-	-	57.02	14.02	9.8	1.00	2.580	12.22	9.45	1000	-39	-	400	3000	3100	0	57	
26-Apr-21	18:23	952.94	-	-	58.23	14.34	9.8	1.00	2.660	12.21	11.46	1000	-36	-	400	3250	3100	0	53	
26-Apr-21	20:00	952.94	-	-	86.97	14.24	9.9	1.00	2.590	12.19	4.83	1000	-32	-	-				-	Initial reading while circulating
26-Apr-21	20:30	955.94	-	-	86.45	14.93	9.9	1.00	2.990	12.23	11.78	1000	-32	-	500	3250	2250	0	61	
27-Apr-21	18:43	1000.36	-	-	100.00	16.38	9.6	1.00	2.630	11.97	9.66	1000	-25	-	600	2700	2000	25	64	

APPENDIX B

IG_BH04 Drilling and Drill Fluid Parameter Figures



CONSULTANT

WSP GOLDER

CLIENT

NWMO Ignace Drilling IG_BH04

TITLE

Figure B-1: Drilling Parameters

DATE

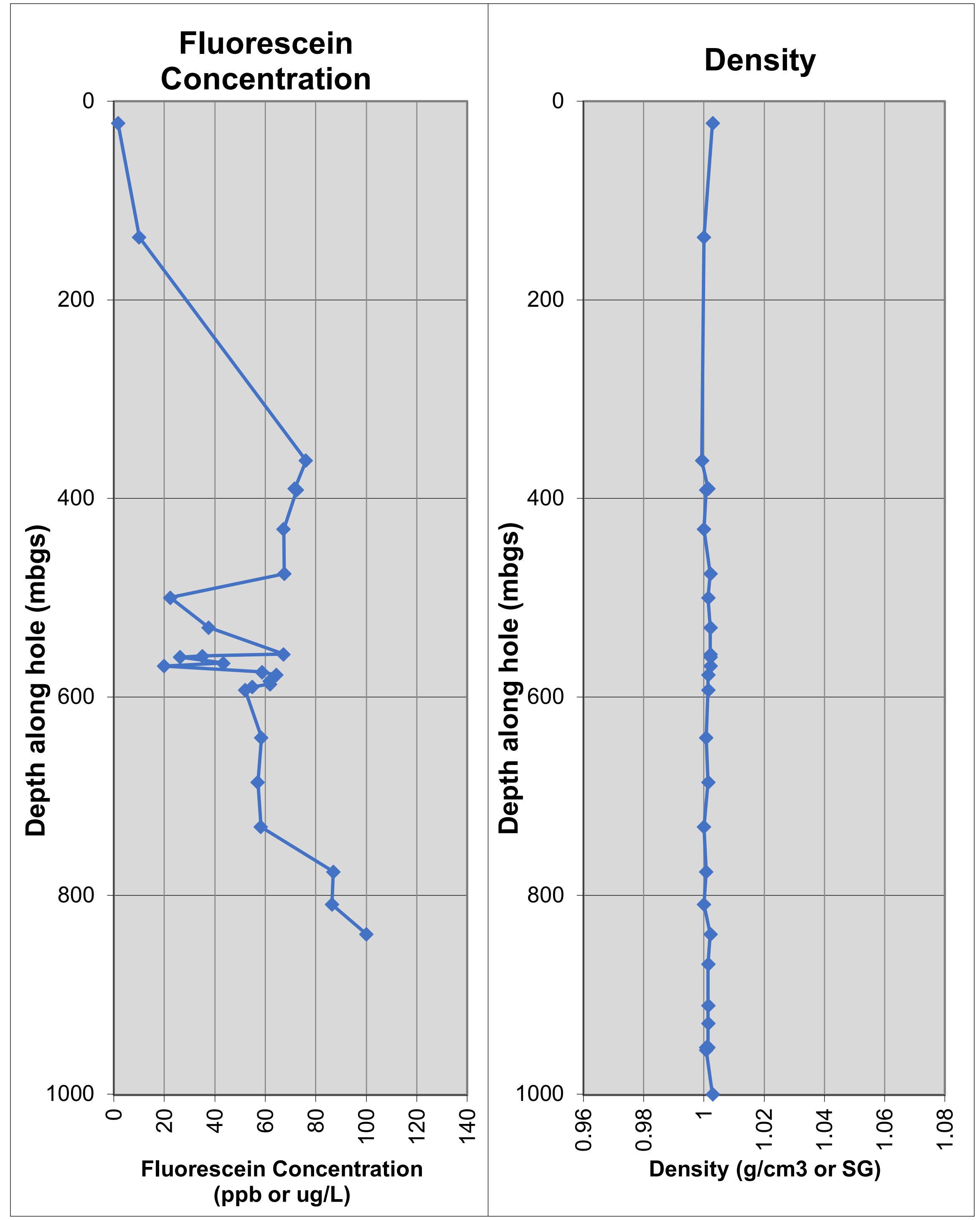
November 2022

DRAWN/REV

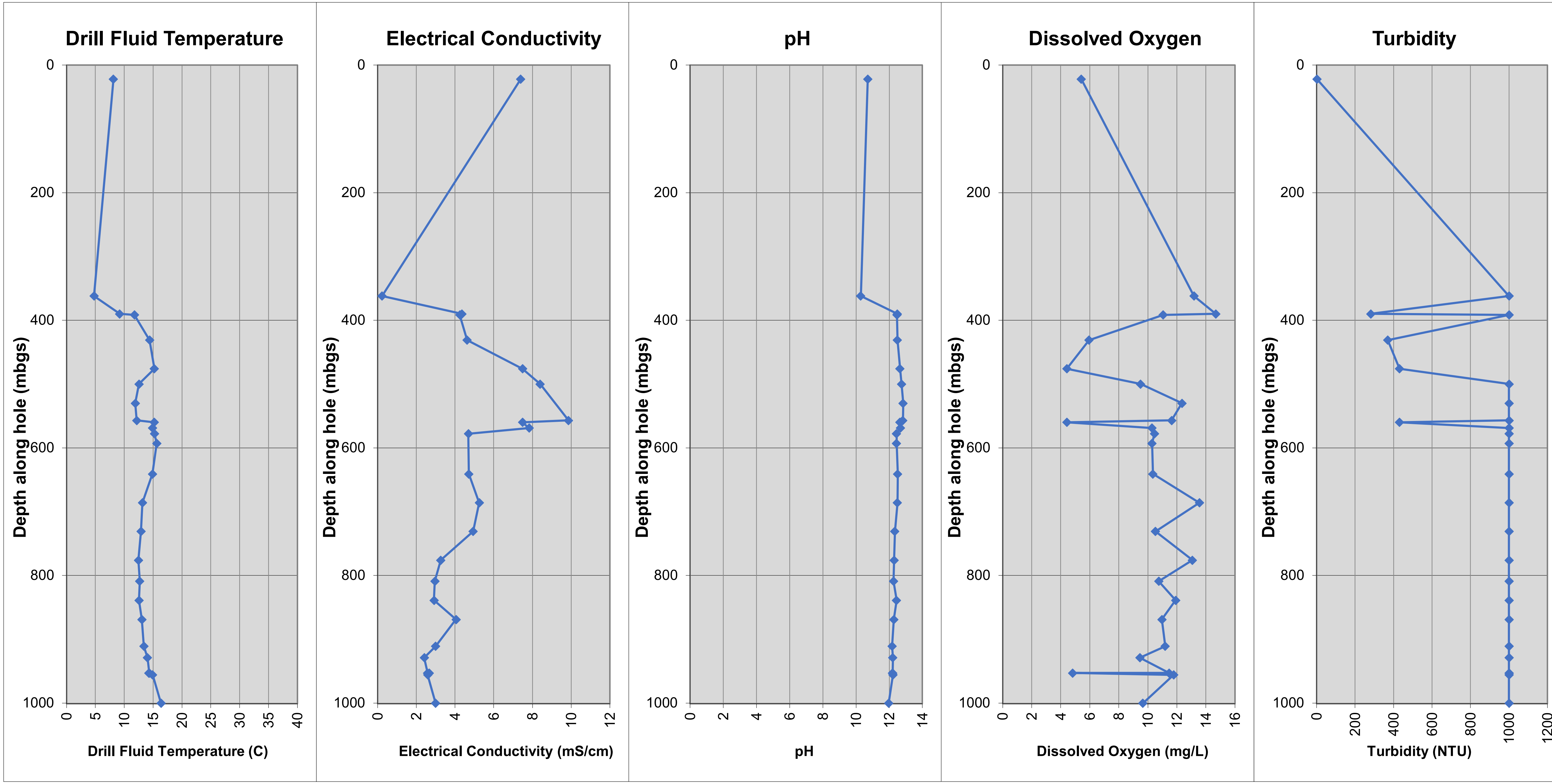
AKV / JLC

PROJECT NO.

20253946 (4020)



CONSULTANT	CLIENT	DATE
WSP GOLDER	NWMO Ignace Drilling IG_BH04	November 2022
	TITLE	DRAWN/REV
	Figure B-2: Drill Fluid Parameters	AKV / JLC
		PROJECT NO.
		20253946 (4020)



CONSULTANT	CLIENT	DATE
WSP GOLDER	NWMO Ignace Drilling IG_BH04	November 2022
		DRAWN/REV: AKV / JLC
	TITLE: Figure B-3: Drill Fluid Parameters	PROJECT NO.: 20253946 (4020)

APPENDIX C

Final IG_BH04 Flushing Data

Flush Sequence	Date / Time	Elapsed Time (Hours)	Approx. Volume (L)	Fluorescein (ppb)	Temperature (°C)	pH	ORP (mV)	Conductivity (mS/cm)	Turbidity (NTU)	DO (mg/L)
1	28-Apr-21 / 19:55	-	-	98.5	12.02	8.04	283	0.064	14.8	10.54
	28-Apr-21 / 22:56	0.00	0	17.93	13.63	11.07	-868.00	1.630	1000.00	11.63
	28-Apr-21 / 23:30	0.50	2044	37.90	12.87	11.94	-826.00	1.860	1000.00	11.04
	29-Apr-21 / 00:00	1.00	4088	44.90	12.28	11.85	-741.00	1.750	1000.00	11.58
	29-Apr-21 / 00:00	1.25	5167	40.68	12.30	11.68	-469.00	1.390	1000.00	6.47
	29-Apr-21 / 01:00	1.75	7325	54.21	12.25	11.46	-156.00	0.864	1000.00	12.67
	29-Apr-21 / 01:30	2.25	9482	64.36	12.59	11.20	-111.00	0.315	393.00	12.20
	29-Apr-21 / 02:00	2.75	11640	80.64	12.38	11.06	-75.00	0.248	112.00	8.08
	29-Apr-21 / 02:30	3.25	13798	91.29	12.34	10.83	-27.00	0.175	40.00	12.39
	29-Apr-21 / 02:45	3.50	14877	96.59	12.01	10.75	-42.00	0.164	46.70	7.00
	29-Apr-21 / 03:00	3.75	15956	100.80	12.06	10.70	-25.00	0.158	26.90	10.70
	29-Apr-21 / 03:15	4.00	17034	103.50	11.76	10.60	-16.00	0.144	18.50	12.00
	29-Apr-21 / 03:30	4.25	18113	105.30	11.42	10.57	-15.00	0.140	16.40	11.01
	29-Apr-21 / 03:45	4.50	19192	105.30	11.19	10.50	-7.00	0.132	16.00	9.21
	29-Apr-21 / 04:00	4.75	20271	107.60	11.24	10.44	-10.00	0.126	15.90	6.59
	29-Apr-21 / 04:30	5.25	22429	107.20	11.27	10.31	12.00	0.116	13.00	10.44
	29-Apr-21 / 04:45	5.50	23507	107.30	11.02	10.30	20.00	0.115	10.10	7.30
	29-Apr-21 / 05:00	5.75	24586	110.20	10.84	10.28	16.00	0.112	10.00	7.68
	29-Apr-21 / 05:30	6.25	26744	107.40	10.88	10.19	14.00	0.108	11.50	10.80
	29-Apr-21 / 05:45	6.50	27823	108.20	10.83	10.18	25.00	0.104	15.00	6.75
2	29-Apr-21 / 05:55	-	-	108.9	10.95	8.10	269	0.069	14.3	10.78
	29-Apr-21 / 06:15	7.00	29980	108.30	10.86	10.11	-45.00	0.110	33.00	9.79
	29-Apr-21 / 06:30	7.25	31059	108.40	10.34	10.11	25.00	0.104	14.00	6.38
	29-Apr-21 / 06:45	7.50	32138	109.20	10.13	10.10	17.00	0.100	10.10	11.76
	29-Apr-21 / 08:30	7.75	33217	87.81	9.78	10.73	-233.00	0.250	870.00	11.18
	29-Apr-21 / 08:45	8.00	34523	87.25	9.72	10.84	-208.00	0.226	421.00	11.18
	29-Apr-21 / 09:15	8.50	36454	93.37	9.90	10.31	-13.00	0.111	18.00	11.85
	29-Apr-21 / 09:30	8.75	37759	92.66	10.12	10.21	6.00	0.103	10.10	5.36
	29-Apr-21 / 09:45	9.00	38611	93.41	10.19	10.16	18.00	0.100	8.70	5.39
	29-Apr-21 / 10:00	9.25	39917	94.03	10.30	10.12	15.00	0.098	10.30	11.10
	29-Apr-21 / 10:15	9.50	40769	93.49	10.36	10.08	17.00	0.098	10.40	5.29
	29-Apr-21 / 10:30	9.75	41734	96.42	10.44	10.03	28.00	0.101	17.70	4.95
	29-Apr-21 / 11:00	10.25	43494	94.59	10.68	10.04	1.00	0.105	28.00	6.38
	29-Apr-21 / 11:30	10.75	45368	94.78	10.92	10.00	24.00	0.100	15.00	10.65

Note:

Indicates baseline readings for water source