CITY OF YELLOWKNIFE

SOLID WASTE FACILITY
INTERIM GROUNDWATER MONITORING PLAN

Version 2

January 2021

DOCUMENT CONTROL

Significant changes have been made to this document, refer to the revision table below.

Version	Date	Document Section	Page	Revision	Author
2	January 2021	All	All	Water Licence Renewal Application	Associated Environmental on behalf of the City of Yellowknife
1.1	November 2017	3,4, 5, 6, 7, 9, 10, 12, 14, 15, and Appendix B, C, E, and F		Including comments from Mackenzie Valley Land and Water Board	City of Yellowknife
1	March 2017	All	All	In compliance with Type A Water Licence MV2009L3-0007	City of Yellowknife

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1. INTRODUCTION

The City of Yellowknife's Solid Waste Facility (SWF) is located approximately 2 km north of the City's downtown and is bound by Yellowknife Highway (Hwy 3) to the south and Ingraham Trail (Hwy 4) to the east. The site plan showing the location of the SWF with approximate lease boundaries is shown in Figure 1 of Appendix A.

The City is subject to the terms and conditions of the Mackenzie Valley Land and Water Board (MVLWB) Type A Water Licence (No. MV2009L3-007, 2019) issued by the MVLWB on May 31, 2010, which expires on May 30, 2022.

This document presents the Interim Groundwater Management Plan (IGMP) to support the Type A Water Licence renewal application to be submitted to the MVLWB in 2021 before the current Type A Water Licence expires. The document will be termed as 'Interim" until current groundwater quality can be established for the SWF from upgradient groundwater monitoring and after monitoring wells MW-10, MW-11, and MW-12 have been monitored consecutively for three years.

1.1. Objective

The objective of the IGMP is to provide consolidated information related to regulatory approved groundwater monitoring at the SWF. The IGMP will be updated as required to reflect changes in operations and to include new information, where appropriate.

1.2. Facility Description and Operations

The description off the Solid Waste Facility and the operations are discussed in the City's Solid Waste Facility Operations and Maintenance (O&M) Plan and the Compost Facility O&M Plan.

2. HYDROGEOLOGICAL SETTING

2.1. Climate, Terrain and Topography

The climate in Yellowknife is comprised of long cold winters and short cool summers. The mean air temperatures are -25.6ºC in January and 17.0ºC in July. The mean annual precipitation is 288.6 mm, which is generally spilt between snowfall and rainfall (Government of Canada 2019a).

The dominant terrain at the SWF consists of overburden and fill material with small ponds scattered throughout the facility. Surface water runoff follows the topography at the SWF.

The surface topography is roughly bell-shaped, which is created by a mix of fill and soils, with a local surface divide that causes a topographic low towards the south and east (Dillon 2012). The mean surface elevation is 204.3 metres above sea level (masl) with a maximum relief of 20.0 m (Government of Canada 2019b).

2.2. Geology

Local overburden consists of limited soils and fill in the north and northwest portions of the SWF to variable soil coverage with thickness interpreted between 25 m and 40 m to the southern property boundary and along the central eastern section (Dillon 2017). The local bedrock is shaped contrastingly from the surface topography. The bedrock is bowl-shaped and primarily of the Kam Group (Yellowknife Bay Formation), consisting of andesite, basalt (i.e., volcanic rocks), gabbro, and diorite (i.e., intrusive equivalent rocks) (Dillon 2012; Brophy 1991). The top of bedrock elevation varies from approximately 170 masl to 200 masl, locally (Dillon 2012; Dillon 2017).

2.3. Hydrology

The SWF is located near Great Slave Lake, within the Mackenzie River watershed. Great Slave Lake has a surface water area of 28,570 km^2 and is approximately 614 m at its deepest. The primary outflow of Great Slave Lake is to the Mackenzie River. The Mackenzie River is 1,802 km and the largest North American freshwater discharge to the Arctic Ocean (INAC 2010). Most of the SWF drains to the south and east through culverts directing surface runoff to adjacent ponds. Some precipitation infiltrates to subsurface, and the remainder is routed to small ponds located at the SWF. The hydrology of these ponds is subject to the pond storage capacity and evaporation (Dillon 2012).

2.4. Hydrogeology

Precipitation in the area infiltrates the unconsolidated overburden and areas of the SWF that are not capped during rain or snowmelt events. This surface water typically infiltrates vertically downwards until it contacts the bedrock, a capping layer, or saturated zones. The groundwater then moves horizontally down-gradient towards the southeast portion of the SWF. In areas with vertical bedrock fractures or with steep grading / bedrock dip, there are little to no saturated conditions above the top of bedrock existing year-round.

Regional groundwater flow is anticipated to flow through fractured bedrock. The regional groundwater flow direction has been determined to flow southeast (Figure 2) towards Jackfish Lake, Fault Lake, and Great Slave Lake. The local groundwater flow direction is towards the west (Associated 2020).

Historical groundwater monitoring results from 2010 and 2011 indicated a that the horizontal hydraulic gradient ranged between 0.017 m/m and 0.022 m/m (Dillon 2012).

3. POTENTIAL SOURCES OF CONTAMINATION

The following areas are potential areas of contamination:

- Main active landfill area – While waste for landfill is screened by scale staff and operators at the main operations, there is still potential for illegal items to be deposited and become a source of contamination. It is also likely that the landfill historically accepted items that are currently not accepted due to human health or environmental risk, which could remain a contaminant.
- Hazardous waste storage areas – Hazardous waste is collected and stored on-site until it is collected and removed by a contractor. There is potential for contamination at the storage locations if hazardous materials are improperly labelled and not managed with the hazardous waste and get deposited in the main active landfill area. Some hazardous waste stored in drums, totes, or containers can be damaged and leak. For this document, hazardous materials can be categorized as follows:
    - Asbestos
    - Glycols
    - Household Hazardous Waste
    - Mercury Containing Materials
    - Ozone Depleting Substances
    - Propane Tanks
    - Batteries
    - Heating Oil Tanks
    - Oily Debris
    - Paint
    - Residue Fuel Tanks/Drums
    - Used Oil
- Off-site roads - Groundwater monitoring wells MW-10, MW-11, and MW-12 have been installed near roadways. This allows for improved access for groundwater monitoring; however, it also increases potential for contaminants that are not sourced from the SWF to affect the groundwater monitoring wells, such as petroleum hydrocarbons, and salts used for de-icing or dust mitigation. Borehole logs for these groundwater monitoring wells indicate that 2.6 m to 16.6 m of bentonite was used to seal the wells during construction. Based on the amount of bentonite seal, the risk is low for a hydraulic connection from roadway contaminants to groundwater through MW-10, MW-11, or MW-12. The surface seal and surface casing will be regularly inspected and monitored. If surface casing becomes loose or the surface seal cracks, prompt repairs will be required to mitigate risk. Additionally, surface casing will be locked to mitigate tampering, and well caps will be inspected for proper seal and repaired if missing or damaged.

3.1. Contaminant Preventative and Mitigation Strategy

The main preventative measure at the SWF is an ongoing capping program to reduce the amount of surface water infiltration and leachate generation. In addition, surface water is also monitored at the SWF. If groundwater monitoring results indicate that landfill leachate is found in the monitoring wells, runoff diversion and/or construction of sediment/treatment ponds to limit effects on surface runoff will be undertaken. Further controls may be needed if potential leachate infiltration pathways are identified during the monitoring program.

4. REGULATORY

Landfill planning, design, operations and maintenance are guided by the Government of Northwest Territories (GNWT) (Marchall and Hawke 2003) and regulated through the City's Water Licence, issued by the MVLWB. Presently there are no groundwater quality guidelines specific to Northwest Territories landfills or site-specific criteria. Consequently, the Standards for Landfills in Alberta (Alberta Government 2010), Alberta Code of Practice for Landfills in Alberta, and Alberta Tier 1 Groundwater Remediation Guidelines for Commercial/Industrial Land Use and Coarse-grained Soil (2019) (Tier 1 CL/IL CS) (Alberta Government 2019) are used for groundwater quality results from the SWF. The Tier 1 CL/IL CS is a conservative guide to the SWF as the dominant fill material at the SWF is coarse-grained soils through which surface water infiltrates to bedrock. The Guidelines are used to gauge quality impacts over time as a result of landfill activity. Environment and Climate Change Canada's (ECCC) (2017) Solid Waste Management for Northern and Remote Communities: Planning and Technical Guidance Document was consulted and is also followed for groundwater monitoring for best practices at the SWF.

5. GROUNDWATER MONITORING PROGRAM

Groundwater sampling and monitoring analysis at the SWF was conducted in 2010, 2011 and annually since 2016. Ongoing sampling and monitoring are planned to be conducted semi-annually and the laboratory results will be submitted with the annual report to the MVLWB. Current groundwater quality and compliance boundary monitoring at the SWF has not been established for the SWF groundwater quality control limits (criteria). The following sections discuss the groundwater monitoring program in more detail.

5.1. Groundwater Monitoring Well Network

The locations of the SWF groundwater monitoring wells are shown on Figure 2 of Appendix A. The groundwater monitoring wells are depicted as either active or inactive (i.e., not sampled or monitored or sampled since 2017 or earlier). Active wells have been completed with screens in overburden or bedrock. The active overburden wells are MW-2B and MW-5B. The SWF active bedrock wells are MW-2A, MW-3, MW-6, MW-10, MW-11, and MW-12. Table 1 presents a summary of the SWF groundwater monitoring wells, based on information provided on the borehole logs. Appendix B includes the construction summary table for the groundwater monitoring wells installed at the SWF.

Based on the well construction data and groundwater monitoring data collected at the wells completed in overburden, MW-2B and MW-5B are likely hydraulically connected. Based on the borehole logs, and 2020 groundwater level monitoring data, the bedrock groundwater monitoring wells are likely not all hydraulically connected due to open and closed fractures within the bedrock.

Table 1: Groundwater Monitoring Well Status

Well ID	Installation (Year)	Status	Well Completion	Monitoring Rationale
MW-1	2012	Inactive	Bedrock	Biotreatment Pad monitoring. The Biotreatment Pad was decommissioned in 2015.
MW-1A	2010	Inactive; Sampled in 2016	Bedrock	SWF Monitoring. Characterization of shallow and deep groundwater flow migrating from the northern property boundary towards the center of the SWF.
MW-1B	2010		Bedrock	
MW-2	2012	Inactive	Bedrock	Biotreatment Pad monitoring. The Biotreatment Pad was decommissioned in 2015.

Well ID	Installation (Year)	Status	Well Completion	Monitoring Rationale
MW-2A	2010	Active	Bedrock	SWF Monitoring. Characterization of shallow groundwater to potentially migrate off site to the eastern property boundary.
MW-2B	2010	Active	Overburden	
MW-3	2012	Name changed to MW-8. See MW-8 details		
MW-3	2010	Active	Bedrock	SWF Monitoring. Characterization of shallow groundwater at topographic low.
MW-4	2010	Inactive; Sampled in 2017	Bedrock	SWF leachate monitoring.
MW-5A	2010	Inactive/collapsed; Sampled 2016 to 2018	Bedrock	SWF Monitoring. Characterization of deep groundwater adjacent to a small pond and near the southwestern property boundary.
MW-5B	2010	Active	Overburden	SWF Monitoring. Characterization of shallow groundwater adjacent to a small pond and near the southwestern property boundary.
MW-6	2010	Active	Bedrock	SWF Monitoring. Characterization of shallow groundwater from localized standing water near the western property boundary.
MW-7	2010	Inactive; Sampled in 2016	Overburden	On-site leachate monitoring.
MW-8 (Originally MW-3)	2012	Inactive - buried	Bedrock	SWF Monitoring. This well was originally installed for Biotreatment pad monitoring; however, the Biotreatment Pad was decommissioned in 2015 and the well has since been buried.
MW-9	N/A	Location proposed	TBD	Proposed up-gradient monitoring for current groundwater quality. Two boreholes have been drilled, however, the wells were dry.

Well ID	Installation (Year)	Status	Well Completion	Monitoring Rationale
MW-10	2018	Active	Bedrock	Down-gradient and off site. The wells are located outside of the property boundary and to the southeast, down-gradient from the SWF and within the inferred groundwater flow direction. This provides off-site monitoring of potential migration of contaminants from the SWF.
MW-11	2018	Active	Bedrock	
MW-12	2018	Active	Bedrock	

Notes:
N/A – not applicable
TBD – to be determined

5.2. Well Monitoring and Sampling Protocols

Technical procedure protocols for groundwater quality and quantity monitoring are described in the Groundwater Sampling Procedure provided in Appendix C.

5.3. Sampling and Monitoring Schedule

Groundwater sampling and monitoring will be undertaken semi-annually at the SWF once the ground has thawed in late spring/early summer (anticipated mid-July) and prior to fall freeze (anticipated in late September). Table 2 presents a summary of the groundwater monitoring frequency.

Table 2: Groundwater Monitoring Schedule

Monitoring Well	Spring	Fall
MW-2A, MW-2B, MW-3, MW-5B, MW-9, MW-10, MW-11, MW-12	Mid-July	Late September

5.4. Groundwater Quality and Quantity Monitoring

Groundwater quality and quantity monitoring is an important part of SWF management to monitor quality trends to conduct adaptive management should varying trends be observed and to verify predicted water quality. Monitoring may change as directed by the City, subject to approval by the MVLWB. The following sections discuss the groundwater quantity and quality monitoring.

5.4.1 Water Quantity Monitoring

Groundwater quantity refers to the groundwater levels measured at the SWF. Groundwater levels will be measured prior to water quality sampling and tabulated for comparison to historical results. Water level variations observed over time help to understand the local hydrogeology at the SWF, and historical trends provide an opportunity to improve efficiency for planning and scheduling sampling events prior to winter freeze and after spring melt.

Consistent groundwater level monitoring presents verification for seasonal and temporal groundwater flow directions and aquifer storage. These data are useful if a contaminant source needs to be identified or mitigated. Long-term water quantity trend analysis provides an opportunity to determine potential impacts on groundwater related to climate change, surface recharge rates, and hydraulic connections to other monitoring wells and nearby waterbodies.

5.4.2 Water Quality Sampling

Groundwater is sampled to monitor potential changes in groundwater quality that could be a result of SWF operations. The groundwater quality is sampled at the active monitoring wells and tested at an accredited laboratory to assess and verify the water quality at the SWF. Table 3 presents a summary of the groundwater parameters tested as specified in the Standards for Alberta Landfills[1].

Table 3: Groundwater Testing Parameters

General and Inorganic Parameters
pH, total dissolved solids (TDS), alkalinity, specific conductivity, hardness ($CaCo_3$), bicarbonate, carbonate*
Nutrients
Ammonia, nitrate-N, nitrite-N, total kjeldhal nitrogen (TKN)
Major Ions
Chloride, calcium, magnesium, sodium, potassium, sulphate
Dissolved Metals
Arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, manganese, molybdenum, mercury, nickel, phosphorous, silicon, silver, strontium, thallium, tin, vanadium, uranium, zinc
Other Organics
Dissolved organic carbon (DOC)
Volatile Organic Carbons**
Benzene, toluene, ethylbenzene, and xylene (BTEX), phenols, polycyclic aromatic hydrocarbons (PAHs) F1 and F2, methylene chloride, vinyl chloride, trichloroethylene (TCE), tetrachloroethylene (PCE)

Notes:

*The inclusion of bicarbonate and carbonate was recommended in 2017 to develop time series piper plots to assist with determining area of influence and leachate migration indicators.

**Parameters not naturally present in groundwater.

Groundwater field parameters are recorded at the same time samples are collected. Field

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[1] Standards for Alberta Landfills (2010), Table 5.2: Groundwater parameters for background and detection level monitoring parameters.

parameters are measured using a handheld multi-parameter instrument and include temperature, pH, and specific conductivity.

5.5. Groundwater Quality Criteria

The City of Yellowknife Solid Waste Facility – Drainage Study conducted in 2006 showed that arsenic concentrations were greater than the Canadian Council of Ministers of the Environment (CCME) Canadian Environment Quality Guidelines (CEQG) for the protection of aquatic life (FAL) criteria of 0.005 mg/L (Dillon 2006). As discussed in Section 4, the Alberta Tier 1 CL/IL CS is currently used as the groundwater quality guideline.

In 2019, arsenic concentrations exceeded the Alberta Tier 1 CL/IL CS guideline (0.005 mg/L) at all but one monitoring well (MW-2B, July 2019). However, elevated arsenic concentrations around Yellowknife are known to be naturally occurring or associated with localized and historical industry. It is likely that arsenic identified in groundwater at the SWF could be associated to other influences and not related to SWF operations.

Similar historical groundwater quality results are used to develop current groundwater quality and compliance boundary monitoring criteria. Presently, both current groundwater quality and compliance boundary monitoring need to be established for the SWF. The following sections discuss the City’s current groundwater and compliance boundary quality implementation strategies.

5.5.1 Current Groundwater Quality

Current groundwater quality is used to develop criteria for naturally occurring parameters in the groundwater and is commonly established by testing historical groundwater quality prior to operations or by installing monitoring wells in a nearby area that will not be affected by landfill operations and up-gradient of groundwater flow. If analytical results of any given parameter or a suite of parameters exceeds the Guideline, they will be compared to the available current groundwater quality to determine if parameter exceedances could be due to natural elevated concentrations or require mitigation.

Since historical groundwater monitoring quality results were not obtained at the SWF prior to operations beginning in the 1970s, the City attempted to install a groundwater monitoring well to the east-northeast of the SWF (MW-9 on Figure 2) in an area not affected by SWF operations and up-gradient from estimated groundwater flow direction. Two well locations were drilled in 2018; however, the installation of a groundwater monitoring well was unsuccessful because groundwater saturated conditions were not encountered in either drilling location.

The City is presently working with a qualified Hydrogeologist to develop a plan to establish groundwater quality up-gradient from the SWF. Once a plan has been developed and a groundwater monitoring well has been successfully installed up-gradient, groundwater will be monitored for the same parameters and frequency as other SWF monitoring wells. After the first three years of monitoring the new upgradient wells, the data will be analyzed to establish a groundwater quality criterion for the SWF.

5.5.2 Compliance Boundary Quality

Compliance boundary monitoring is undertaken to evaluate groundwater quality within landfill property boundaries.

Six active groundwater monitoring wells are located within the compliance boundary for the SWF (MW-2A, MW-2B, MW-3, MW-5B, and MW-6). Monitoring and sampling will follow the schedule outlined in Section 5.3.

5.5.3 Off-site Monitoring

Three active groundwater monitoring wells are located outside the SWF property boundary, within 60 m from the waste footprint, and to the east (MW-10, MW-11, and MW-12). These wells were installed in 2018 to monitor potential contaminant migration away from the SWF through groundwater. Groundwater quality monitoring began in 2019 at these wells. After three years of monitoring these wells along with monitoring of the upgradient monitoring well, a water quality trend analysis will be performed to assess potential contaminant migration from the SWF, and the results utilized to establish a groundwater quality criterion for the SWF.

5.6. Groundwater Performance Standards

Based on the Standards for Landfills in Alberta (2010), groundwater quality within the compliance boundary should meet the following performance standards, based on the Tier 1 CL/IL CS and in the absence of site-specific quality criteria:

- “Groundwater quality of one or more parameters shall not display an increasing trend” (results obtained over successive sampling events are not increasing over time, or showing as an increased trend in the long-term);
- “Groundwater parameters shall not exceed the corresponding groundwater quality control limits” (as defined by the current quality); and
- “Any parameters not naturally present in groundwater should not be detected in three consecutive sampling events.”

Deviation from the performance standards will initiate the Response Plan.

5.7. Response Plan

Deviation from the performance standard is considered immediately after groundwater quality results are provided from laboratory analysis and reviewed by City staff. Parameters that exceed groundwater quality criteria (Tier 1 CL/IL CS) will initiate the following response:

- Confirm the parameters in question in the specific well by resampling and analysis, if required reduce laboratory detection limits;
- Complete initial interpretation of data and associated potential causes;
- Conduct a field audit to ascertain if there are areas and types of waste that could cause potential leachate and contamination to groundwater and compare to well location;
- Conduct an additional investigation to delineate contaminant source and potential groundwater plumes using geophysical surveys and or drilling;

- Once the potential source is identified, manage or remove the source to stop leachate from infiltration. Management and removal will depend on various factors and will be determined accordingly, as and when required; and
- Continue monitoring during this time to confirm upward trends.

The mitigation plan will be prioritized to:

- Protect human health and the environment;
- Achieve groundwater protection standards; and
- Control, mitigate, reduce or reduce the source of contaminant to the environment.

5.8. Groundwater Monitoring Report

Groundwater monitoring will be conducted as part of the Water Licence requirements and results will be included as part of the City's Annual Water Licence Report.

6. QUALITY ASSURANCE PROTOCOLS / QUALITY CONTROL PROCEDURES

Quality assurance (QA) refers to programs or plans that include a wide range of external and internal technical and management practices to allow for known quality data collection that meets the intended use for the data. Quality control (QC) refers to a specific part of QA related to the internal processes used to quantify and assess the quality of data. QA and QC methods will be followed during sampling performed for groundwater monitoring.

6.1. Quality Assurance

The following sections described three areas of external and internal management quality assurance: training, laboratory, and data management.

6.1.1 Training

City field staff complete groundwater monitoring and sampling training internally as necessary. The purpose of the training is to train field staff in sampling procedures, data recording, and equipment operation used for the Groundwater Monitoring Program. The City seeks training from external qualified professionals as necessary.

City field staff will conduct groundwater monitoring and sampling following the technical procedure protocols (Appendix C).

6.1.2 Laboratory

Accreditation programs are applied to laboratories by routinely evaluating and assessing performance, methods, procedures, and quality control to ensure compliance and standardization. Accredited laboratories will be selected for water quality analysis of groundwater from the SWF, and groundwater quality results will be compared to the relative QA/QC groundwater quality samples for compliance.

6.1.3 Data Management

Data management will be used to consistently collect, organize, and control groundwater monitoring and sampling data for analysis, filing, and reporting purposes. Relevant items may include but are not limited to:

- Required field parameters are collected;
- Required groundwater levels and samples are collected;
- Proper sample labelling, and handling procedures are followed;
- Laboratory data are reviewed in a timely manner and compared to previous data and QA/QC samples to validate quality and accuracy; and
- Field and laboratory data are promptly recorded and filed to the appropriate locations.

6.2. Quality Control

Quality control includes proper field and sample handling procedures, and the preparation and submission of quality control samples to the laboratory for analysis. Quality control samples include duplicate and blank (e.g., trip, field) samples.

Sample bottle preparation, field measurements and sample handling procedures are as follows:

- Sample bottles will be provided to the City by an accredited laboratory and stored in a clean environment with the caps remaining closed.
- Field staff conducting the water sampling will wear clean gloves, replacing them between samples, and will refrain from smoking or eating during sampling.
- Equipment required to be used at multiple sampling locations will be cleaned appropriately between locations.
- Only staff with the proper training in groundwater sampling techniques will undertake water sampling.
- Field parameters will be measured and recorded using a handheld meter that has been calibrated daily during sampling.
- Where appropriate, samples will be preserved with laboratory supplied reagents to reduce chemical, physical, biological progressions that may alter the sample water chemistry after sample collection and before laboratory analysis.
- Samples will be placed in a cooler with ice or ice pack as soon as possible after collection to keep samples at a temperature of approximately 4°C.
- Samples will be carefully packed for transporting to the laboratory to minimize possible breakage and to allow for the temperature to be maintained (approximately 4°C).
- Samples will be dropped-off at the laboratory as soon as reasonably possible to meet laboratory hold times. Sample event scheduling will be coordinated to allow for timely shipping that will minimize transport companies from storing sample shipments at their facilities due to holiday or weekends.
- Chain of custody forms will be completed by field sampling staff for the groundwater samples and will be submitted to the laboratory with the samples.

Implemented QC procedures will include the preparation and submission of QA/QC samples, such as duplicate water samples, field blanks, and trip blanks. Duplicate samples are used to assess water quality variations at the monitoring well or laboratory analysis processes. Field blanks are used to detect potential sample contamination during collection, shipping and analysis. Trip blanks are used to detect potential sample contamination during transport and storage.

QA/QC procedures are as follows:

- **Duplicate Sample:** Two samples will be collected from a sampling location using identical sampling procedures. Both samples will be labelled and preserved individually and submitted to the laboratory for analyses (not marked duplicate or the same as the sample ID). Approximately, one sample for every ten (10) sampling locations will be collected as a duplicate and submitted to the laboratory for analyses. For smaller sampling events (less than 10), at least one duplicate will be collected and submitted for analysis.
- **Field Blank:** A sample will be collected in the field using identical sampling methods, equipment and preservatives; however, the water used for the field blank sample will

be laboratory-provided deionized water instead of water from a groundwater monitoring well. The field blank will then be submitted to the laboratory for the same analysis as other groundwater samples. One field blank will be submitted to the laboratory for analysis per sampling event.

- **Trip Blank:** A sample using laboratory-provided deionized water will be prepared and preserved by the laboratory prior to the sampling event. The sample will remain unopened throughout the duration of the sampling trip and will then be submitted to the laboratory for the same analysis as other groundwater samples collected during the same sampling event. One trip blank sample will be submitted to the laboratory for analysis per sampling event.

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APPENDIX A

Figures

Figure 1 NWT.mxd / 4/14/2020 / 9:45:53 AM

Associated Environmental

PROJECT NO.: 2019-8509.000.000
DATE: April 2020
DRAWN BY: DA

0 100 200 300 400 500
Meters

FIGURE 1: SOLID WASTE FACILITY SITE PLAN AND LOCATION

City of Yellowknife

Groundwater Monitoring Plan

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Associated Environmental

PROJECT NO.: 2019-8509.000.000
DATE: November 2020
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0 100 200 300 400 500
Meters

FIGURE 2: GROUNDWATER MONITORING WELL LOCATIONS

City of Yellowknife

Groundwater Monitoring Plan

APPENDIX B

Groundwater Monitoring Well Construction Summary & Active Monitoring Well Borehole Logs

Table B-1: Groundwater Monitoring Well Construction Summary

Monitoring Well	Installation Date (dd-mm-yy)	UTM Coordinates (Zone 11)		Ground Elevation (masl)	Top of Pipe Elevation (masl)	Well Diameter (mm)	Surveyed Stick-up (m)	Well Depth (mbgs)	Measured Well Depth (mbgs)	Top of Screen (mbgs)	Bottom of Screen (mbgs)	Screen Mid-point Elevation (masl)	Type	Screened Geology
		Easting (m)	Northing (m)											
MW-1	26-07-2012	635066.49	6929672.17	100.26	101.18	50.8	0.92	12.65		1.30	12.65	94.59	PVC	bedrock
MW-1A	16-08-2010	-	-	182.49	-	50.8	-	23.50		17.15	23.5	179.32		bedrock
MW-1B	17-08-2010	-	-	174.28	-	50.8	-	36.60		33.66	36.60	172.81		bedrock
MW-2	27-07-2012	635092.82	6929642.65	99.18	100.00	50.8	0.82	12.75		3.00	12.75	94.31		bedrock
MW-2A	17-08-2010	635358.50	6930121.41	191.65	192.41	50.8	0.76	23.80	15.10	20.99	23.80	190.24		bedrock
MW-2B	18-08-2010	635362.79	6930027.41	189.07	191.23	50.8	2.16	3.00	2.22	1.66	3.00	188.40		overburden
MW-3	17-08-2010	635260.54	6929713.59	195.35	196.5	50.8	1.15	42.7	12.01	39.66	42.7	193.83		bedrock
MW-4	18-08-2010	-	-	199.04	-	-	-	12.20		9.33	12.20	197.61		bedrock
MW-5A	31-08-2010	-	-	174.13	-	-	-	42.70		39.66	42.70	172.61		bedrock
MW-5B	9-Aug-2010	634749.96	6929812.02	205.74	206.73	50.8	0.99	9.10	8.51	6.15	9.10	204.27		overburden
MW-6	17-08-2010	634586.71	6929958.29	208.48	209.72	50.8	1.24	7.30	7.14	4.15	7.30	206.91		bedrock
MW-7	17-08-2010	-	-	197.91	-	-	-	12.20		9.15	12.20	196.39		overburden
MW-8	27-07-2012	635056.58	6929622.80	100.27	101.18	50.8	0.91	12.60		3.00	12.60	95.47		bedrock
MW-10	18-09-2018	635665.02	6930147.28	187.89	188.94	50.0	1.05	11.50	6.50	8.10	11.10	186.39		bedrock
MW-11	17-09-2018	635602.33	6929893.47	192.17	193.37	50.0	1.19	21.00	20.77	17.50	20.50	190.67		bedrock
MW-12	17-09-2018	635417.03	6929527.90	194.33	195.43	50.0	1.10	6.70	6.33	3.40	6.40	192.83		bedrock

Notes:

m - metres

masl - metres above sea level

mbgs - metres below ground surface

mbTOP - metres below top of pipe

- no data

N/A - not applicable

APPENDIX C

Sampling Procedures

CITY OF YELLOWKNIFE

Water Licence – Solid Waste Facility Sampling Procedure

Surface Water and Groundwater

Revised:

January 2020

1.0 Table of Contents

2.0 List of Figures

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1 INTRODUCTION

The purpose of this document is to provide a general guideline and procedure for groundwater and surface water sampling at the City's Solid Waste Facility (SWF). Sampling at the SWF is a requirement of the City's Water Licence; groundwater and surface water is required to be sampled twice (spring and fall) annually. The specific dates for each year are found in the corresponding Water Licence Sampling Calendar (DM Folder #544567). The locations of the groundwater wells as well as the surface water sampling locations can be found in Figure 1.

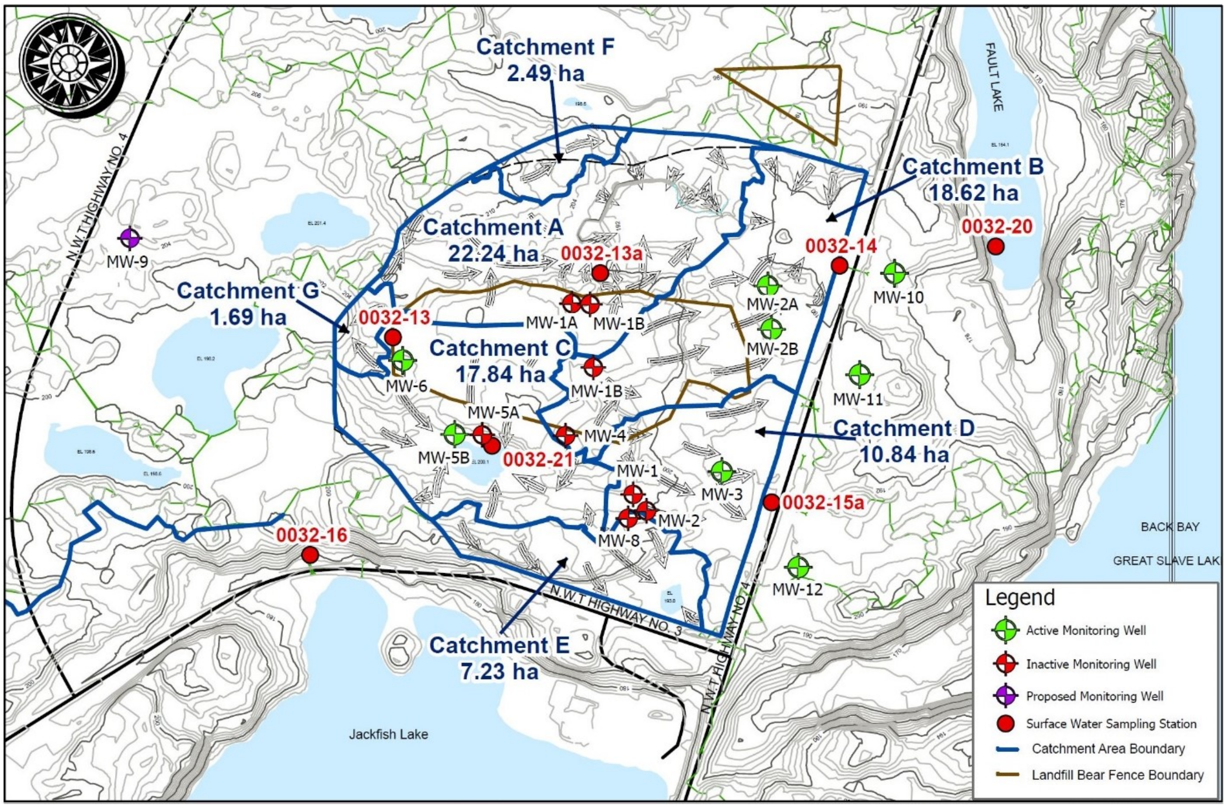

Figure 1: SWF monitoring locations and catchment areas

There are four sections to this document:

Section 2 - Items Completed Before Going to Site

Section 3 - Sampling Procedure by Bottle Type

Section 4 - SWF Surface Water Sampling

Section 5 - SWF Groundwater Sampling

Each section will provide an outline of the steps to properly complete each aspect of the work. It is important to follow the sampling procedures outlined as variations in sampling techniques can affect the data collected. In addition, it is possible that contaminants are present in the sampling effluent; therefore, following the procedure is important to ensure that sampling is being done safely.

2 Items Completed Before Going to Site

Before going to the SWF to begin filling sampling kits, there is work that needs to be done at the office. This includes contacting the lab, preparing equipment, and notifying relevant personnel. Keep in mind when preparing to take groundwater samples that you need to plan to go out and purge the wells at least one week in advance of sampling. Well purging is discussed further in Section 5.3.

2.1 Contacting the Lab

The lab should be notified at least one week in advance of sampling dates to ensure that they will have the sample kits prepared for the day they are needed. When emailing the lab, the following should be included:

- The proposed date of sampling
- The type of samples that will take place (surface water or groundwater)
- A chain of custody (COC) form

It is likely that the lab in Yellowknife does not have the capability to do all of the testing in house; therefore, the bottles may be flown to Alberta or British Columbia for testing. As some of the analyses that are performed on the samples are time sensitive (such as bacterial tests), it is important to check with the lab what time they will need the samples to be returned to them to ensure that they are able to be tested within their time constraints.

2.1.1 Chain of Custody (COC) Form

The COC provides the lab with all of the necessary information they need to prepare the appropriate sample kits. This includes the number of sample locations, the parameters of interest, and the City's contact information. The blank COC form is DM#532408, and the filled in COC forms are stored in the appropriate place in DM Folder #519136. The COC forms remain the same as long as the same parameters are being sampled. When the sample kits are picked up from the lab, the COC will be included in the cooler that they come in. The date and time of each sample kit should be filled out on the COC and given back to the lab when the full samples are returned.

The parameters that are included in the COC for the sampling kit are outlined in the City's SWF Operations and Maintenance Manual (DM #630443) and the Interim Groundwater Monitoring Plan (DM #630441) for surface water and groundwater testing, respectively. Tables 1 and 2 display the parameters that will be tested when the 2022 Water Licence begins. These parameters are approved by the Mackenzie Valley Land and Water Board (MVLWB), and may change over time.

Table 1: Surface Water Testing Parameters

ICP-MS Metal Scan (Total)
Aluminum, Arsenic, Beryllium, Boron, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, Strontium, Vanadium, Zinc
Field Parameters
Dissolved Oxygen, Temperature, pH, Conductivity
Major Ions
Calcium, Magnesium, Chloride, Sodium, Alkalinity, Fluoride, Potassium, Sulphate, Total Dissolved Solids, Total Hardness
Other
Faecal Coliforms, Total Ammonia, Nitrate and Nitrite, BOD5, Total Mercury, Oil and Grease, Total Phenols, Methyl Tert Butyl Ether, Total & Ortho Phosphorus, Dissolved Organic Carbon, Benzene, Toluene, Ethybenzene and Xylene (BTEX), Total Petroleum Hydrocarbons – Fraction 1 (C6-C10) + Fraction 2 (>C10-C16) + Fraction 3 (.C16-C34) + Fraction 4 (>34)

Table 2: Groundwater Sampling Parameters

General and Inorganic Parameters
pH, total dissolved solids (TDS), alkalinity, specific conductivity, hardness ($CaCo_3$), bicarbonate, carbonate[1]
Nutrients
Ammonia, nitrate-N, nitrite-N, total kjeldhal nitrogen (TKN)
Major Ions
Chloride, calcium, magnesium, sodium, potassium, sulphate
Dissolved Metals
Arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, manganese, molybdenum, mercury, nickel, phosphorous, silicon, silver, strontium, thallium, tin, vanadium, uranium, zinc
Other Organics
Dissolved organic carbon (DOC)
Volatile Organic Carbons[2]
Benzene, toluene, ethylbenzene, and xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs) F1 and F2, methylene chloride, vinyl chloride, trichloroethylene (TCE), tetrachloroethylene (PCE)

Notes:

[1] The inclusion of bicarbonate and carbonate was recommended in 2017 to develop time series piper plots to assist with determining area of influence and leachate migration indicators.

[2] Parameters not naturally present in groundwater.

2.1.2 Sample Pick-Up and Drop-Off

On the day of sampling, the sample kits can be picked up from the lab in the morning. Check in with the lab to see the earliest time sampling kits can be picked up, as certain labs may not be open until 8:30am. The sample kits will come in coolers with ice packs in them. The ice packs are used to ensure that the samples remain at an appropriate temperature until they are returned to the lab. Each cooler usually has a maximum of four (4) sample kits in it. As previously mentioned one of the coolers will contain the COC to be filled out and returned to the lab with the samples.

Once the samples have been collected, the coolers with the filled up sample kits are returned to the lab. Be sure to provide the lab with an appropriate amount of time to get the samples to the airport, if required.

2.2 Preparing Equipment

Before heading to the SWF, it is important to ensure you have all of the necessary equipment with you. The equipment that is needed from outside of the SWF includes:

Personal protective equipment

- Disposable latex/nitril gloves (can pick up from City Stores if there are not any at City Hall)
- Safety glasses
- High visibility vest
- Steel toed boots
- Bear bangers/bells/spray for wildlife protection
- Bug spray
- Sunscreen
- Phone/radio

General items needed for surface water and groundwater sampling

- Hanna pH/conductivity detection probe (in equipment cupboard)
- 20L bucket (in City work truck or in storage room)
- Map of well locations/surface water locations
- Notebook to record field data
- Pen and permanent marker

Items needed specifically for groundwater sampling

- Keys for wells located at the Ski Club (in Engineer's office)
- Measuring tape (in City work truck or at PW Garage)
- Water level meter (in the storage room in the basement of City Hall)
- Hydrolift (in the storage room in the basement of City Hall)
- Extra Waterra tubing (in the storage room in the basement of City Hall)
- Extra Waterra tubing foot valves (in the storage room in the basement of City Hall)
- Duct Tape, rope, lock de-icer (for fall groundwater sampling) and needle nose plyers are not a necessity for sampling, but it is a good practice to bring them in the case that something does not go as planned (kept in City work truck, or can get from the PW Garage/City Stores)

2.2.1 Hanna pH/Conductivity Probe (Hanna)

The Hanna is a device used to detect the pH, conductivity, and temperature of the effluent being sampled while in the field. This data is necessary, as it is important to be able to see the change in these values from the field measurements to the lab measurements. The pH, conductivity, and temperature can all have an effect on the results of the sample.

The Hanna is a delicate piece of equipment as it has a sensitive probe that can be easily damaged. Therefore, the probe must be stored in a solution, so that it is able to maintain moisture and perform accurately. The probe is stored in the equipment cupboard along with the solutions used to store, clean, and calibrate the device. The device is stored in the pH 4.01 solution.

The morning before using the device, the Hanna is calibrated to ensure the results are accurate. The manual with detailed steps on calibration and care of the device is kept with the device for reference. The device needs to be calibrated with the 7.01 pH, 4.01 pH, and 1880 µs/s solution. Once the device has been calibrated, it is ready for use.

The Hanna probe is used at each sampling location and the results are recorded in the tracking spreadsheet (DM Folder #152684). Once sampling has been completed for the day, the probe is soaked in the cleaning solution for 20 minutes, before being stored in a fresh quantity of the pH 4.01 solution.

2.2.2 Waterra Tubing and Foot Valves

The Waterra tubing is what is used to access the water in the well while groundwater sampling. The tubing is left in the wells throughout the year; therefore, it is important to bring extra tubing in the case the tubing has become damaged. The foot valve goes on the end of the Waterra tube in the bottom of the well. It includes a small plastic ball inside of it that closes the valve, holding the water in, when the tube is pull upwards, and opens the valve, allowing more water in, when the tube is pushed down. It is possible for foot valves to fall off while the tube is being moved up and down by the Hydrolift (see following section), preventing water from moving up the tube. Therefore, it is a good idea to be prepared with extra valves so that the sample kit can be completed.

2.2.3 Hydrolift

The Hydrolift is used only in groundwater sampling. It is a piece of equipment that enables the Waterra tube and foot valve to collect water much faster than would be possible manually. The Hydrolift attaches to the well casing and requires a generator to function. The generator, gasoline, and extension cord can all be found at the SWF upon arrival. A more detailed explanation of setting up the Hydrolift is explained in Section 5.2.

2.3 Notifying Relevant Personnel

Another important step before commencing sampling is notifying the affect parties. This Includes the Ski Club and the Manager of Sustainability and Solid Waste (SWF Manager). As three (3) of the City's wells are located on the Ski Club property, it is important to ensure that contact has been made with the Trail's manager to ensure that they are aware that you will be on site. It is also important to notify the SWF Manager as a safety measure. There may be wildlife spotted at the SWF or Ski Club, and if the appropriate personnel know when you will be on site, they can be sure to keep you informed.

3 Sampling Procedure by Bottle Type

3.1 Routine and Biochemical Oxygen Demand (BOD) Bottles

Routine and BOD bottles are used to test the general water quality and biochemical oxygen demand of the effluent. These bottles do not contain any preservatives inside of them and are the only bottles that can be submerged in the water to fill. These bottles are used to pour into other sample bottles that cannot be submerged.

Figure 2: Routine and BOD sampling bottles

3.2 Metals

Metals bottles test for trace metals in the water. These bottles contain a preservative; therefore, they cannot be filled by being submerged in the water in case the preservative falls out of the bottle. They also cannot not be filled, poured out, and refilled. These bottles are filled to approximately to the top horizontal surface on the bottle, using the Routine or BOD bottle, allowing some air to stay in the bottle.

Figure 3: Metals sampling bottle

3.3 Bacteria

These bottles test for fecal coliforms. They are filled to the indicator line just above the top of the label using the Routine or BOD bottle as they contain a powder preservative. They cannot be filled by being submerged in the water in case the preservative falls out of the bottle. They also cannot not be filled, poured out, and refilled.

Figure 4: Bacterial bottles

3.4 Major Analytes, Mercury, Total Nutrients, and Hydrocarbons

All of these bottles must be filled to the brim, with no air trapped in the bottle. The air prevents the test associated with each bottle from being performed properly. As these bottles also contain preservatives, they must be filled by being poured into by a Routine or BOD bottle. The following filling procedure explains this process in more detail.

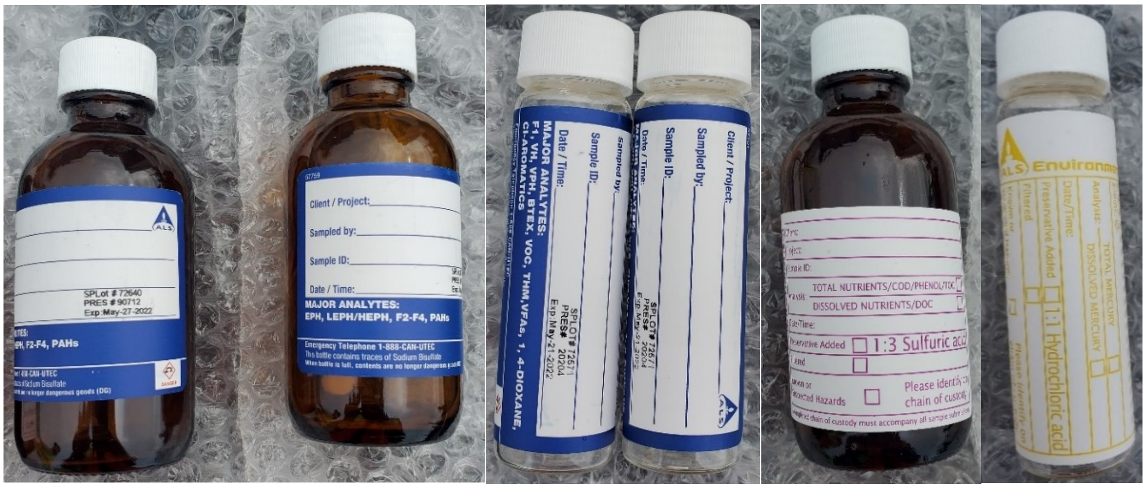

Figure 5: Major analytes, mercury, total nutrients, and hydrocarbon sampling bottles

3.4.1 Major Analytes, Mercury, Total Nutrients, and Hydrocarbons Filling Procedure

1. To fill the bottle, put it on a level surface and use the Routine or BOD bottle to slowly pour the sample water to the top of the Hydrocarbon bottle. Sample water can also be poured into the cap, although this is unnecessary with practice and/or a level surface.

Figure 6: Pouring water into bottle with routine sample bottle

2. The sample water should look concave at the top of the bottle. Carefully put the cap on the top of the bottle, and slowly screw on the cap until it’s tight. If there is water in the cap, then the cap must be quickly put on the bottle and screwed on. This may increase the chance that water is spilled, so it is recommended that the process be tried without water in the cap first.

Figure 7: Meniscus of water in bottle before putting lid on

3. Check the top of the lid for air bubbles. If none are present, then turn the bottle upside down and tap it a couple times. If no air bubbles appear, then the bottle is ready for analysis

Figure 8: Bottle lid showing proper closure with no bubbles, and improper closure with an air bubble

4. If in step #3 any air bubbles appear, then put the bottle on a level surface and unscrew the top. Use the Routine or BOD bottle to add more sample water, and attempt to screw the lip back on. Should this process continue to be unsuccessful, try putting water in the cap.

4 Surface Water Sampling

Once you have completed the necessary preparation for sampling, including picking up the sampling kits, you are ready to head to the SWF to begin. Once you arrive on site, you need to stop by the office and check in with the SWF Manager. They may provide you with a radio to ensure that they can contact you in the case of an emergency on site. It is also important to check in with them when you leave the site.

Use the map you brought with you to find the sampling locations. Before you start a sample kit, you need to label the sample kit bag. It is not necessary to label each bottle if the bag is labelled with the date, time and location of the sample (i.e. 0032-20). It is important that the bag be closed carefully once the sample kit is filled to ensure unlabelled bottles do not fall out of the labelled bag.

The first step when sampling is to put on a fresh pair of nitril/latex gloves at each location. Then, fill the Routine or BOD bottle and use the water to perform the Hanna tests required. Once the Hanna test is complete, record the data in your notebook. Once the data has been recorded, you can begin sampling. Surface water sampling is done directly from the water source if possible. If the water is difficult to access, the 20L bucket can be used to collect the water and bring it to a more suitable location for sampling. Submerge the Routine and BOD bottles directly into the water and use them to fill up the additional bottles. Ensure a flat surface is available to for filling airtight bottles. Once the entirety of the bottle kit is filled, seal the bag and return it to the cooler. Fill out the time in which the sample was taken in your notebook so that you can transfer it to the COC when you are finished all of the samples.

4.1 Sampling Location 0032-13

This location is defined in the Water Licence as:

> “A point approximately 400 metres northwest of the Solid Waste Disposal Facilities above the confluence of an unnamed feeder creek.”

Figure 9: 0032-13 Location

Go through the gate to the composting retention pond and drive around the pond to the southwest end. Take the steep incline towards groundwater monitoring well MW-6, the sampling location is the nearby pond. This location is filled with debris swept away by the wind from the SWF; take care not to include this debris in the sample bottles.

4.2 Sampling Location 0032-13a

This location is defined in the Water Licence as:

> "A point approximately 400m northwest of the Solid Waste Disposal Facilities that captures the drainage from the facility and draining from the snow disposal area."

Figure 10: 0032-13a location

Access is through NWT quarry. Sign the logbook at the front gate, and then proceed to the snow dump area. This area goes further west every year. Will likely be dry in the fall.

4.3 Sampling Location 0032-14

This location is defined in the Water Licence as:

> "Upstream of culvert location on Hwy #4, upstream of fault and downstream of confluence of unnamed feeder creek."

Figure 11: 0032-14 location

This location is more or less opposite of the start of the trail leading to 0032-20. There is a small, steep incline to the sampling point.

4.4 Sampling Location 0032-15a

This location is defined in the Water Licence as:

> "West side of Hwy#4, across from SNP 0032-15."

Figure 12: 0032-15a location

This location is before the entrance to the SWF, on highway # 4 leading to Giant Mine.

4.5 Sampling Location 0032-16

This location is defined in the Water Licence as:

> "Upstream of Culvert on Hwy#3, opposite of Jackfish Lake."

Figure 13: 0032-16 Location

There is a double culvert at this location; flow may be leading to one or both of them. As this is along a busy highway, take precautions when parking on the shoulder of the road.

4.6 Sampling Location 0032-20

This location is defined in the Water Licence as:

> "At the south end of Fault Lake where the run-off enters the lake."

Figure 14: 0032-20 Sampling location

To access the site, the vehicle can be parked along the side of highway #4 leading to Giant Mine, and the Ski Club trails used to travel to the sampling location. The Ski Club refers to the trail as “Otter Slide”. The area is very heavily inhabited by mosquitoes, so bringing a bug net or bug spray is a good idea. The area leading up to the sampling location is marshy and forms a steady stream of water towards the lake that can make it difficult to walk to.

4.7 Sampling Location 0032-21

This location is defined in the Water Licence as:

> “At Vicinity Lake #3 within the boundaries of the Solid Waste Disposal Facility.”

Figure 15: 0032-21 Location

Located near Groundwater Monitoring well 5A and 5B. Take the access road near the Compost Facility to go south of the old landfill cell. Sample from the edge of the lake.

5 Groundwater Sampling

Once you have completed the necessary preparation for sampling, including picking up the sampling kits, you are ready to head to the SWF to begin. Once you arrive on site, you need to stop by the office and check in with the SWF Manager. They may provide you with a radio to ensure that they can contact you in the case of an emergency on site. It is also important to check in with them when you leave the site.

Once you have checked in with the SWF Manager, you need to pick up the generator, a jerry can of gasoline, and an extension cord. The SWF Manager will direct you to the location that these items are stored; typically, they are either in the Bailing Facility or in the Gatehouse. It is important to return these items at the end of each day, even if you will be returning to use them the following day. The generator is used as a backup power source for the gatehouse during power outages, and they are expensive items that should not be left overnight in the bed of the work truck.

Once you have gathered the necessary equipment, you can use the map you brought with you to find the sampling locations. Before you start a sample kit, you need to label the sample kit bag. It is not necessary to label each bottle if the bag is labelled with the date, time and location of the sample (i.e. MW-6). It is important that the bag be closed carefully once the sample kit is filled to ensure unlabelled bottles do not fall out of the labelled bag. Refer to Section 3 for sampling procedures by bottle type.

5.1 Preparing the Well

In order to perform groundwater sampling, it is necessary to ensure the well is prepared.

1. Open the well top cover, and pull out all the tubing stored inside the well to inspect it for damage and blockages. Damages include kinks and holes in the tubing, and sediments may be in the first couple meters of the tubing that were the deepest in the well.

Figure 16: Tubing stored in well

2. While the tubing is out of the well, use the water level meter to measure and record water level, and well depth. Use a measuring tape to measure the casing stick-up above the ground.

3. Calculate the well volume based on the column of water in the well. Prepare to purge 3-5 times the volume of water in the well. Refer to section 5.5 for anticipated purge volumes for each well. Purging the well ensures the results are an accurate representation of the water in the area and are not affected by standing water.
4. After recording your measurements, insert the tubing back into the well. If the tubing was damaged, replace the tubing completely. Be sure to reattach the foot valve on the new tubing and insert the tubing back into the well, leaving enough tubing out of the well to reach the 20L bucket without causing strain on the tube. Tubing should be dedicated to one monitoring well only and not shared between wells during sampling.
5. You can then move on to attaching the Hydrolift.

5.2 Hydrolift Setup Procedure

1. Use the hooks on the Hydrolift to latch onto the metal (not plastic) well casing. Use the ratchet strap to latch the Hydrolift to the metal well casing.

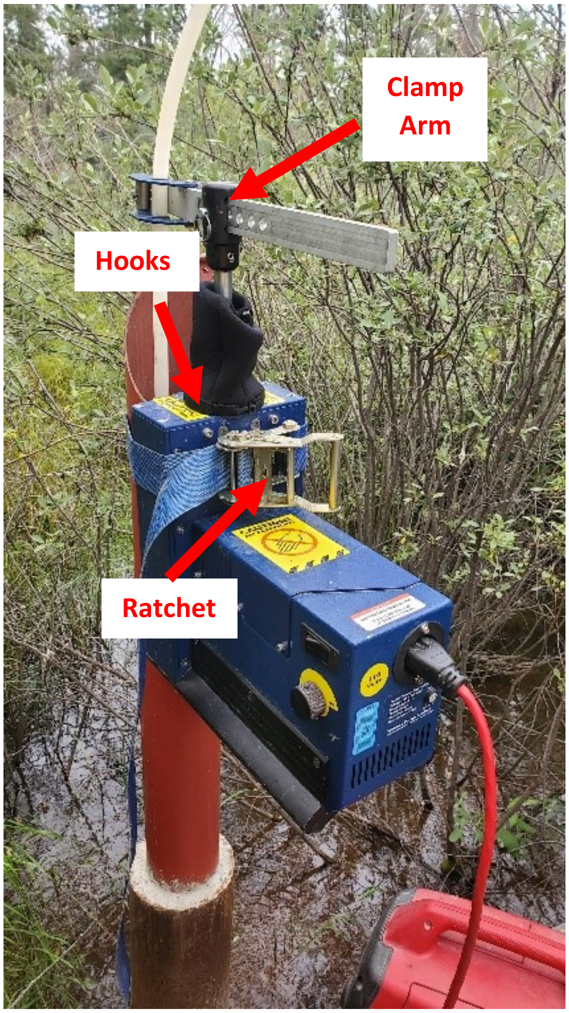

Figure 17: Hydrolift attached for use to pump the well

2. Clamp the plastic tubing to the clamp arm. Ensure that when the tubing is clamped, the plastic tubing will move straight up and down with the clamp arm. Tubing moving at an angle will either rub up against the well piping, or bend.
3. Start the generator by flipping the on switch, enabling the choke (by pushing the choke switch to the right of the generator), and pulling the draw cord. Turn down the choke once started by pushing the choke switch back toward the left gradually.

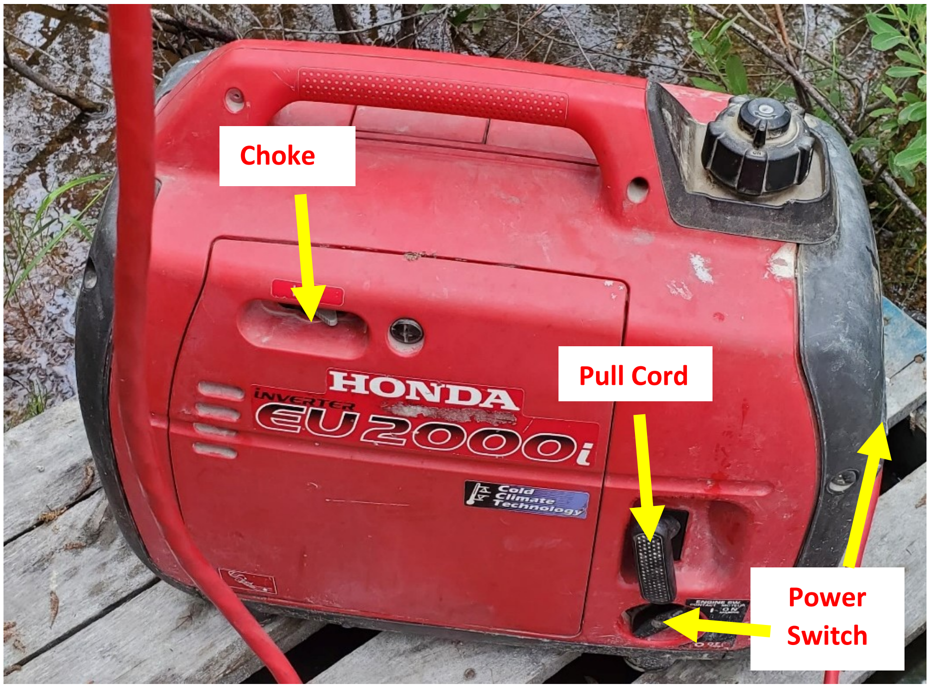

Figure 18: Generator required to power the Hydrolift

4. Ensure that the Hydrolift power switch is on the off position, and that the speed knob is set to the absolute minimum. Connect the generator to the Hydrolift using the extension cord.
5. Flip the on switch on the Hydrolift, with the speed knob turned as slow as possible so that the Hydrolift doesn't move. Slowly turn the speed knob to allow it to move at a very slow pump. Ensure that the clamp arm does not hit the well. Readjust the Hydrolift as necessary (turn off and unplug the Hydrolift before readjusting).

5.3 Well Purging

1. Once the Hydrolift is in the proper position, and the 20L bucket placed to collect the water, slowly turn the speed knob to maximum. Water should start coming up the tubing.
2. Once the 20L bucket is full, shut off the Hydrolift and drain the bucket into the storage barrel in the truck. Record the number of buckets removed from each well in your notebook.
3. Once the storage barrel is full, drive to one of the landfill cells and drain it completely on the cell.
4. Purge between three (3) and five (5) well volumes of the water column; however as noted in the well descriptions, this is not always possible. If the well is pumped dry before at least three well volumes are purged from the well, then enough water has been removed.

5.4 Sampling Process

Due to slow recharge of wells, plan to purge all of the wells at least one (1) week in advance of sampling. Ensure that MW-6 and MW-12 are prioritized as they can take up two weeks to recharge enough to collect a full sample kit. It is important to complete a sample kit in the same day, and all of the wells within a maximum of three (3) days.

1. After the well has recharged enough for sampling, return to the well with the 20L bucket and sample bottles.
2. Draw slightly more than half a bucket (roughly 15L)
3. Fill sampling bottles (refer to Section 3 for proper sample filling procedure). If you are unable to fill all of the bottles, start but do not fill duplicate bottles.

5.5 Well Descriptions

5.5.1 Monitoring Well 2A (MW-2A)

The fastest recharging well, historically it will recharge as fast as it can be purged, and the water height will remain nearly unchanged. Can be purged and then sampled immediately. Easy to use as the duplicate sample due to fast recharge. See Figure 19 for location.

Approximate Depth	25m
Expected Purge Volume	100L (5 Buckets)

5.5.2 Monitoring Well 2B (MW-2B)

Top of the well is high, requires a step stool to stand on for access. Purge, then return in the afternoon (if purging in the morning) or the next day (if purging in the afternoon) to sample. See Figure 19 for location.

Approximate Depth	4m
Expected Purge Volume	10-15L (1 bucket)

Figure 19: MW-2A and MW-2B

5.5.3 Monitoring Well 3 (MW-3)

Located a bit into the bush. Purge, then return in the afternoon (if purging in the morning) or the next day (if purging in the afternoon) to sample.

Approximate Depth	43m
Expected Purge Volume	100L (5 Buckets)

Figure 20: MW-3

5.5.4 Monitoring Well 5B (MW-5B)

Located right beside defunct MW-5A. Purge, and then return the next day to sample. Purging brings up significant sediments, so the tube will likely be plugged, and needs to be cleared before sampling.

Approximate Depth	9m
Expected Purge Volume	20L (1 Bucket)

Figure 21: MW-5B

5.5.5 Monitoring Well 6 (MW-6)

Located beside the compost pond. After purging, this well does not significantly recharge, even after 3 days, not enough for samples to be taken. Under consideration for removal from SNP.

Approximate Depth	8m
Expected Purge Volume	5-10L (1 Bucket)

Figure 22: MW-6

5.5.6 Monitoring Well 9 (MW-9)

Desktop study is currently underway to determine the most suitable location for this well.

5.5.7 Monitoring Well 10 (MW-10)

This well is located off of Highway #4, slightly after the gravel turnout section towards Giant Mine. There is a path leading off the highway. Park the truck at the entrance to the path and carry equipment to well location. Well can be found on the Ski Club trail overlooking Fault Lake. MW-10 can recharge within a day during summer sampling, but can take up to 3 days during the fall.

Approximate Depth	12m
Expected Purge Volume	40L (2 Buckets)

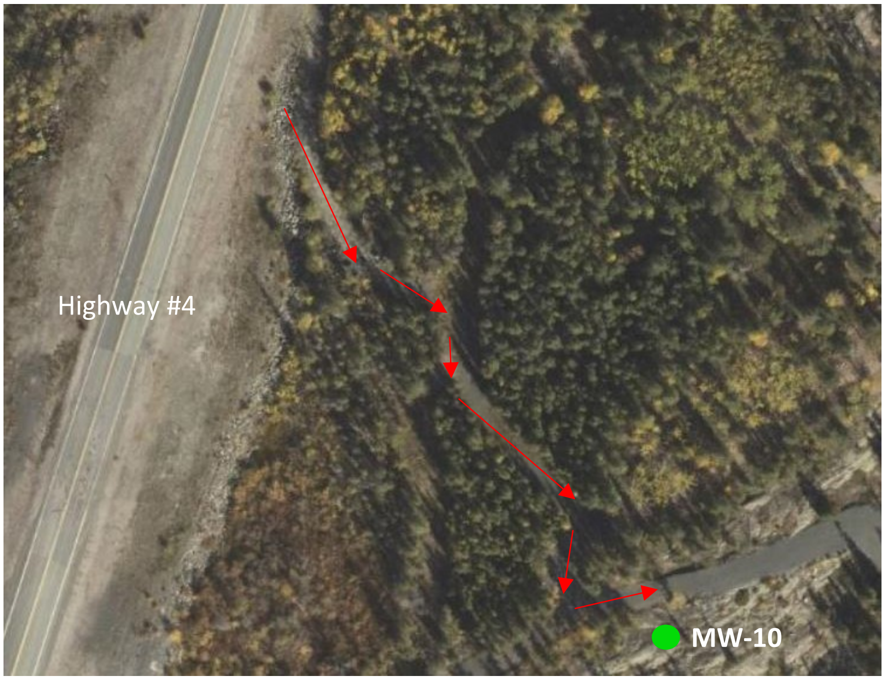

Figure 23: MW-10

5.5.8 Monitoring Well 11 (MW-11)

Well is located on Ski Club trail off of Highway #4. Park the truck and carry the needed equipment straight back until reaching a clearing where the well is located. MW-11 will usually recharge within a day.

Approximate Depth	22m
Expected Purge Volume	60L (3 Buckets)

Figure 24: MW-11

5.5.9 Monitoring Well 12 (MW-12)

This well is located in the Ski Club parking lot. Truck can be pulled up close to the well for easy sampling. MW-12 recharges very slowly and can take 3 days during summer, and longer than a week during fall sampling.

Approximate Depth	8m
Expected Purge Volume	60L (3 Buckets)

Figure 25: MW-12

TECHNICAL MEMORANDUM

Issue Date:	December 9, 2020	**File No.:**	
To:	Maddison Warren, Municipal Engineer	**Previous Issue Date:**	
From:	Jennifer Brown, P.Eng., MEERL	**Project No.:**	2019-8509.000.006
Client:	City of Yellowknife		
Project Name:	Solid Waste Facility Hydrogeological Desktop Study		
Subject:	SWF Hydrogeological Desktop Study		

1 INTRODUCTION

Associated Environmental Consultants Inc. was retained by the City of Yellowknife (the City) to complete a hydrogeological desktop study for the Solid Waste Facility (SWF) located at the corner of the Yellowknife Highway and Ingraham Trail in Yellowknife, Northwest Territories (Figure 1 - attached). The entire property is approximately 75 hectares (748,164 m^2).

2 BACKGROUND

The SWF opened in 1974 and for the first 16 years of operation it was used as a non-licensed, unmonitored waste dump with uncontrolled burning. In 2011, a second-generation landfill cell was constructed in a quarry adjacent to the existing SWF (City of Yellowknife 2020). The cell features a liner and leachate collection system to contain the leachate generated by the cell. In 2016, the cell was starting to reach its design capacity and an additional landfill cell was constructed with the same design as the first cell. With the waste and granular materials above the composite liner system, the liner is not accessible for visual inspection; therefore, the integrity of the liner is determined through the monitoring of groundwater monitoring wells around the facility (City of Yellowknife 2020).

Eight groundwater monitoring wells are sampled as part of the monitoring program for the SWF; however, none of these eight wells can be considered as representative background wells for current groundwater quality due to all of the current wells being within the Site boundary. The background data is needed to compare and establish groundwater quality criteria for the SWF. In August 2019, two boreholes were drilled west of the SWF (BH-9A and BH-9B – Figure 2) to establish a background groundwater monitoring well but the boreholes were dry, and monitoring wells were not installed.

This memo explores the feasibility and locations to drill and install a background groundwater monitoring well at the SWF, based on data collected from online databases, historic reports, and monitoring well data collected by the City.

3 GEOLOGY

3.1 Regional Surficial Geology

The SWF is located in the physiographic region of the Canadian Shield within the Mackenzie River Basin. Much of the Canadian Shield has a discontinuous cover of thin glacial sediment but thicker deposits occur in correlation to glacial landforms, such as drumlins, eskers and moraines. Extensive glaciolacustrine deposits occur in parts of the Canadian

C:\Users\barretton\AE Environmental\Yellowknife - Solid Waste Facility\mem_SWF-HydrogeoStudy(1.8)

Shield and form clay basins with underlying sand and gravel deposits. The glacial sediments in the Canadian Shield, in particular, the coarse-grained high yield glaciofluvial deposits (e.g., eskers) can be important locations for aquifers (VanGulck 2016).

3.2 Regional Bedrock Geology and Hydrogeology

The structurally complex Canadian Shield is composed of intensely deformed metamorphic, meta-intrusive and meta-volcanic rocks of Archean and Proterozoic age, overlain in part by Neoproterozoic meta-sedimentary rocks (Hannigan et al. 2011). The crystalline rocks of the Canadian Shield are characterized by low primary porosity and permeability, with variable fracture patterns, and generally have a low groundwater yield (VanGulck 2016).

The fracture zones may yield potable water to depths of around 100 m; however, at greater depths the groundwater quality degrades progressively becoming more saline (VanGulck 2016). Recharge and discharge are characterized by local fracture patterns. Water quality may be also be impacted in these fracture systems due to bedrock mineralization. Elevated hydraulic heads are common in the Canadian Shield rocks as a result of surface loading from the Laurentide Ice Sheet. The undulating, and low to modest relief of the Canadian Shield, leads to slow groundwater movement and reduced mixing at depth (VanGulck 2016).

3.3 Permafrost

The permafrost in the area is categorized as discontinuous, which occurs in scattered regions ranging in size from a few square meters to several hectares, with thicknesses that can vary from a few centimetres to as much as 100 m (Andersland & Ladanyi, 2004). With respect to hydrogeology, permafrost may be considered an aquiclude; the pores and fractures of the medium are filled with ice, acting as a barrier to groundwater flow. However, the active layer of permafrost can function as an unconfined aquifer for shallow groundwater seasonally when thawed (VanGulck 2016). These shallow aquifers may still be vulnerable to contamination from landfills, particularly in the discontinuous permafrost zone.

3.4 Site-Specific Geology

Three cross-sections (attached – Figure 2) were created from historical borehole logs (Figure 2A, 2B, and 2C) and illustrate the subsurface lithology at the SWF. Cross Section A-A’ runs along the northern part of the SWF from west to east and comprises strictly bedrock. Cross Section B-B’ starts at Jackfish Lake and dissects the SWF from the southwest to the northeast section of the SWF at MW-10. The lithology at Jackfish Lake is assumed to be bedrock based on visual inspection using Google Earth, continuing to MW-5B and MW-2B which are described as overburden wells before connecting to MW-10, which is a bedrock well. Cross Section C-C’ transects the eastern edge of the landfill from south (MW-12) to north (MW-10). This cross-section presents three wells drilled into bedrock. Irwin 2020 presents bedrock lithology comprising the Yellowknife Supergroup which is mainly basaltic volcanic and related intrusive rock such as minor andesite and rhyolite.

Regional maps for geological structures (Irwin 2020) and KMZ Google Earth files were obtained and overlain onto the site map (Figure 3); structural features of the area were interpreted for the SWF. Faults are located at the northerly edge of the SWF striking northwest to southeast; however, no faults are indicated on the map to the immediate west of the SWF. Satellite imagery (Google Earth) shows smaller lineaments in conjugate pairs west of the SWF in the area where BH-9A and BH-9B were drilled. These are likely smaller faults created subsequent to the processes causing the larger regional faults. It is not clear from well data which of these smaller lineaments are open to groundwater flow and which were closed because of the pressure during creation.

Several mafic dykes are mapped (NTGS 2017) within the SWF; however, no dykes are indicated in the upgradient area where BH-9A/9B were drilled. It is not evident from the well logs of MW-1, MW-2, MW-3 and MW-8 that any dyke material was encountered. Groundwater saturated conditions were found in MW-3; however, no relationship with dyke material could be made.

A review of the Geophysical Survey Metadata database via the Northwest Territories Geological Survey (NTGS) and a broader internet search concluded with no geophysical data for the SWF or the surrounding area.

4 HYDROGEOLOGY

Groundwater level measurements were collected by the City on July 17, 2020 (summer) and September 25, 2020 (fall). The City was not able to collect data from some wells due to ice build-up in the well or issues with access.

The groundwater levels were converted to groundwater elevations based on geodetic survey data provided by the City. The groundwater elevation data was gridded and contoured using Surfer third-party software to determine the groundwater flow direction, and hydraulic gradient for the time measurements were recorded. The groundwater flow direction is used to assess which wells can be considered upgradient, cross gradient and down gradient of the SWF.

Table 4-1 summarizes the groundwater elevations collected for the summer and fall monitoring events. Only monitoring wells MW-2A, MW-2B, MW-3, MW-5B, MW-6, MW-10, MW-11 and MW-12 were monitored.

Monitoring data from bedrock groundwater monitoring wells MW-2A, MW-3, MW-6, MW-10 and MW-12 were used to create groundwater level contour maps for the summer and fall monitoring events (Figure 4 and 5, respectively), and presents the groundwater water flow direction from west to east. These wells were selected as they are interpreted to be screened across the same lithological unit. Monitoring wells MW-2B and MW-5B were installed in the surficial geology and were not used to interpret the groundwater flow direction at the SWF, as they are in a different hydrogeological unit. These groundwater wells could not be used for surficial groundwater flow interpretation as there are only two wells installed in the hydrogeological unit and three wells are required to calculate groundwater flow direction.

Table 4-1
Groundwater Elevations for Monitoring the Well Network at the SWF for July and September 2020

Monitoring Well ID	Summer (m amsl)	Fall (m amsl)
MW-2A	-	190.28
MW-2B	189.16	189.10
MW-3	194.90	194.75
MW-5B	199.52	199.26
MW-6	202.27	201.95
MW-10	181.90	-
MW-11	-	-
MW-12	188.49	188.27

Note:
m amsl - meters above mean sea level
- no data collected
***Bold* -** bedrock monitoring well

There are some local changes in groundwater flow that are not fully understood with the limited data in hand. Jackfish Lake to the south would likely be a cause of local deviation in flow towards the south. As the Great Slave Lake is considered the regional groundwater discharge boundary, the general flow is towards the east. Some potential higher-pressure conditions observed in MW-3 caused a localized change in groundwater flow.

Using the July 2020 groundwater elevations, the hydraulic gradient for the northern section of the SWF (monitoring wells MW-6 and MW-10) calculation is 0.0195. For the southern section (MW-3 and MW-12) the hydraulic gradient is approximately 0.0308.

Using the fall 2020 groundwater elevations, the hydraulic gradient for the northern section (using monitoring wells MW-6 and MW-2A) is approximately 0.0147. For the southern section (using MW-3 and MW-12) the hydraulic gradient is approximately 0.0267. The average groundwater hydraulic gradient is; therefore, 0.025 during July and 0.021 indicating a slight change for the two different seasons.

Based on the groundwater flow direction, monitoring well MW-6 would currently be used as an upgradient well; however, due to MW-6 being located within the SWF it is not a true representation of groundwater quality.

5 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the desktop study the following conclusions can be made:

- There are some inconsistencies with measured data and the well logs provided. This could be a result of frost heaving or blocked wells. It was unclear if the wells were locked at the SWF or if objects could be causing a blockage.
- Only four wells could be used for calculating groundwater flow in the bedrock unit with likely higher-pressure conditions observed in MW-3 causing localized change in groundwater flow.
- No distinct relationship between the structural geology and the occurrence of groundwater at the SWF is seen. The groundwater levels are highly variable based on the complex strutucal sytems seen at the Site and the surrounding area.
- Mafic dykes are indicated to transect the SWF; however, no relationship could be established between the dykes and groundwater monitoring wells installed at the SWF, as no dyke material was recorded in the well logs specifically.
- No geophysical data were found for the SWF to help with further delineation of structures for drilling targets.

Based on the results of the desktop study the following are recommended:

- Perform a cost analysis to establish if drilling exploratory groundwater monitoring wells that target geological structures observed from the satellite image outweighs the cost of completing a ground geophysical, magnetic, electromagnetic and resistivity survey prior to a drilling program.
- Based on the outcome of such analysis, commence drilling to establish a background upgradient well west of the SWF.

Prepared by:	**Reviewed by:**
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Neal Barretto, B.Sc. G.I.T. Junior Hydrogeologist	Jennifer Brown, P.Eng., MEERL Hydrogeologist

[JG/RK]

Attachments

Figure 1 – Site Location and Groundwater Monitoring Well Locations
Figure 2 – Groundwater Well Locations and Cross Section Lines
Figure 2A – Cross Section A-A'
Figure 2B – Cross Section B-B'
Figure 2C – Cross Section C-C'
Figure 3 – Structural Geology Map of the Solid Waste Facility Area
Figure 4 – July 2020 Groundwater Contours
Figure 5 – September 2020 Groundwater Contours
Well Logs – MW-1, MW-1A, MW-1B, MW-2, MW-2A, MW-2B, MW-3, MW-4, MW-5A, MW-5B, MW-6, MW-7, MW-8, MW-10, MW-11, MW-12, BH-9A, BH-9B

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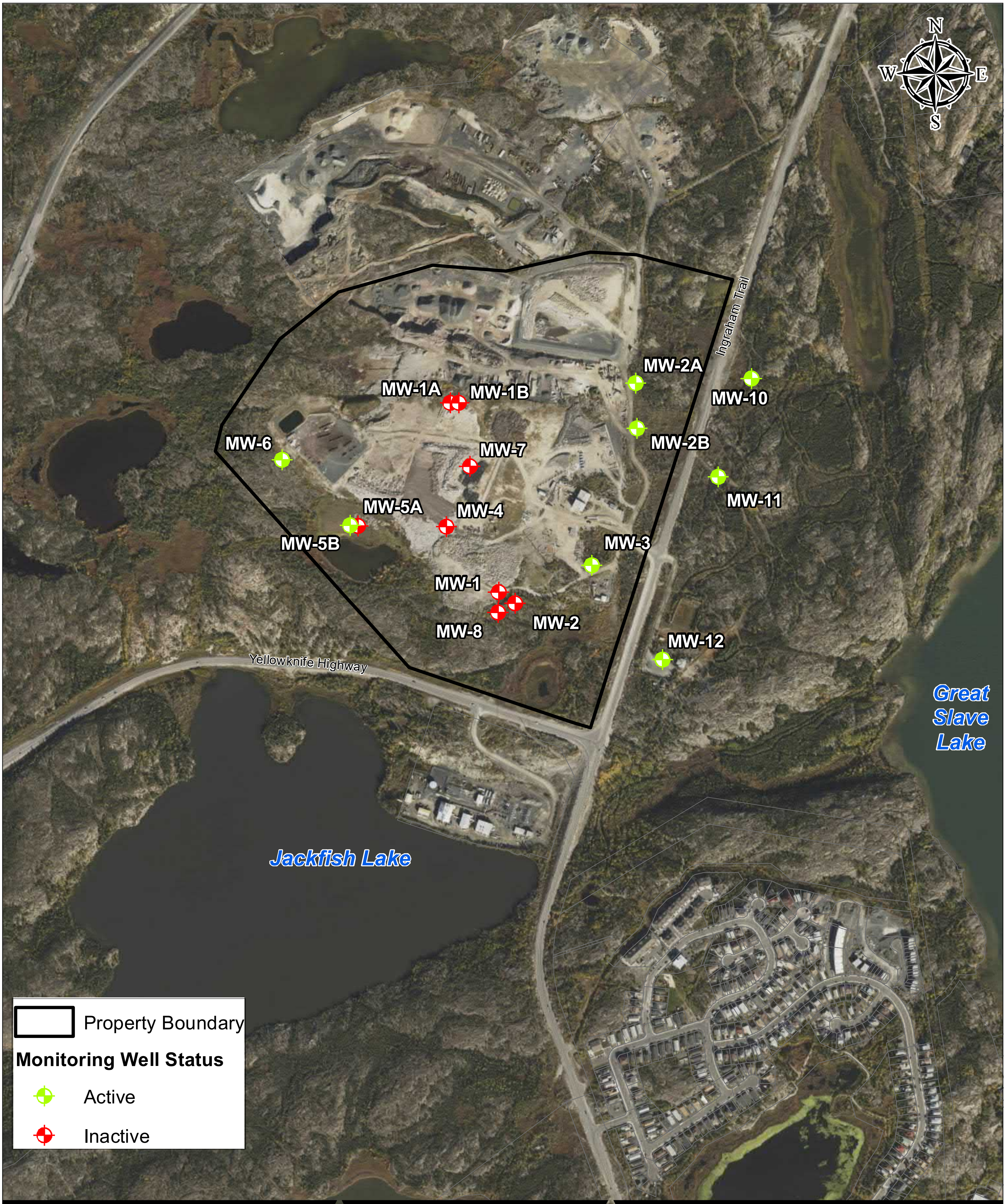


Figure 1.mxd / 12/07/2020

Associated Environmental

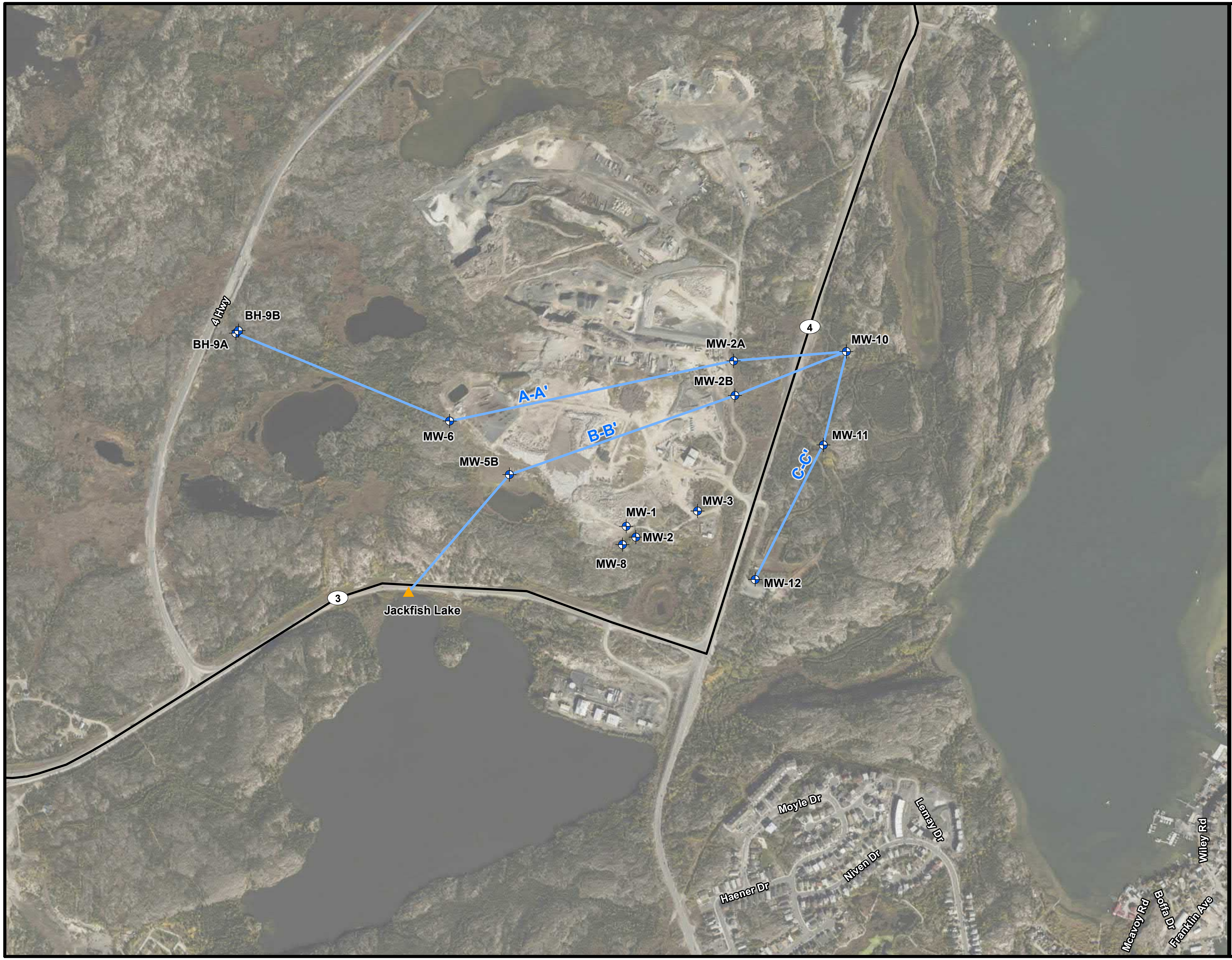
PROJECT NO.: 2019-8509.000.000
DATE: December 2020
DRAWN BY: NB

0 100 200 300 400 500
Meters

FIGURE 1: SITE LOCATION AND GROUNDWATER MONITORING WELL LOCATIONS

City of Yellowknife

Groundwater Monitoring Plan



Associated Environmental

CITY OF YELLOWKNIFE

Legend

⌖ Monitoring Well

▲ Surface Water Monitor

— Cross Section Line

Base Data

— Highway

0 100 200 300 400 500 m

N

Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Road: Statistics Canada, 2019.

FIGURE 2
Groundwater Well Locations
And Cross Section Lines

The City of Yellowknife
Yellowknife Solid Waste Facility

AE PROJECT No.	2019-8509
DATE	2020 DECEMBER
SCALE	1:10,000
COORD. SYSTEM	NAD 1983 UTM Zone 11N
REV	0
DESCRIPTION	ISSUED FOR REPORT
DRAWN BY	WL
CHECKED BY	KN

FILE: C:\Users\law\Desktop\Proj\Yellowknife\GIS\ArcMap\HYDROGEO\AE20198509_Fig2_MW_201202.mxd

Associated Environmental

PROJECT NO.: 2019-8509.000

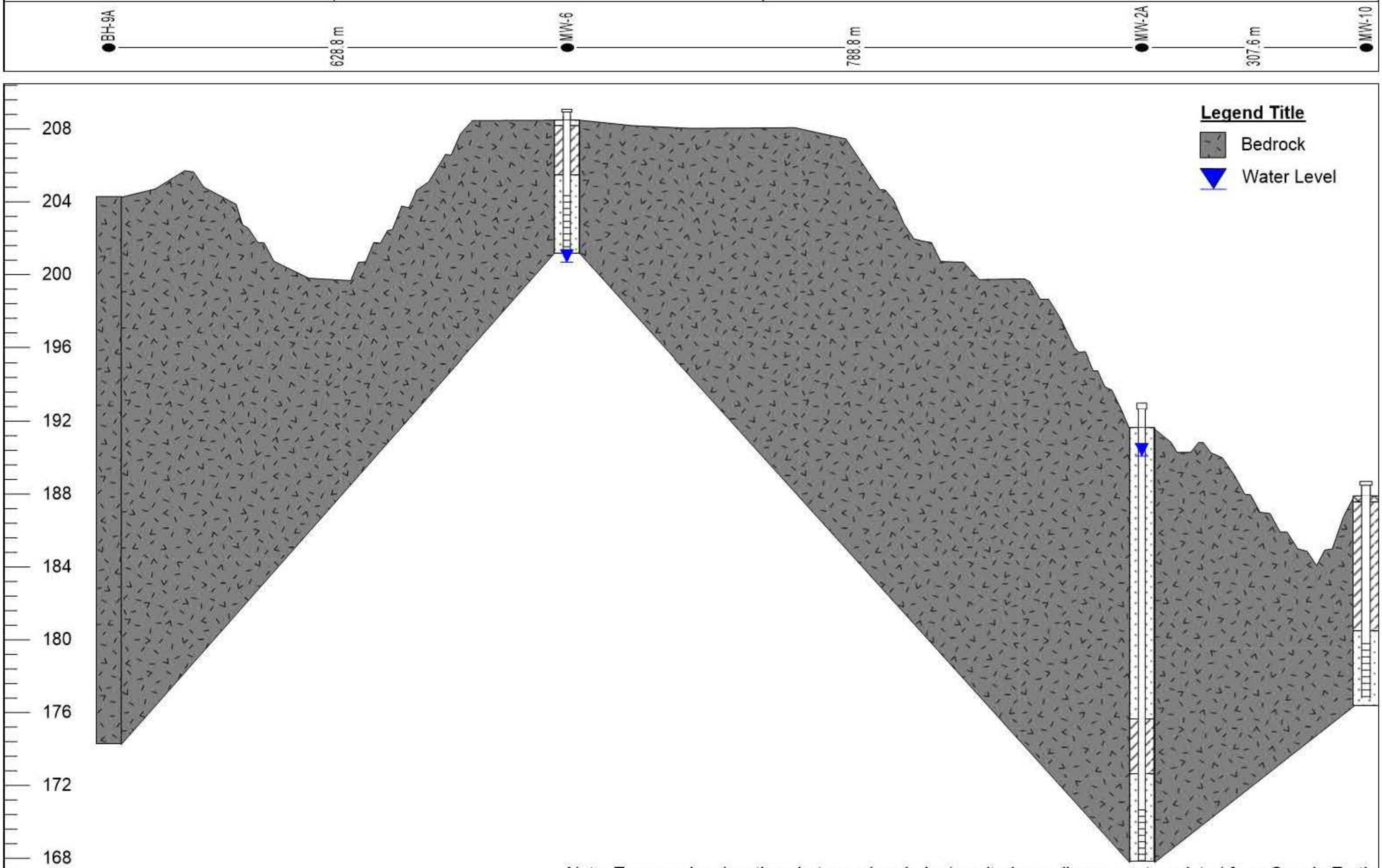
DATE: November 2020

DRAWN BY: NB

FIGURE 2A: CROSS SECTION A-A'

City of Yellowknife Solid Waste Facility

Hydrogeological Desktop Study



Note: Topography elevations between boreholes/monitoring wells were extrapolated from Google Earth.

Associated Environmental

PROJECT NO.: 2019-8509.000

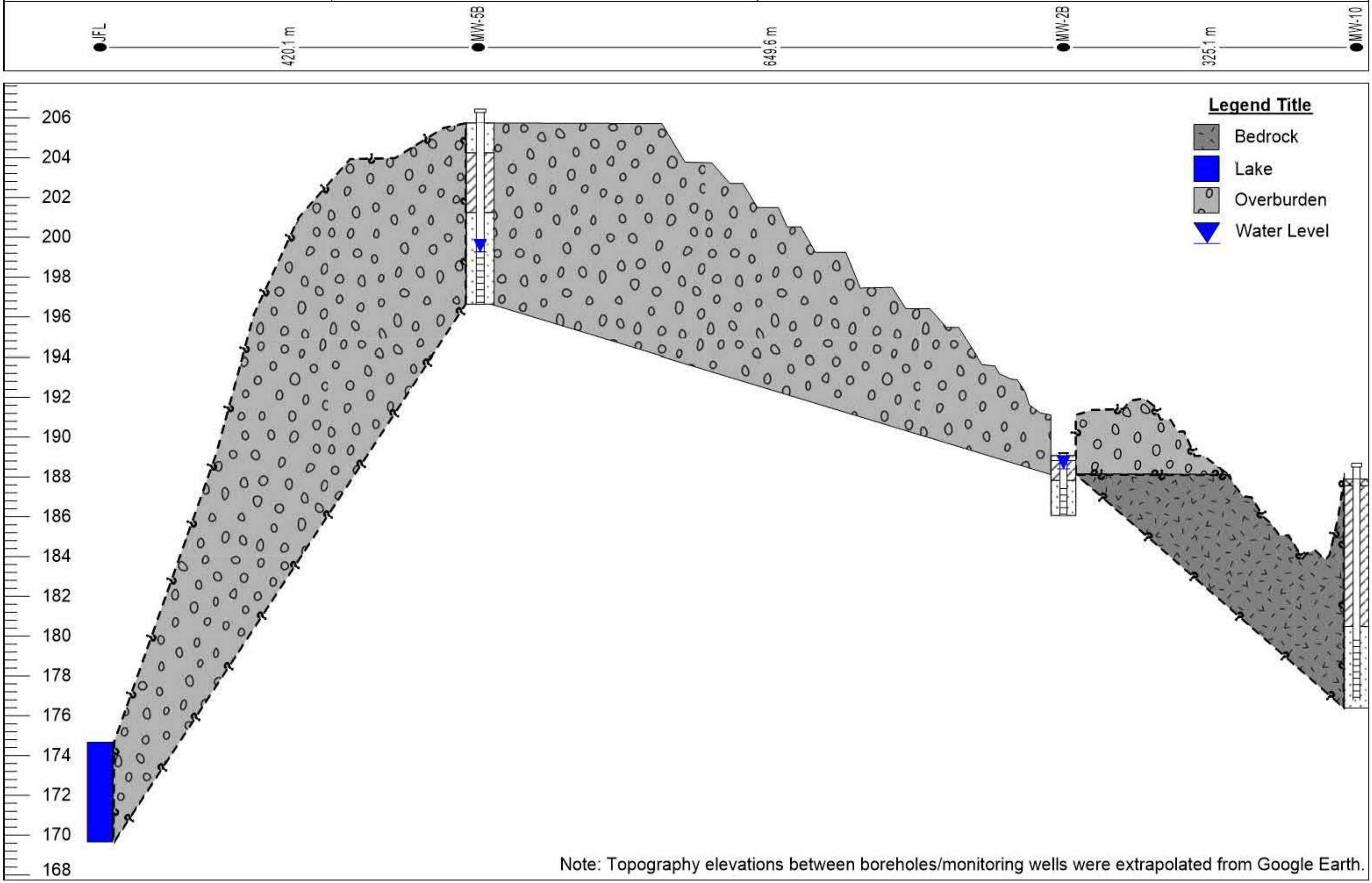
DATE: November 2020

DRAWN BY: NB

FIGURE 2B: CROSS SECTION B-B'

City of Yellowknife Solid Waste Facility

Hydrogeological Desktop Study



Note: Topography elevations between boreholes/monitoring wells were extrapolated from Google Earth.

Associated Environmental

PROJECT NO.: 2019-8509.000

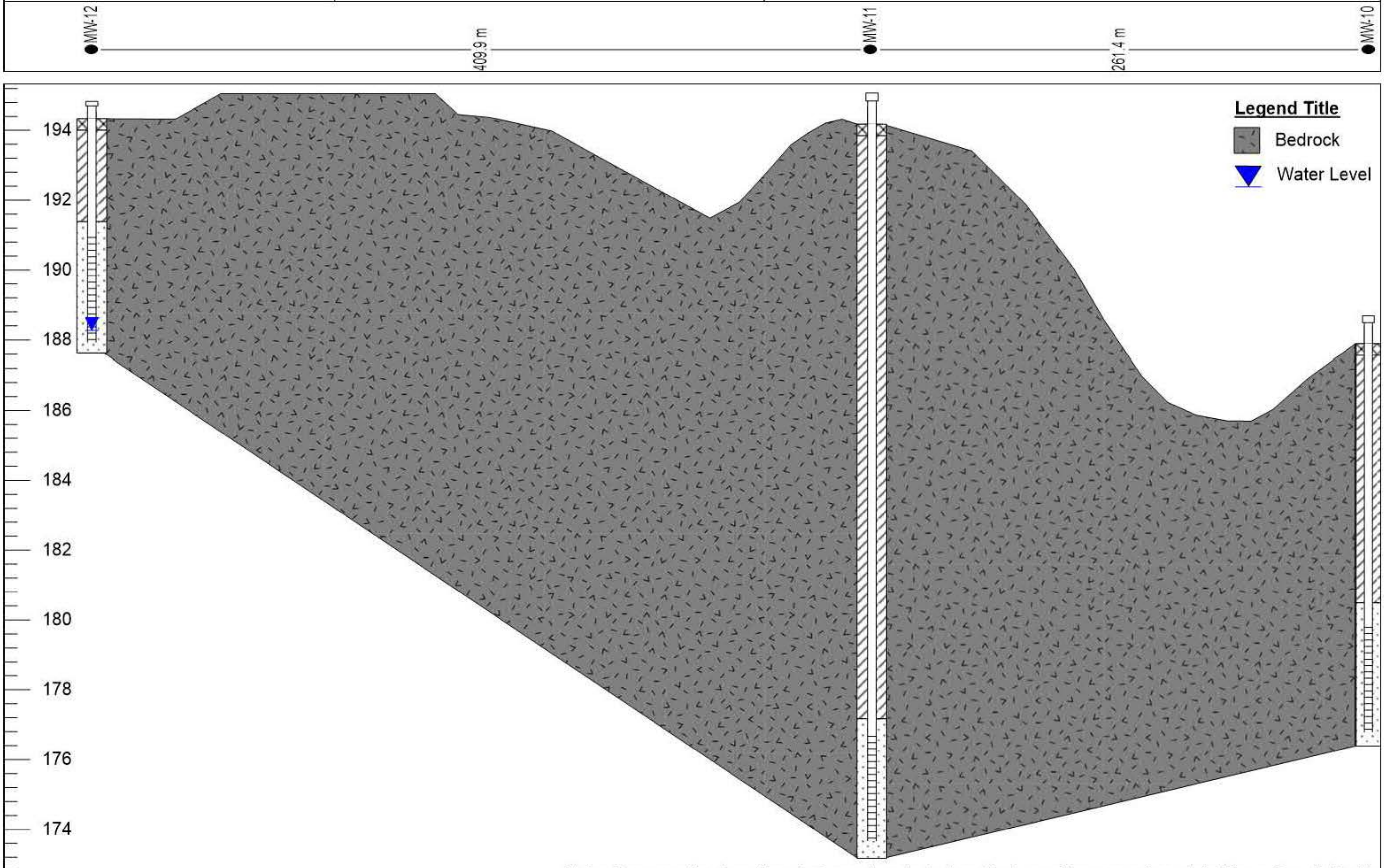
DATE: November 2020

DRAWN BY: NB

FIGURE 2C: CROSS SECTION C-C'

City of Yellowknife Solid Waste Facility

Hydrogeological Desktop Study



Note: Topography elevations between boreholes/monitoring wells were extrapolated from Google Earth.

Associated Environmental

CITY OF YELLOWKNIFE

Legend

⌖ Monitoring Well

▲ Surface Water Monitor

Fault

Mafic Dyke

Base Data

Highway

0 100 200 300 400 500 m

N

Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Road: Statistics Canada, 2019.

FIGURE 3
Structural Geology Map Of The Solid Waste Facility Area

The City of Yellowknife
Yellowknife Solid Waste Facility

AE PROJECT No.	2019-8509
DATE	2020 DECEMBER
SCALE	1:15,000
COORD. SYSTEM	NAD 1983 UTM Zone 11N
REV	0
DESCRIPTION	ISSUED FOR REPORT
DRAWN BY	WL
CHECKED BY	KN

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Associated Environmental

CITY OF YELLOWKNIFE

Legend

⊕ Monitoring Well

▲ Surface Water Monitor

— Contour (July 2020)

Base Data

— Highway

Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Road: Statistics Canada, 2019.

FIGURE 4
July 2020 Groundwater Contours

The City of Yellowknife
Yellowknife Solid Waste Facility

AE PROJECT No.	2019-8509
DATE	2020 DECEMBER
SCALE	1:10,000
COORD. SYSTEM	NAD 1983 UTM Zone 11N
REV	0
DESCRIPTION	ISSUED FOR REPORT
DRAWN BY	WL
CHECKED BY	KN

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Associated Environmental

CITY OF YELLOWKNIFE

Legend

- ⊕ Monitoring Well
- ▲ Surface Water Monitor
- — Contour (September 2020)

Base Data

- — Highway

0 100 200 300 400 500 m

N

Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Road: Statistics Canada, 2019.

FIGURE 5
September 2020 Groundwater Contours

The City of Yellowknife
Yellowknife Solid Waste Facility

AE PROJECT No.	2019-8509
DATE	2020 DECEMBER
SCALE	1:10,000
COORD. SYSTEM	NAD 1983 UTM Zone 11N
REV	0
DESCRIPTION	ISSUED FOR REPORT
DRAWN BY	WL
CHECKED BY	KN

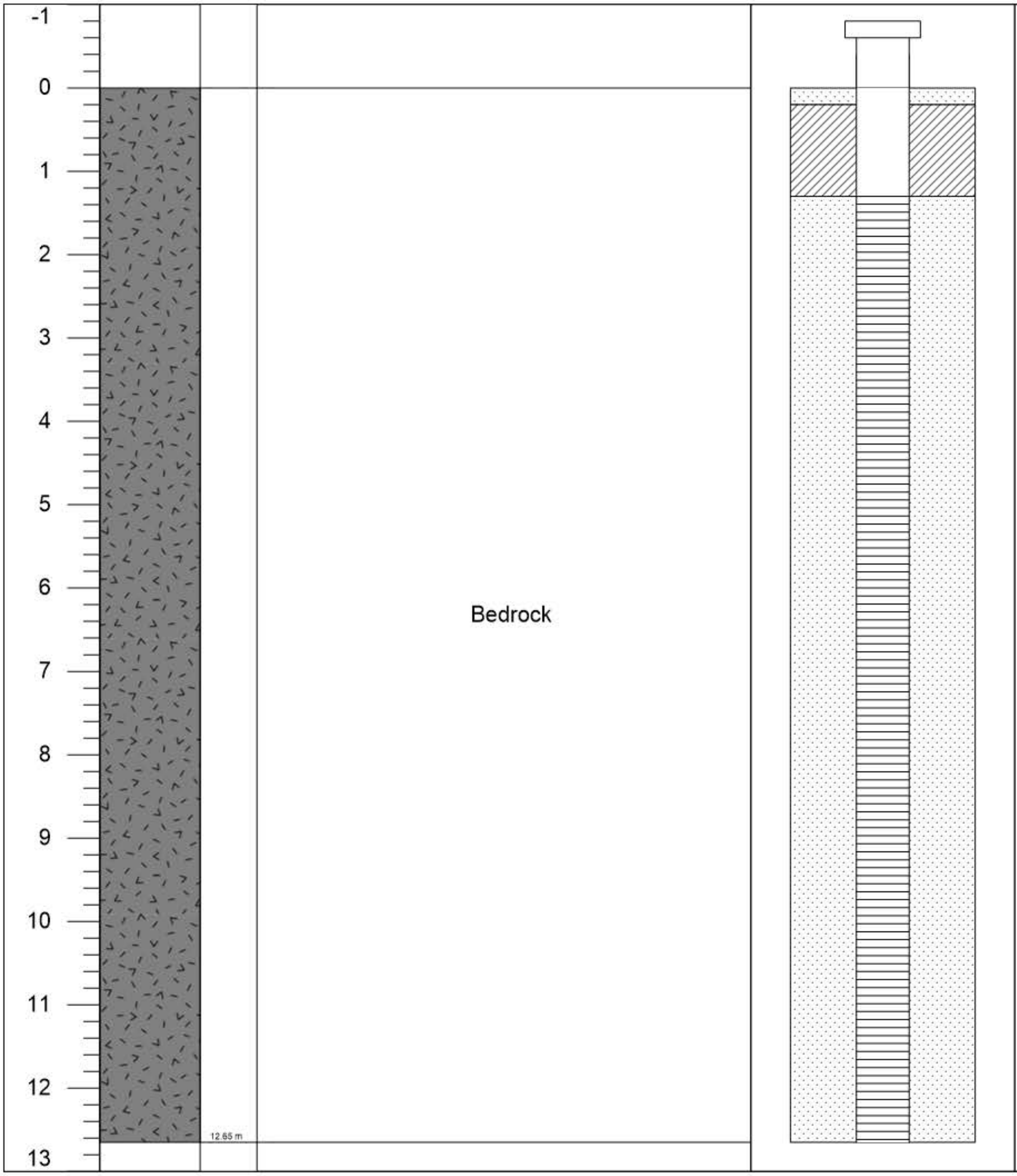
FILE: C:\Users\law\Desktop\Proj\Yellowknife\GIS\ArcMap\HYDROGEO\AE20198509_Fig5_September_201202.mxd

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-1	Northing (m):	6929672	Survey Method: N/A Zone:
Client:	City of Yellowknife		Easting (m):	635066	
Location:	Yellowknife, NWT		Elevation (m):	100.26	

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Casing Stick-Up (0.92 m)

Silica Sand (0 - 0.2 m bgs)

Bentonite (0.2 - 1.3 m bgs)

50 mm PVC Casing (0 - 1.3 m bgs)

Silica Sand Filter (1.3 - 12.65 m bgs)

50 mm PVC Screen (1.3 - 12.65 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

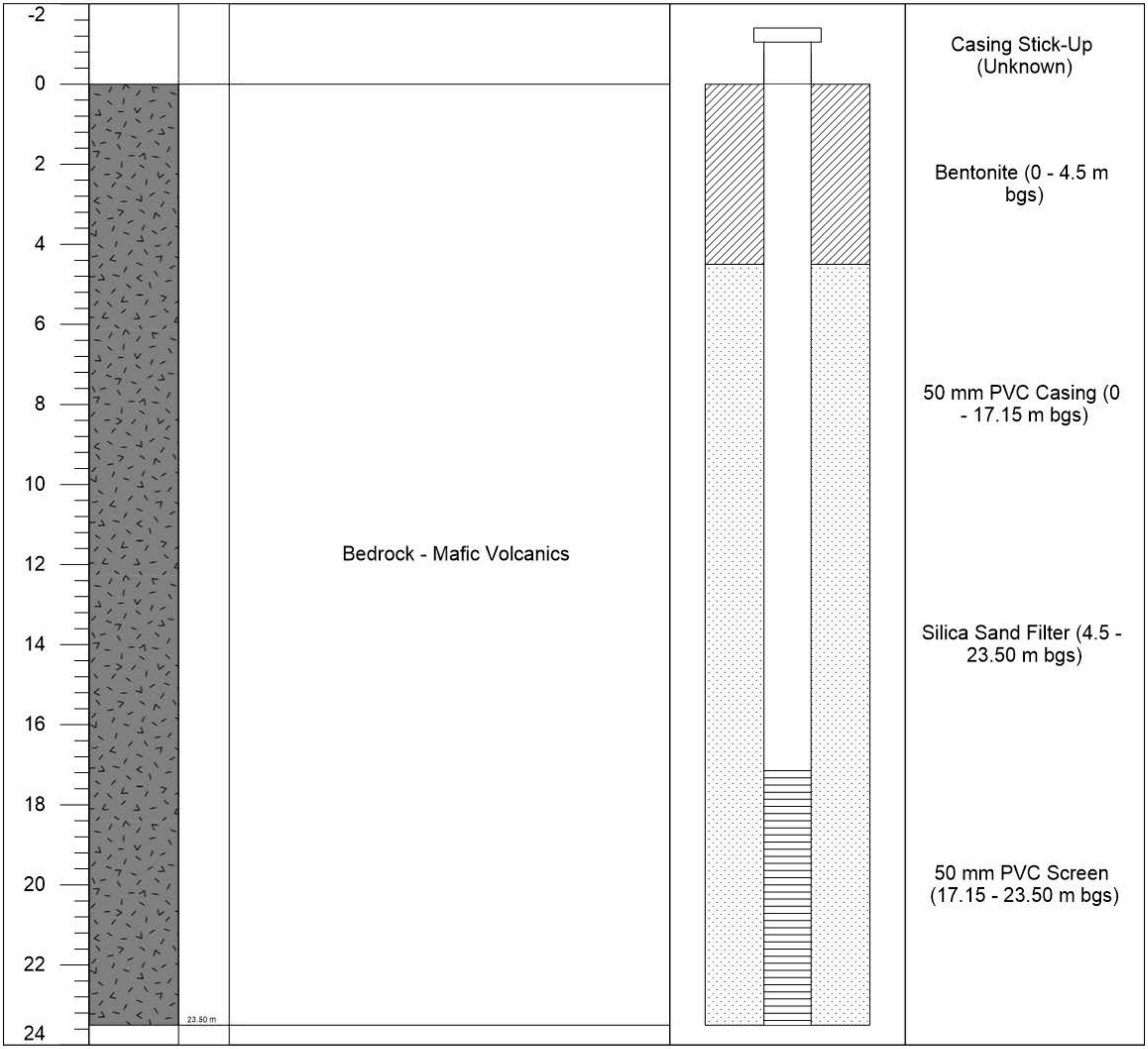
Drawn by: NB

Project Details		Well / Borehole ID	Location	
Project Number:	2019-8509.000	MW-1A	Northing (m):	Survey Method: N/A
Client:	City of Yellowknife		Easting (m):	Zone:
Location:	Yellowknife, NWT		Elevation (m): 182.49	

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Bedrock - Mafic Volcanics

Casing Stick-Up (Unknown)

Bentonite (0 - 4.5 m bgs)

50 mm PVC Casing (0 - 17.15 m bgs)

Silica Sand Filter (4.5 - 23.50 m bgs)

50 mm PVC Screen (17.15 - 23.50 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

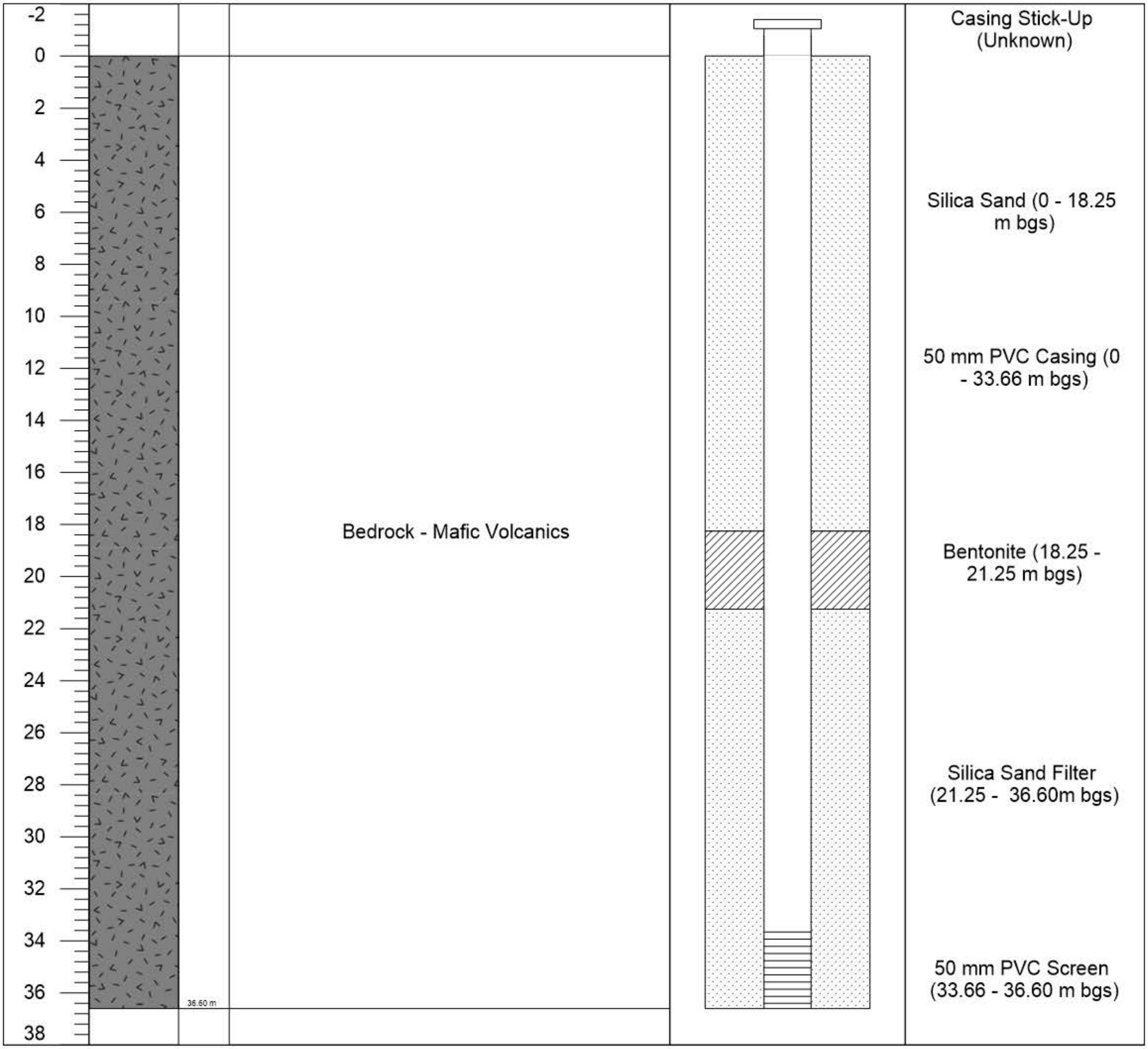
Page 1 of 1

Project Details		Well / Borehole ID	Location	
Project Number:	2019-8509.000	MW-1B	Northing (m):	Survey Method:
Client:	City of Yellowknife		Easting (m):	N/A
Location:	Yellowknife, NWT		Elevation (m): 174.28	Zone:

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

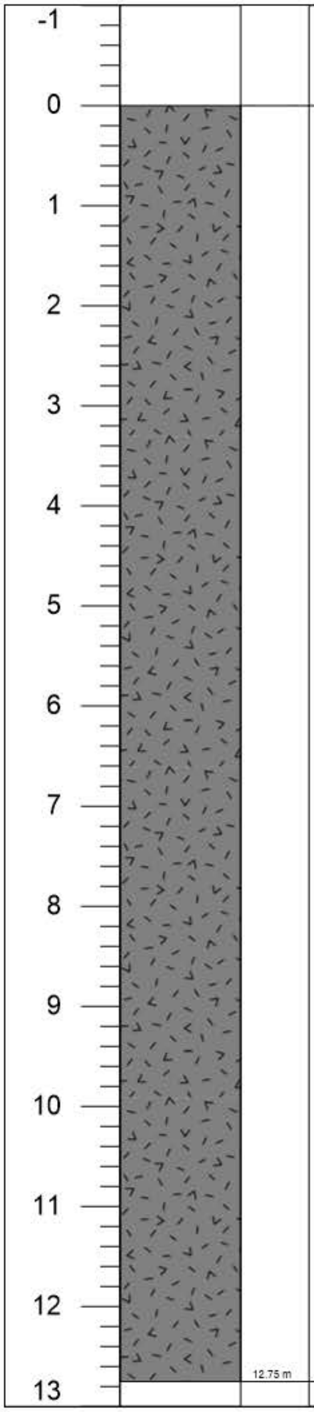
Page 1 of 1

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-2	Northing (m):	6929643	Survey Method:
Client:	City of Yellowknife		Easting (m):	635093	N/A
Location:	Yellowknife, NWT		Elevation (m):	99.18	Zone:

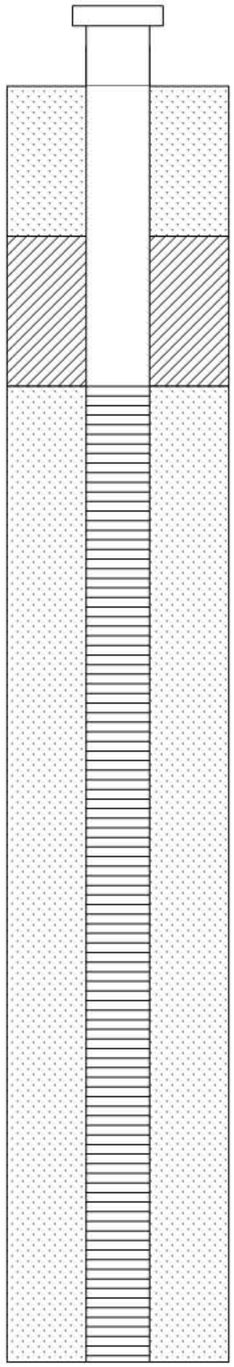
Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Bedrock



Casing Stick-Up (0.82 m)

Silica Sand (0 - 1.5 m bgs)

50 mm PVC Casing (0 - 1.3 m bgs)

Bentonite (1.5 - 3.0 m bgs)

Silica Sand Filter (3.0 - 12.65 m bgs)

50 mm PVC Screen (3.0 - 12.65 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

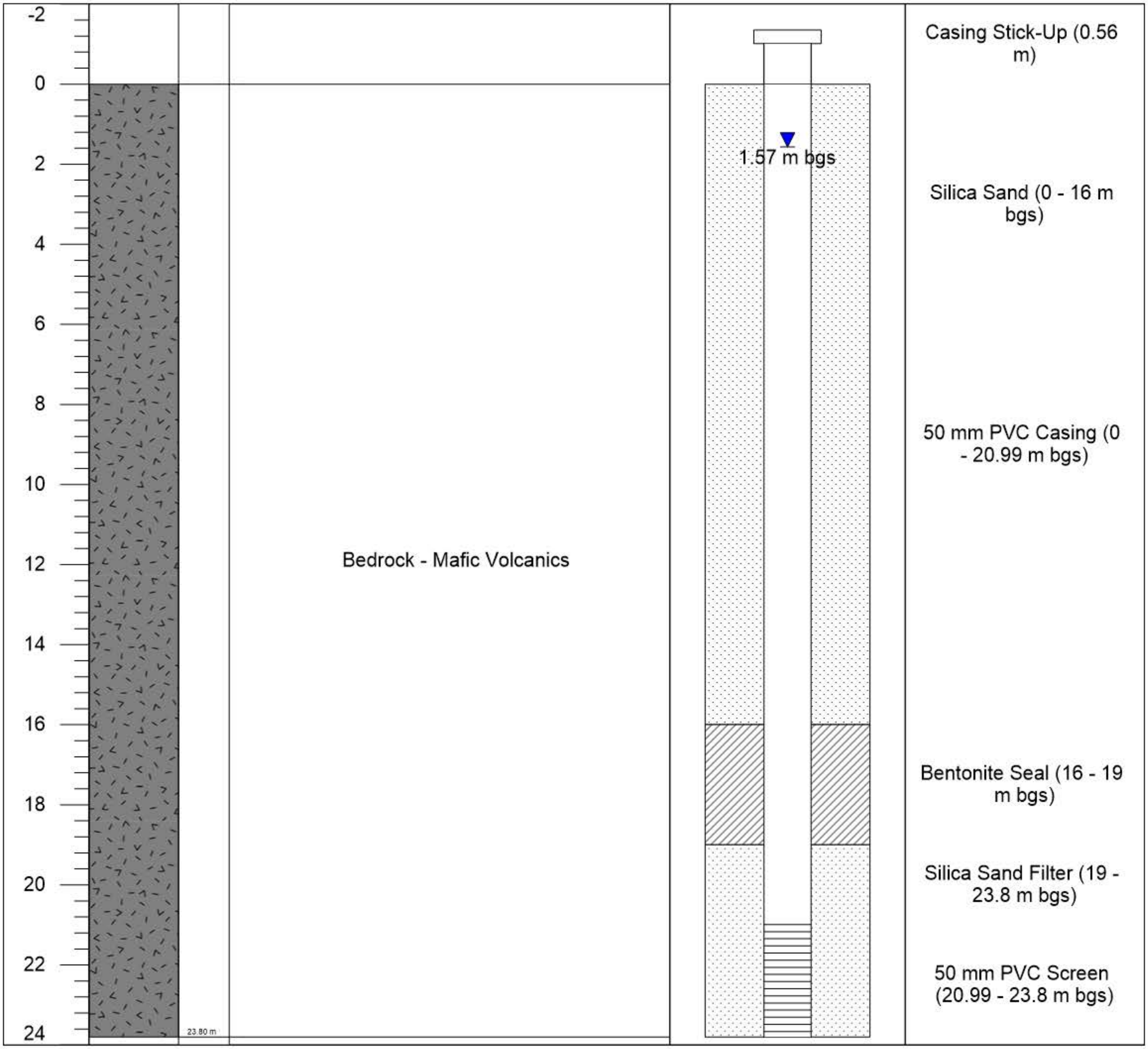
Drawn by: NB

Project Details		Well / Borehole ID	Location	
Project Number:	2019-8509.000	MW-2A	Northing (m): 6930121	Survey Method: N/A
Client:	City of Yellowknife		Easting (m): 635359	Zone:
Location:	Yellowknife, NWT		Elevation (m): 191.65	

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Bedrock - Mafic Volcanics

Casing Stick-Up (0.56 m)

Silica Sand (0 - 16 m bgs)

50 mm PVC Casing (0 - 20.99 m bgs)

Bentonite Seal (16 - 19 m bgs)

Silica Sand Filter (19 - 23.8 m bgs)

50 mm PVC Screen (20.99 - 23.8 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

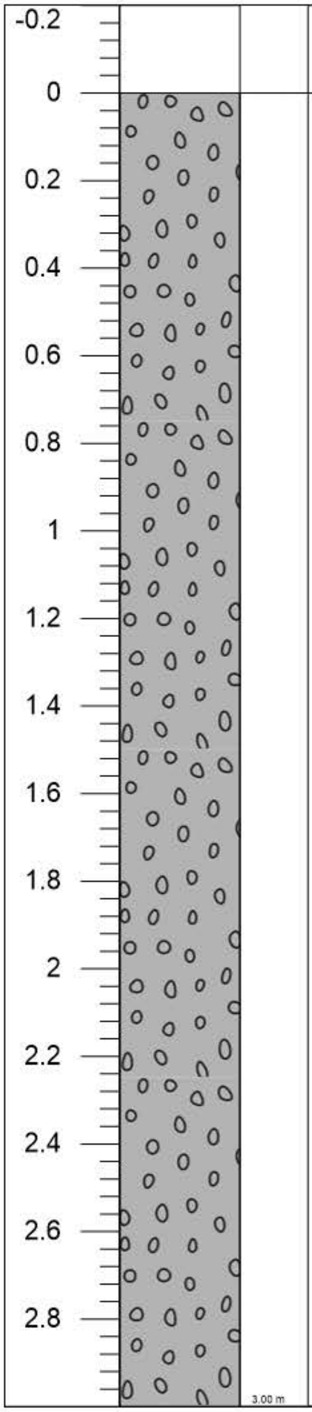
Drawn by: NB

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-2B	Northing (m):	6930027	Survey Method: N/A
Client:	City of Yellowknife		Easting (m):	635363	Zone:
Location:	Yellowknife, NWT		Elevation (m):	189.07	

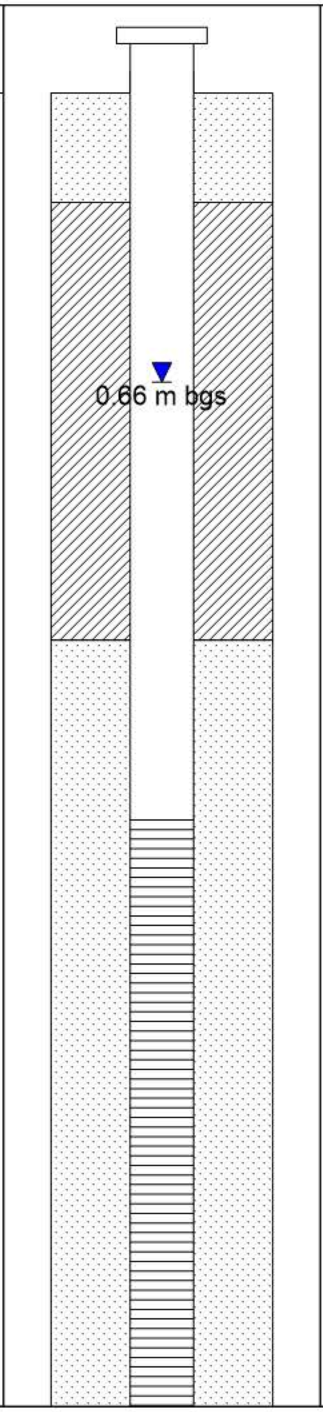
Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Overburden



Casing Stick-Up (1.47 m)

Silica Sand (0 - 0.25 m bgs)

50 mm PVC Casing (0 - 1.66 m bgs)

Bentonite Seal (0.25 - 1.25 m bgs)

Silica Sand Filter (1.25 - 3 m bgs)

50 mm PVC Screen (1.66 - 3 mbgs)

Associated Environmental

Lithology Legend

0 Overburden

Contractor:	N/A
Operator:	N/A
Date of construction:	
Drilling method:	N/A

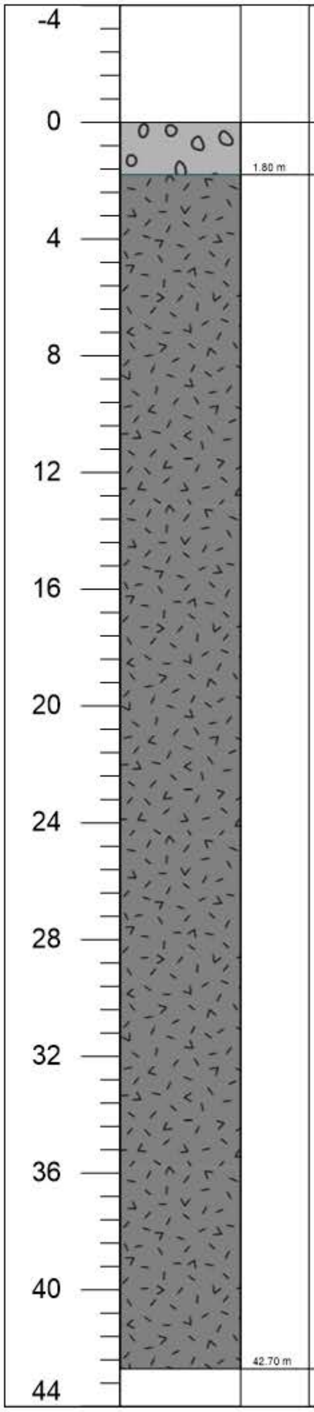
Drawn by: NB

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-3	Northing (m):	6929714	Survey Method: N/A
Client:	City of Yellowknife		Easting (m):	635261	Zone:
Location:	Yellowknife, NWT		Elevation (m):	195.35	

Subsurface Profile

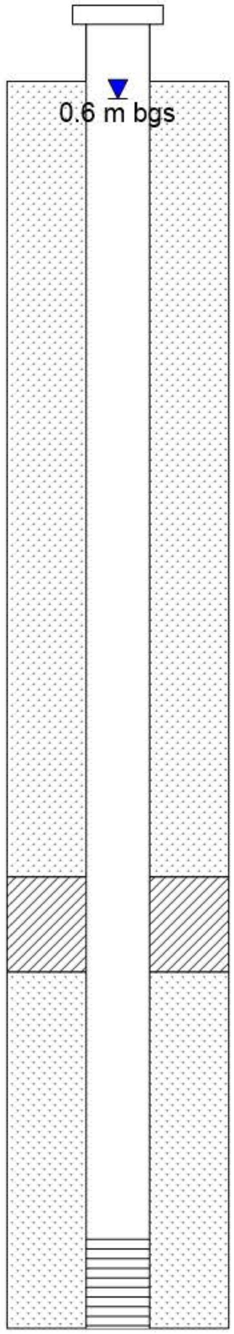
Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Overburden

Bedrock - Mafic Volcanics



Casing Stick-Up (Unknown)

Silica Sand (0 - 27.25 m bgs)

50 mm PVC Casing (0 - 39.66 m bgs)

Bentonite Seal (27.25 - 30.50 m bgs)

Silica Sand Filter (30.50 - 42.70 m bgs)

50 mm PVC Screen (39.66 - 42.70 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock ▢ Overburden

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

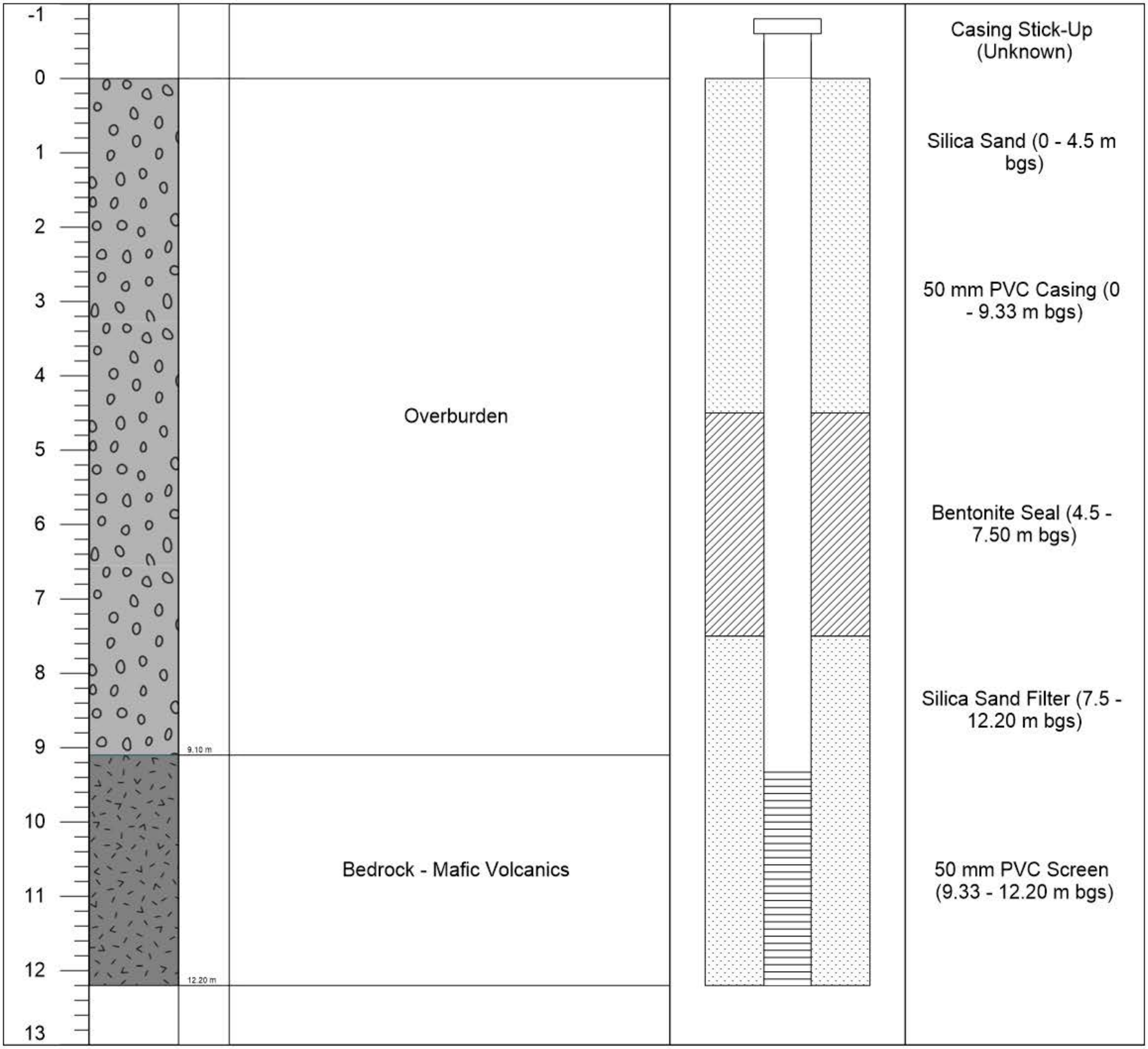
Drawn by: NB

Project Details		Well / Borehole ID	Location	
Project Number:	2019-8509.000	MW-4	Northing (m):	Survey Method:
Client:	City of Yellowknife		Easting (m):	N/A
Location:	Yellowknife, NWT		Elevation (m): 199.04	Zone:

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Overburden

Bedrock - Mafic Volcanics

Casing Stick-Up (Unknown)

Silica Sand (0 - 4.5 m bgs)

50 mm PVC Casing (0 - 9.33 m bgs)

Bentonite Seal (4.5 - 7.50 m bgs)

Silica Sand Filter (7.5 - 12.20 m bgs)

50 mm PVC Screen (9.33 - 12.20 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock ▨ Overburden

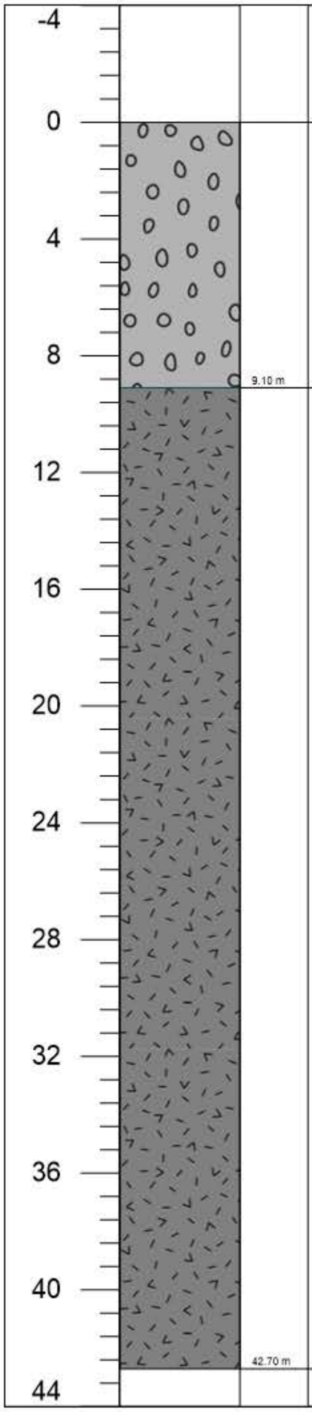
Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

Project Details		Well / Borehole ID	Location	
Project Number:	2019-8509.000	MW-5A	Northing (m):	Survey Method: N/A
Client:	City of Yellowknife		Easting (m):	Zone:
Location:	Yellowknife, NWT		Elevation (m): 174.13	

Subsurface Profile

Depth (m)	Graphic Log	Description

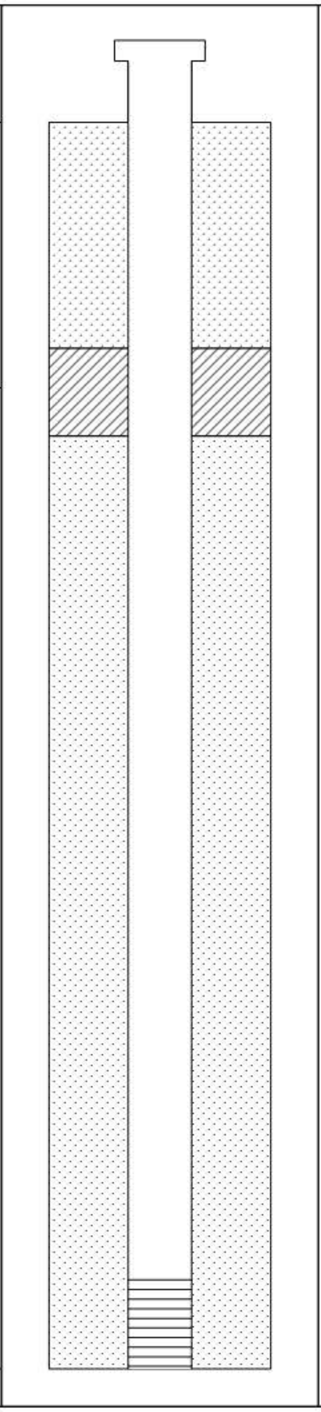


Overburden

Bedrock - Mafic Volcanics

Well Completion

Well Construction	Details



Casing Stick-Up (Unknown)

Silica Sand (0 - 7.75 m bgs)

Bentonite (7.75 - 10.75 m bgs)

50 mm PVC Casing (0 - 39.66 m bgs)

Silica Sand Filter (10.75 - 42.70 m bgs)

50 mm PVC Screen (39.66 - 42.70 m bgs)

Lithology Legend

Bedrock

Overburden

Contractor:	N/A
Operator:	N/A
Date of construction:	
Drilling method:	N/A

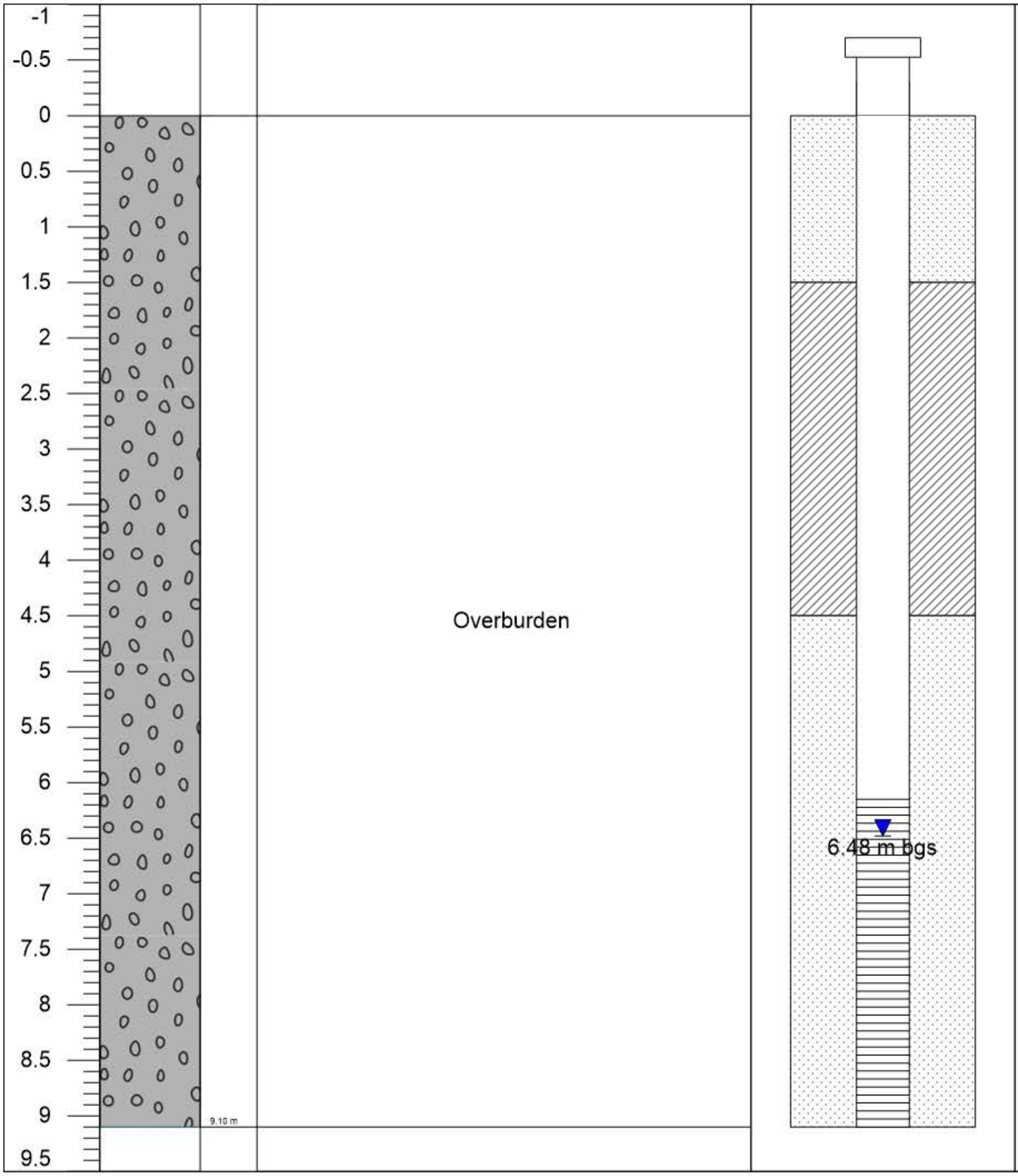
Drawn by: NB

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-5B	Northing (m):	6929812	Survey Method: N/A Zone:
Client:	City of Yellowknife		Easting (m):	634750	
Location:	Yellowknife, NWT		Elevation (m):	205.74	

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Overburden

Casing Stick-Up (0.99 m)

Silica Sand (0 - 1.50 m bgs)

50 mm PVC Casing (0 - 6.15m bgs)

Bentonite Seal (1.5 - 4.50 m bgs)

Silica Sand Filter (4.5 - 9.10 m bgs)

50 mm PVC Screen (6.15 - 9.10 m bgs)

Associated Environmental

Lithology Legend

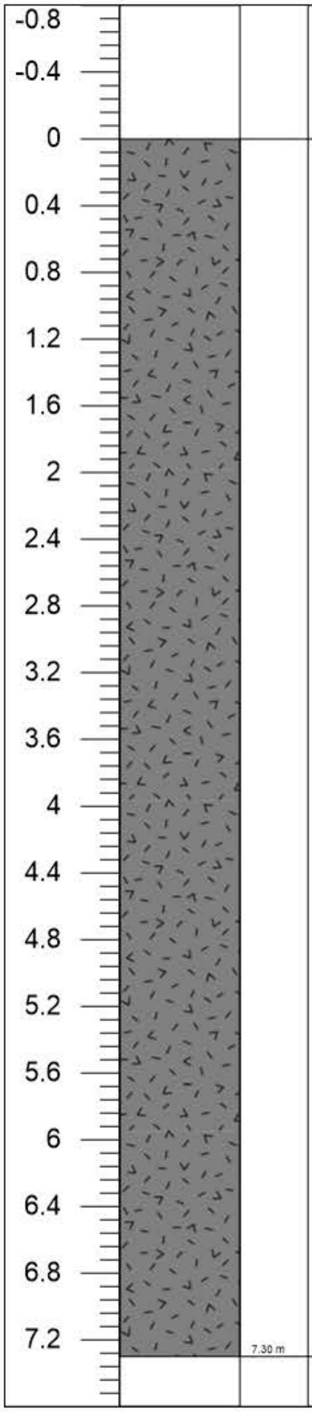
0 Overburden

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

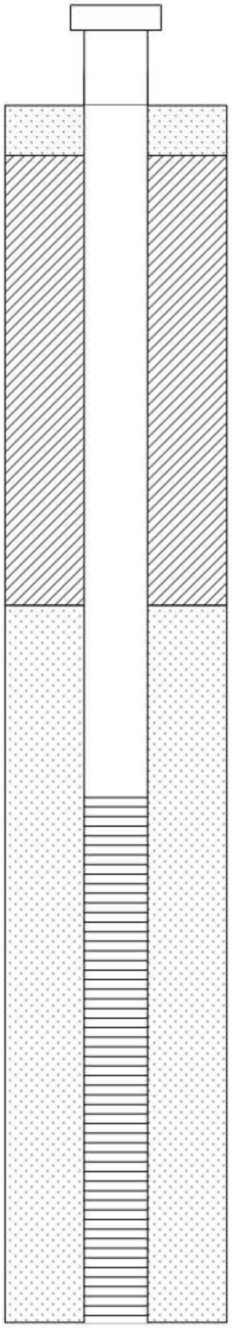
Drawn by: NB

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-6	Northing (m):	6929958	Survey Method: N/A Zone:
Client:	City of Yellowknife		Easting (m):	634587	
Location:	Yellowknife, NWT		Elevation (m):	208.48	

Subsurface Profile			Well Completion	
Depth (m)	Graphic Log	Description	Well Construction	Details



Bedrock - Mafic Volcanics



Casing Stick-Up (Unknown)

Silica Sand (0 - 0.3 m bgs)

Bentonite (0.3 - 3.0 m bgs)

50 mm PVC Casing (0 - 4.15 m bgs)

Silica Sand Filter (3 - 7.30 m bgs)

50 mm PVC Screen (4.15 - 7.30 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

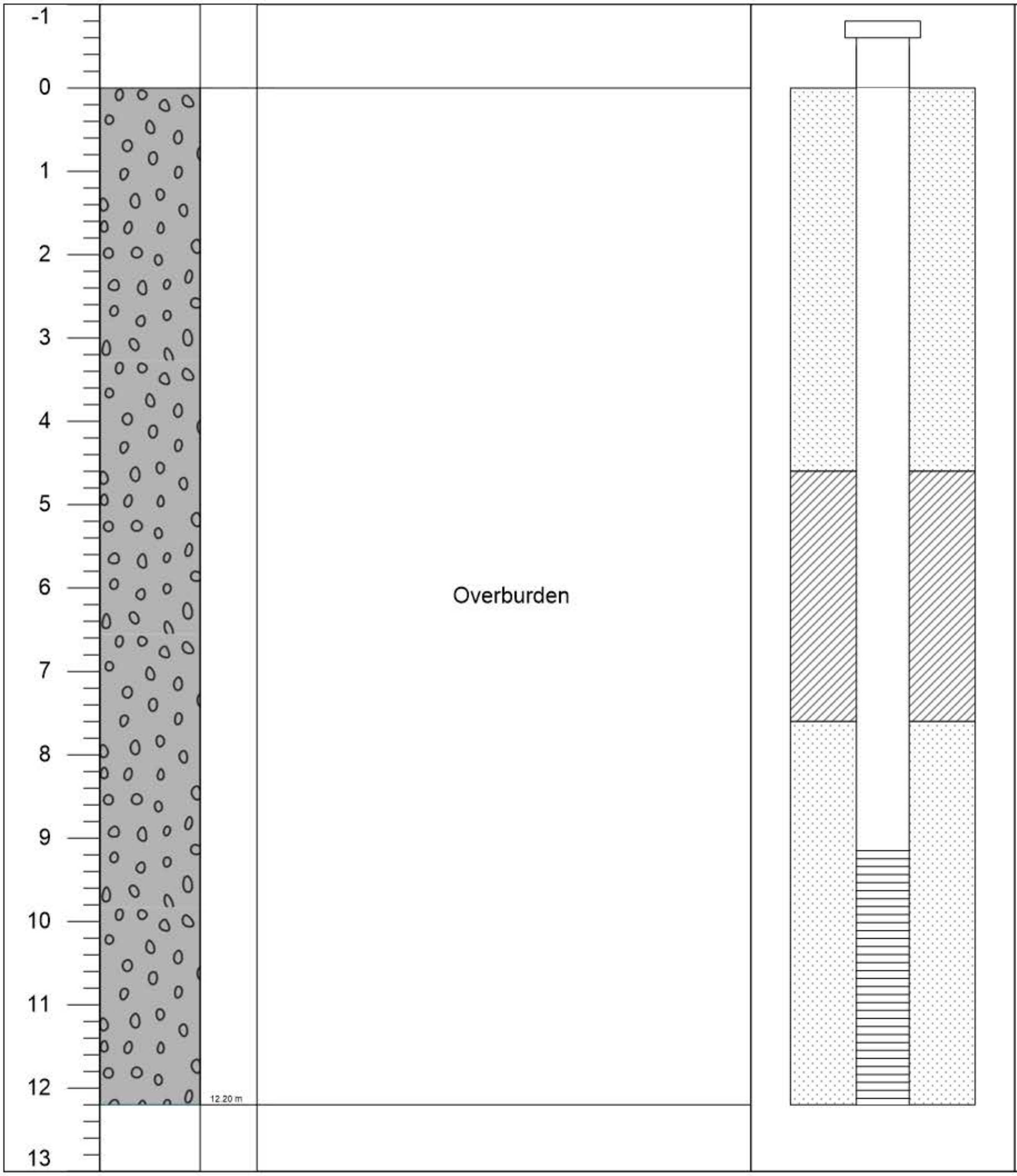
Drawn by: NB

Project Details		**Well / Borehole ID**	**Location**	
Project Number:	2019-8509.000	MW-7	Northing (m):	Survey Method: N/A
Client:	City of Yellowknife		Easting (m):	Zone:
Location:	Yellowknife, NWT		Elevation (m): 197.91	

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Casing Stick-Up (Unknown)

Silica Sand (0 - 4.6 m bgs)

50 mm PVC Casing (0 - 4.15 m bgs)

Bentonite (4.6 - 7.6 m bgs)

Silica Sand Filter (7.60 - 12.20 m bgs)

50 mm PVC Screen (4.15 - 12.0 m bgs)

Associated Environmental

Lithology Legend

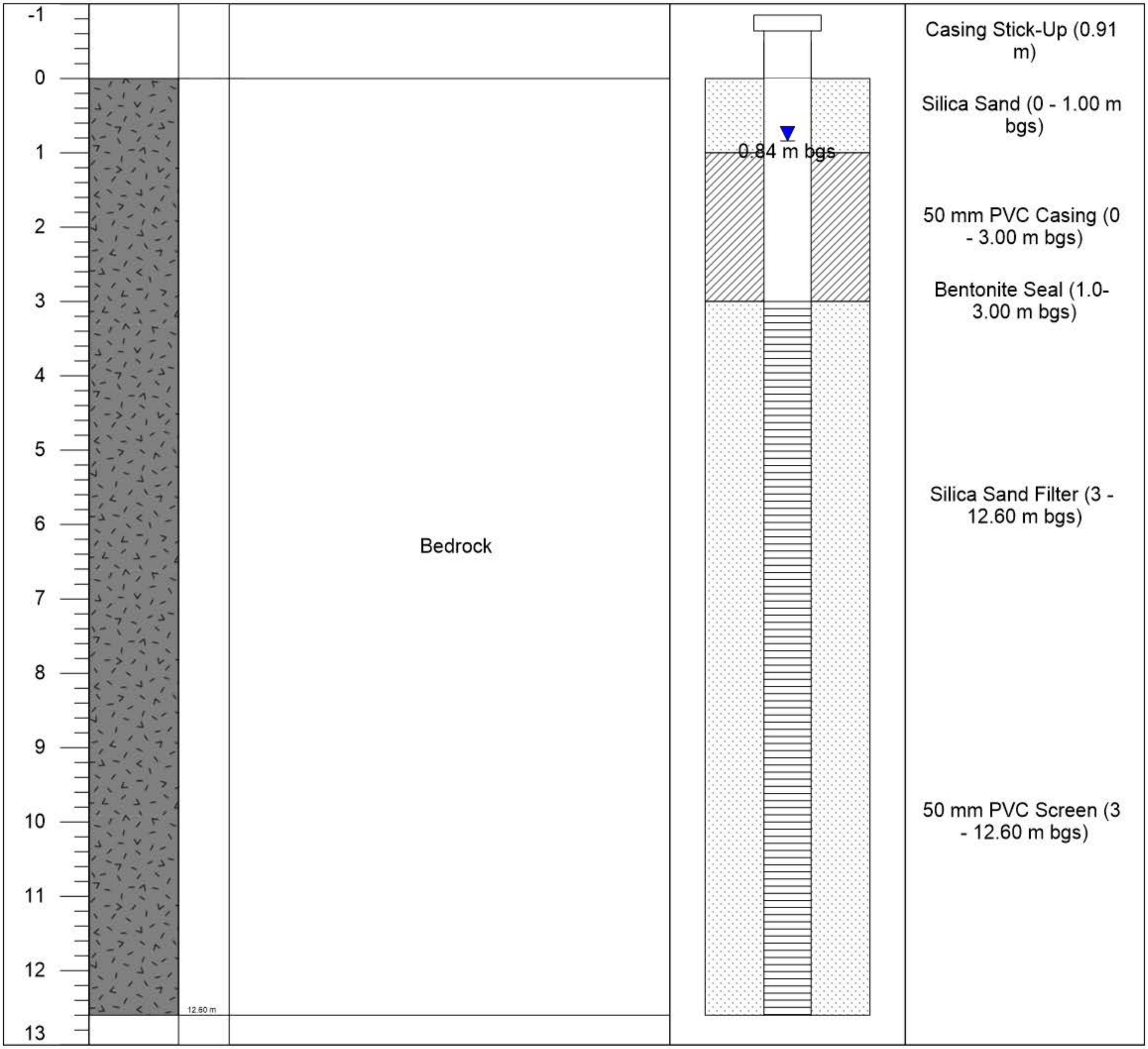
0	Overburden

Contractor:	N/A
Operator:	N/A
Date of construction:	
Drilling method:	N/A

Drawn by: NB

Project Details		Well / Borehole ID	Location		Survey Method:
Project Number:	2019-8509.000	MW-8	Northing (m):	6929623	N/A
Client:	City of Yellowknife		Easting (m):	635057	Zone:
Location:	Yellowknife, NWT		Elevation (m):	100.27	

Subsurface Profile			Well Completion	
Depth (m)	Graphic Log	Description	Well Construction	Details



Casing Stick-Up (0.91 m)

Silica Sand (0 - 1.00 m bgs)

50 mm PVC Casing (0 - 3.00 m bgs)

Bentonite Seal (1.0-3.00 m bgs)

Silica Sand Filter (3 - 12.60 m bgs)

50 mm PVC Screen (3 - 12.60 m bgs)

Lithology Legend

▨ Bedrock

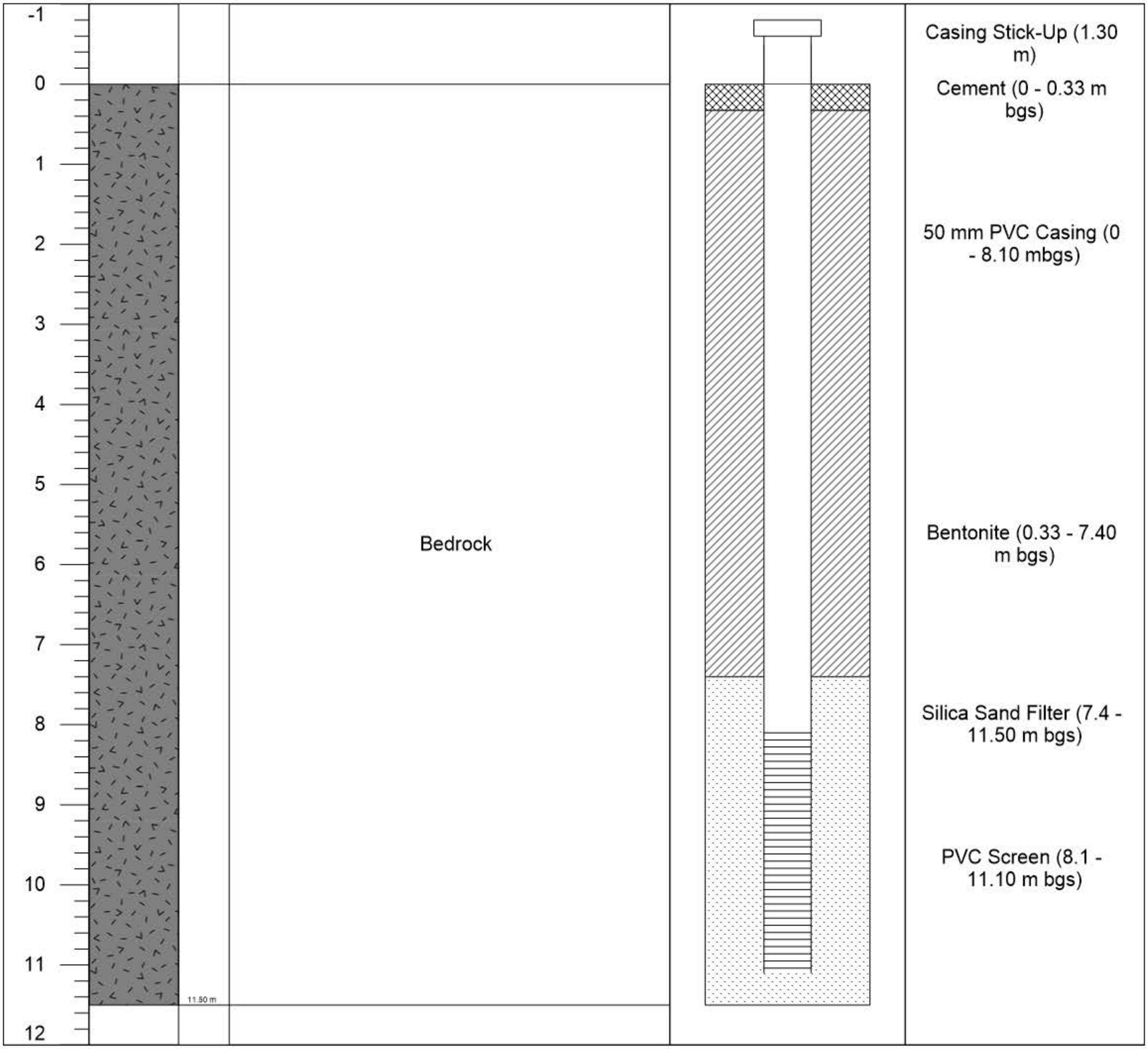
Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

Page 1 of 1

Project Details	**Well / Borehole ID**	**Location**
Project Number: 2019-8509.000 Client: City of Yellowknife Location: Yellowknife, NWT	MW-10	Northing (m): 6930147 Easting (m): 635665 Elevation (m): 187.89 Survey Method: N/A Zone:

Subsurface Profile			Well Completion	
Depth (m)	Graphic Log	Description	Well Construction	Details



Casing Stick-Up (1.30 m)

Cement (0 - 0.33 m bgs)

50 mm PVC Casing (0 - 8.10 mbgs)

Bentonite (0.33 - 7.40 m bgs)

Silica Sand Filter (7.4 - 11.50 m bgs)

PVC Screen (8.1 - 11.10 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

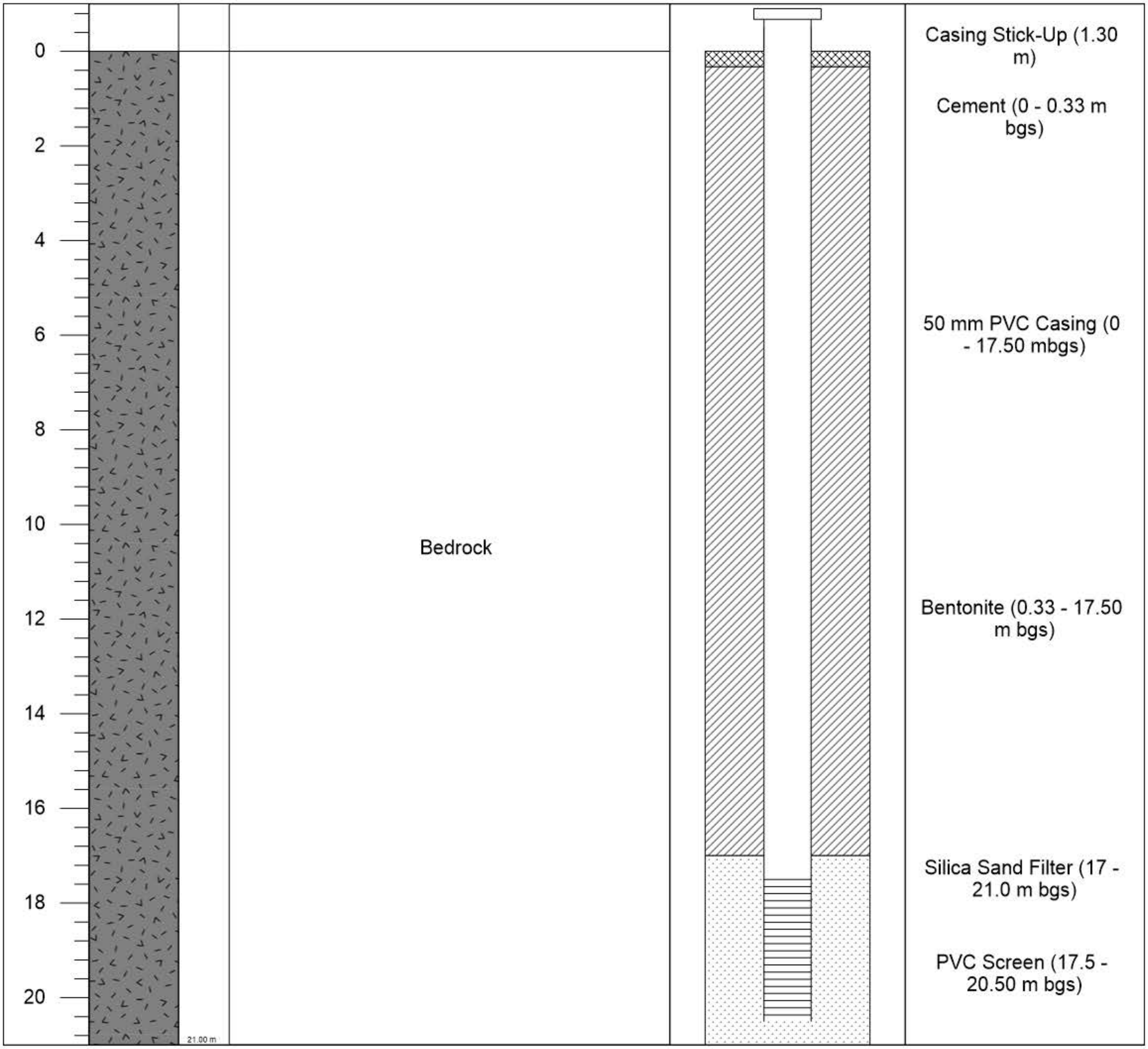
Contractor:	N/A
Operator:	N/A
Date of construction:	
Drilling method:	N/A

Drawn by: NB

Page 1 of 1

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	MW-11	Northing (m):	6929893	Survey Method: N/A Zone:
Client:	City of Yellowknife		Easting (m):	635602	
Location:	Yellowknife, NWT		Elevation (m):	194.17	

Subsurface Profile			Well Completion	
Depth (m)	Graphic Log	Description	Well Construction	Details



Bedrock

Casing Stick-Up (1.30 m)

Cement (0 - 0.33 m bgs)

50 mm PVC Casing (0 - 17.50 mbgs)

Bentonite (0.33 - 17.50 m bgs)

Silica Sand Filter (17 - 21.0 m bgs)

PVC Screen (17.5 - 20.50 m bgs)

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

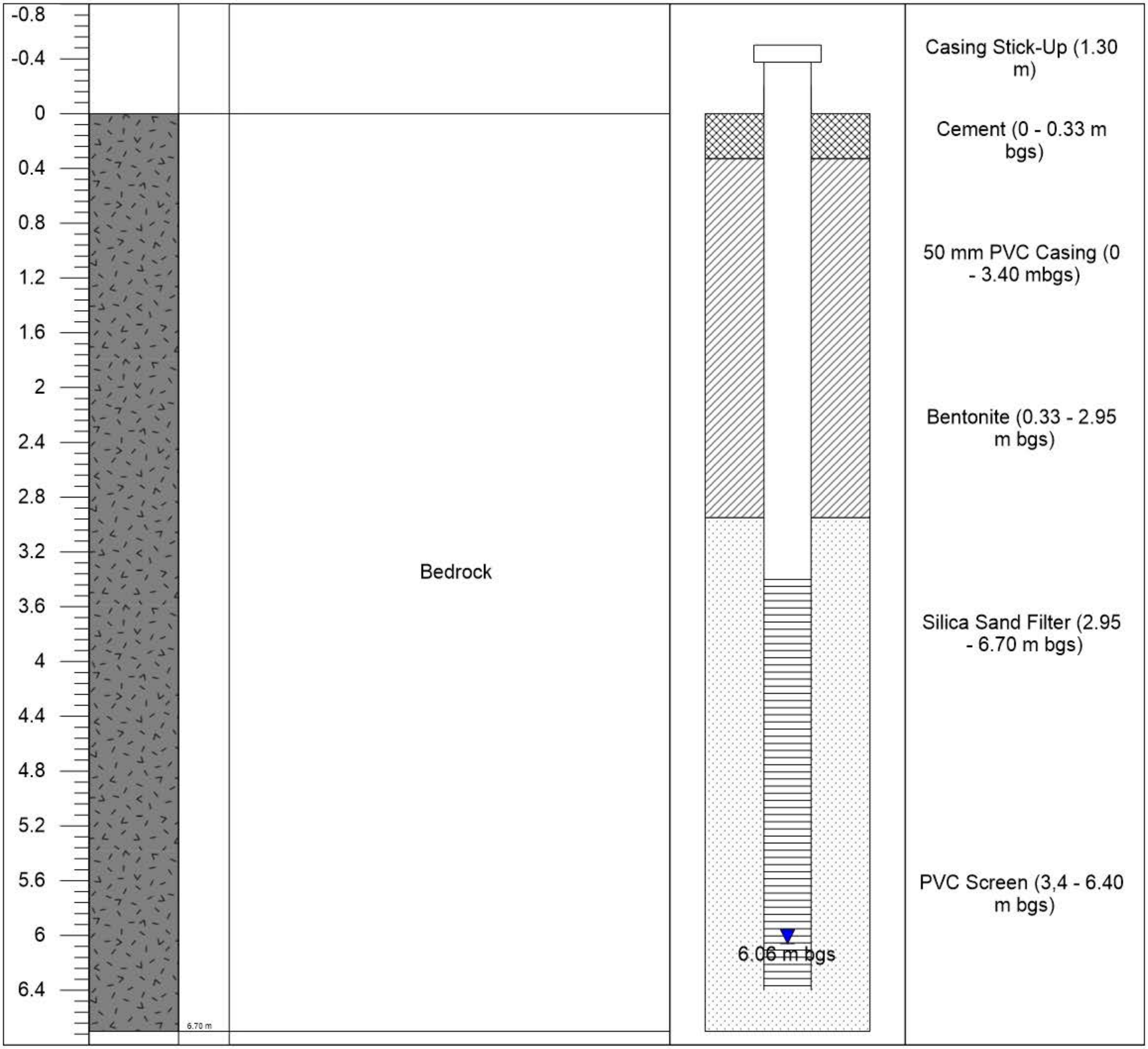
Page 1 of 1

Project Details		**Well / Borehole ID**	**Location**		
Project Number:	2019-8509.000	MW-12	Northing (m):	6929528	Survey Method: N/A Zone:
Client:	City of Yellowknife		Easting (m):	635417	
Location:	Yellowknife, NWT		Elevation (m):	194.33	

Subsurface Profile

Well Completion

Depth (m)	Graphic Log	Description	Well Construction	Details



Associated Environmental

Lithology Legend

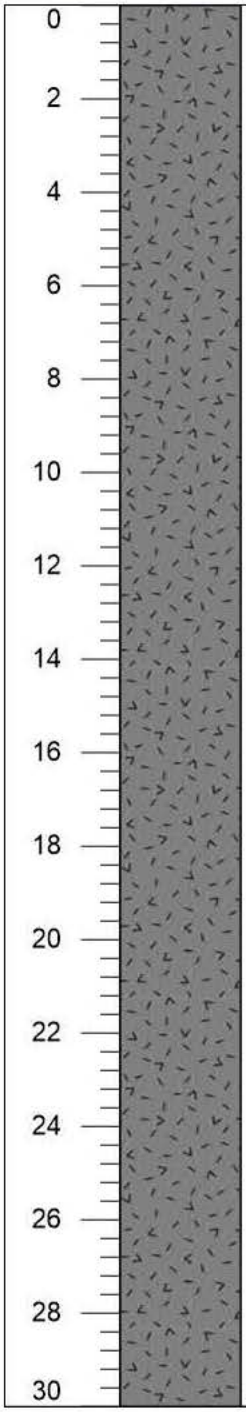
▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

Project Details		Well / Borehole ID	Location		
Project Number:	2019-8509.000	BH-9A	Northing (m):	6930197	Survey Method: N/A
Client:	City of Yellowknife		Easting (m):	634005	Zone:
Location:	Yellowknife, NWT		Elevation (m):	204.29	

Subsurface Profile			Well Completion	
Depth (m)	Graphic Log	Description	Well Construction	Details



30.00 m

Bedrock

Associated Environmental

Lithology Legend

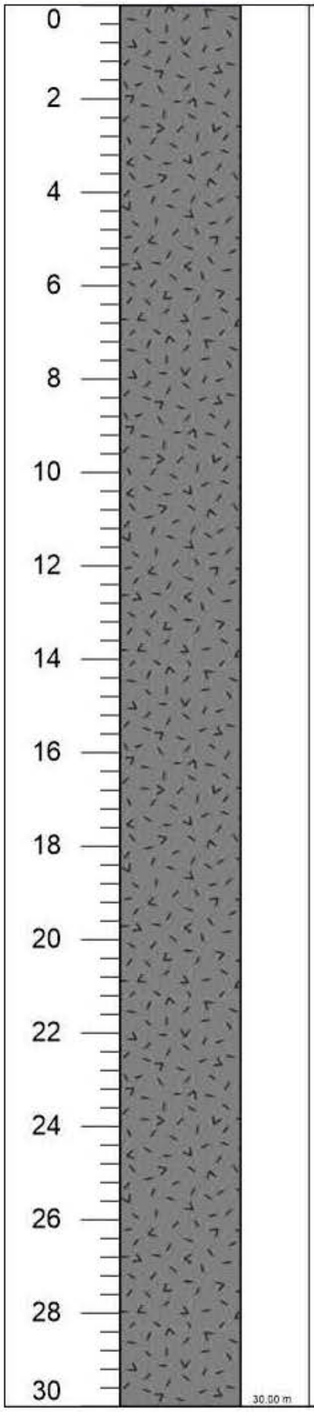
▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB

Project Details	Well / Borehole ID	Location
Project Number: 2019-8509.000 Client: City of Yellowknife Location: Yellowknife, NWT	BH-9B	Northing (m): 6930204 Easting (m): 634012 Elevation (m): 204.29 Survey Method: N/A Zone:

Subsurface Profile			Well Completion	
Depth (m)	Graphic Log	Description	Well Construction	Details



Bedrock

Associated Environmental

Lithology Legend

▨ Bedrock

Contractor: N/A
Operator: N/A
Date of construction:
Drilling method: N/A

Drawn by: NB