New Water Treatment Facilities & Associated Infrastructure at Arctic Bay

Business Case Report

Government of Nunavut

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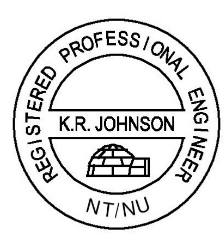

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List of Terms

The following terms are used as acronyms or short forms:

Short Form or Acronym	Reference Document or Term
AO	Aesthetic Objective
CSA	Canadian Standards Association
CT	(Chlorine) Contact Time
DAF	Dissolved Air Flotation
DBPs	Disinfection By-Products
GCDWQ	Guidelines for Canadian Drinking Water Quality
GN-CGS	Government of Nunavut – Community and Government Services
Lpcd	Litres per capita per day
MAC	Maximum Allowable Concentration
NWT - MACA	Northwest Territories - Municipal and Community Affairs
MCL	Maximum Concentration Limit
NWT	Northwest Territories
O&M	Operations and Maintenance
RWU	Residential Water Use
SWTT	Standard Water Treatment Train
TDS	Total Dissolved Solids
THMs	Trihalomethanes
TTHMs	Total Trihalomethanes
TOC	Total Organic Carbon
TWUC	Total Water Usage per Capita
UF	Ultrafiltration
USEPA	United States Environmental Protection Agency
WTP	Water Treatment Plant

Executive Summary

The main objective of this Business Case Report is to summarize the findings and work undertaken as part of the Business Case Study for High Arctic Water Treatment Facilities and Associated Infrastructure at Arctic Bay. The scope of this project included the following:

- Scouting study using satellite images to identify potential sites for the new Water Treatment Plant (WTP)
- Site visit to Arctic Bay to confirm the scouting study and select potential sites for the new WTP based upon site inspections and discussions with the Hamlet's community council and the GN-CGS
- Technical investigations (Hydrological/Water Balance study, Climate Risk Screening, Geotechnical investigations, Environment Site Assessment, Land Topographic and Bathymetric Survey, and Wind Blowing and Snow Drifting study)
- Review of existing conditions, water quality information, water quality requirements, hydrological information and proposed water treatment process trains to develop service conditions and water treatment plant components/requirements
- Development of schematic designs for the preferred site locations
- Preparation of cost estimates including capital, operations and maintenance (O&M) and life-cycle costs for the preferred sites
- Options Evaluation for the preferred sites
- Site recommendation for the new WTP at Arctic Bay

1. An initial desktop scouting study to identify potential sites was completed. Eight (8) potential sites for the new WTP were identified. From these eight sites, Site 5, Site 6 and Site 7 were eliminated from further consideration due to land use conflicts, significant freezing risks due to length of raw water transmission line, excessive slopes on the site and constructability considerations.

2. Following site visits by representatives of EXP and GN-CGS and discussions with the Hamlet's community council, Site 2 and Site 8 were also eliminated from further consideration due to constructability concerns, contamination concerns and land-use conflicts.

3. Following the screening process, the three preferred sites for the new WTP were Site 1, Site 3 and Site 4.
    - Site 1 – Site 1 is located adjacent to the existing WTP and the existing lake reservoir (Marcil Lake).
    - Site 3 – Site 3 is located next to the new Power Plant which is currently under construction by QEC. It is located approximately 6.6 km north of Marcil Lake reservoir and approximately 1.3 km south of the community.
    - Site 4 – Site 4 is located adjacent to the community on the road to the existing Water Treatment Plant and is approximately 7.9 km (along the existing access road) from Lake Marcil reservoir.

4. Based on the hydrology analysis and bathymetric survey, the existing water source (Marcil Lake watershed) and reservoir (Marcil Lake) is adequate to meet the needs of the community for the 20-year design horizon without supplementary pumping or capacity upgrades to the reservoir. The size of the Marcil Lake watershed is extremely large at 12,660 Ha and is expected to provide significant volumes of water to recharge Marcil Lake. Marcil Lake has substantial reserve storage volume

that can easily accommodate the community's water supply needs. The deepest part of Marcil Lake is 35 m and has an estimated useable operational storage of approximately 14,500,000 m^3.

   i. Results of the Climate Risk / Saline Intrusion potential screening for Marcil Lake suggest that for the "normal" climate change projection scenarios, that site conditions provide for adequate buffer with low risk of saltwater intrusion up until at least 2100. However, for a scenario of more extreme climate change there is significant potential for climate change to impact the lake by overtopping and/ or breaching of the lower lying lake outfall area located along the northwest portion of the ridge that separates Marcil Lake from Arctic Bay.

5. The proposed WTP will continue using Marcil Lake as the primary water source for the community of Arctic Bay – no additional upgrades to the existing road infrastructure or capacity upgrades to the reservoir are anticipated.

6. The proposed WTP shall be provided in a modular building approximately 26 m x 13 m. The treatment train consists of dual raw water intakes, basket inlet strainers, chemical injection points for coagulant and pH adjustment (provisional as required), contact tank, membrane filtration train (UF) with additional spare trains, duty and standby UV reactors, hypochlorite (chlorine) injection, and storage tanks for treated water and process wastewater.

7. The scope of the new WTP includes site development, new WTP (building, process, electrical, mechanical), dual raw water intakes, storage tanks (treated, wastewater) and transmission/recirculation line from pump house to WTP (for Site 3 and Site 4 only).

8. Capital cost estimates (Class D) were prepared for all three sites. The capital costs for Site 3 and Site 4 are significantly higher than Site 1 due to the additional transmission pipeline and pump house building. The estimated capital costs for the three sites are:
   - Site 1 capital costs = $13,147,000
     - A provision of $200,000 is be included for the in-town firefighting storage tank (75m^3)
     - Thus, the Site 1 total capital costs = $13,347,000
   - Site 3 capital costs = $28,237,000
   - Site 4 capital costs = $30,943,000

9. Operations & Maintenance (O&M) costs were prepared for all three sites. The O&M costs for Site 3 and Site 4 are significantly higher than Site 1 due to the additional efforts to operate and maintain the transmission pipeline and pump house building. The estimated O&M costs for the three sites are:
   - Site 1 annual O&M costs = $1,899,304/year
   - Site 3 annual O&M costs = $2,031,984/year
   - Site 4 annual O&M costs = $2,043,809/year

10. The total 30-year lifecycle costs for major repair and rehabilitation works are estimated at:
    - Site 1 – $6,236,701
      - Annual average = $207,890/year
    - Site 3 – $7,877,107

    - Annual average = $262,570/year
- Site 4 –$8,282,518
    - Annual average = $276,084/year

11. An Options Evaluation was completed for the three preferred sites. The criteria included a comparison based upon: capital costs; O&M costs; ease of constructability; community acceptance and aesthetic impact; service life/sustainability; environmental risk; performance risk; space for future expansion; operations and maintenance; public safety; and fire protection considerations. The evaluation applied weighting to specific criteria items. The sites were then scored according to the criteria.

12. The results from the Options Evaluation:
    - Site 1 – Total score = 656
    - Site 2 – Total score = 425
    - Site 3 – Total score = 386

13. Based upon the Options Evaluation, it is recommended that Site 1 be used as the site for the new WTP at Arctic Bay and advanced toward detailed design and implementation. Out of the three potential locations, a new WTP at Site 1 would provide the most reliable water supply system, require the least amount of effort to operate and maintain as it does not include a transmission pipeline or additional pump house building, and would require the least amount of effort to develop the site as the location is relatively flat.

14. As per discussions regarding the Hamlet's Council Meeting and Decision regarding the WTP location (August 17, 2022), the Hamlet and Fire Marshall support the new WTP at Site 1 with the provision that an independent storage tank (75 m^3) used for fire-fighting flows be located within the community limits.
    i. Additional site visits, geotechnical investigations, and discussions with community officials (Council and Fire Marshall) are required to finalize site location for the firefighting storage.
    ii. The estimated capital cost for this additional 75m^3 tank is approximately $200,000.

1 Introduction

1.1 Overview

EXP was retained by the Government of Nunavut – Department of Community and Government Services (GN – CGS) to complete a Business Case for a proposed New Water Treatment Plant (WTP) to meet the operational, water quality and regulatory needs of the community at Arctic Bay for the next twenty years.

This Business Case Report summarizes the development of the entire scope for the proposed WTP and includes discussion on the following tasks that were completed as part of this assignment:

- Initial Site Selection
    - Desktop/Scouting study and a field visit was completed to determine potential sites for the new WTP. This task screened three preferred sites to conduct additional field investigations and subsequent evaluation.
- Hydrological and Water Balance Study
    - Development of raw water extraction and storage requirements and potential upgrades over the 20-year design horizon to confirm a suitable water source for the community
- Geotechnical investigations including field geotechnical studies and development of foundation/geotechnical requirements
- Phase 1 Environmental Site Assessments (ESAs)
- Topographic and Bathymetry Survey
- Wind Blowing and Snow Drifting Study
- Review of existing water quality information, water quality requirements and proposed water treatment process trains
    - Development of service conditions including anticipated population growth, demands and regulatory requirements over a 20-year design horizon
- Technology Assessment was completed to review the previous GN standardization reports to determine if any changes were required to meet regulatory and community needs from an operational and water quality perspective.
    - Development of water treatment plant components including treatment process requirements and recommendations, water storage requirements, fire flow requirements, power considerations, building components, geotechnical considerations, etc.
- Development of schematic designs of the preferred sites for the new WTP
- Preparation of Class D cost estimates including capital, operations and maintenance (O&M) and life-cycle costs for the preferred sites
- Evaluation of alternatives and final site recommendation for the new WTP

1.2 Objectives

The Hamlet of Arctic Bay and the Department of Community and Government Services wish to enhance the quality of life of members of the community through the provision of a water supply that meets the requirements of the Health Act and Guidelines for Canadian Drinking Water Quality (GCDWQ). It is also the intent of the Hamlet and Department to provide water supply infrastructure that optimizes delivery system operation and enhances the ability of the community to meet firefighting needs. The selected solution should be economically efficient, both in terms of initial capital expenditure and life cycle cost. It is desirable that the selected solution benefits the community beyond an improvement to the water supply.

1.3 Background Document Review

We have referenced the following background documentation and research papers:

- CAN/CSA-S136-16, North American Specification for the Design of Cold Formed Steel Structural Members
- Canadian Electrical Code, 2021
- Cold Regions Utilities Monograph, 1996
- CSA-A23.1-14/A23.2-14, Concrete Material and Methods of Concrete Construction / Methods of Test for Concrete
- CSA-A23.3-14, Design of Concrete Structures
- CSA-S16-14, Limit States Design of Steel Structures
- CSA Standards – sewage, drainage
- Design Standard for Water Treatment Plants (SWTT) Phase 1 to 3 Reports. Dillon, 2020
- Feasibility Study (Geotechnical Report) Water Treatment Plant, Arctic Bay, Nunavut (EXP, 2022)
- Fire Protection in the Northwest Territories (Heinke & Marianayagam, 1993)
- Good Building Practice Guidelines, Gov. of Nunavut, 2nd Edition, 2005
- Good Engineering Practice for Northern Water and Sewer Systems (2nd Edition), 2017
- Guidelines for Canadian Drinking Water Quality (GCDWQ), September 2020
- Hydrological and Water Balance Study Report – Arctic Bay, High Arctic Water Supply & Treatment (EXP, March 18, 2022)
- Installation Code for Oil Burning Equipment – CSA 139 Series
- Nunavut Municipal Infrastructure Capital Standards and Criteria, 2012
- Nunavut Standard Water Treatment Train (SWTT) Project Phase 5: SWTT Schematic Design, April 2021
- Nunavut Standard Water Treatment Train (SWTT) Project Phase 6: SWTT Schematic Design, October 2020
- National Building Code of Canada 2015 edition, errata, revisions and supplements
- National Fire Code of Canada, 2015
- National Plumbing Code of Canada, 2015
- Phase I & II Environmental Site Assessment, Proposed Site 1, Arctic Bay, Nunavut (EXP, 2021)
- Phase I & II Environmental Site Assessment, Proposed Site 3, Arctic Bay, Nunavut (EXP, 2021)
- Phase I & II Environmental Site Assessment, Proposed Site 4, Arctic Bay, Nunavut (EXP, 2021)
- Technology Assessment and Service Conditions Report, Arctic Bay (EXP, March 18, 2022)
- Ventilation for Acceptable Indoor Air Quality – ASHRAE 62.1 – 2016
- Water Treatment Plant Design Nunavut Guideline Document (SWTT) Phase 4, August 2020.

2 Background

2.1 Community Information and Existing Conditions

The Hamlet of Arctic Bay, Nunavut is located at 73°02’ N latitude and 85°10’ W longitude on the northern section of Baffin Island. An aerial view of the community is shown in Figure 2-1 below.

The water supply for the Hamlet of Arctic Bay is Marcil Creek discharging into Marcil Lake, which is approximately 9 km from the community. This freshwater lake sits at sea level and is separated from the ocean by a small ridge – along the south edge of the lake, the width of ridge is approximately 150 m to 350 m. The lake water level is at approximately the same elevation as sea level based on available topographic information. The existing truck fill station is located on the lake. A fleet of water delivery vehicles (two duty, one backup) brings water from the lake and distributes it to Arctic Bay residents. Historically, there have been no notable concerns regarding the quality and quantity of the source water. Chlorination is the only method being used for treatment/disinfection. No reliable secondary sources of water close to the community have been identified – the GN has noted that Marcil Lake will continue to supply drinking water to Arctic Bay into the distant future.

The current WTP infrastructure does not have the capacity to meet the Guidelines for Canadian Drinking Water Quality (GCDWQ) requirements. The existing truckfill station provides water delivery refill at a rate that is slower than required and a lack of treated water storage does not provide a sufficient chlorine contact time prior to truck loading.

Figure 2-1: Arctic Bay Water Source (Marcil Lake)

2.2 Findings from Hydrology and Water Balance Report

Based on the Hydrological and Water Balance Study (EXP, 2022) and bathymetry survey (EXP, 2021), the water source of Marcil Lake will be adequate to meet the needs of the community for the 20-year design horizon without supplementary pumping or capacity upgrades to the reservoir.

The size of the Marcil Lake watershed is extremely large at 12,660 Ha and is expected to provide significant volumes of water to recharge Marcil Lake under most climate scenarios. Under all but one scenario (worst-case), any net-positive annual runoff will recharge Marcil Lake and provide a sufficient water supply for the community's needs.

The existing reservoir (Marcil Lake) is large and has substantial reserve storage volume. The deepest part of Marcil Lake is 35 m and has an estimated useable operational storage of approximately 14,500,000 m^3 which can be used to sustain the community over periods where annual net recharge is negative (i.e. drought conditions). The estimated community water demand in 2043 for Arctic Bay is 51,852 m^3/year. Provided that the conservative estimate for available operational storage is 14,517,590 m^3, this would equate to approximately 280 years of available storage from Marcil Lake based on annual water use (assuming no recharge of the lake). Bathymetry survey information has been provided in Appendix G.

It is recommended to continue using Marcil Lake as the primary water source for the community of Arctic Bay – no additional upgrades to the existing road infrastructure or capacity upgrades to the reservoir are anticipated for this configuration.

One potential concern that has been identified is potential saline intrusion due to the proximity of the water source (Marcil Lake) to the ocean. The freshwater lake sits near sea level and is separated from the ocean by a small ridge – along the south edge of the lake, the width of the ridge is approximately 150 m to 350 m. The lake water level is at approximately the same elevation as sea level based on available topographic information. To date there have been no reports of salinity issues or intrusion with Marcil Lake, but this could be a potential issue with sea levels and climate change impacts anticipated to rise over the coming decades.

To assess this risk, a supplementary Climate Risk Screening assessment was completed by EXP. The results from this report are described in the following section.

Figure 2-2: Arctic Bay Watershed for Marcil Lake

2.3 Findings from Climate Risk Screening Report – Arctic Bay Community Water Source

As noted above, to assess the potential for saltwater impacts on the Marcil Lake, a supplementary Climate Risk Screening assessment was completed by EXP. The full report (dated October 31, 2022) is provided in Appendix I. Main findings from the report are provided below.

Marcil Lake is the community's only available water supply and is located near the ocean. The lake is interpreted to be protected from saltwater intrusion by a natural perimeter ridge of variable elevation. The main climate change risks interpreted included:

- Direct saltwater impacts by lateral migration of seawater into the lake;
- Sea level rise/ storm surge overtopping or breaching the existing barrier ridge; and
- Permafrost thaw leading to ridge erosion or release of relic saline porewater from watershed sediments of marine depositional origin.

Results of the screening suggest that for the "normal" (i.e. median) projections of most climate change scenarios (Shared Socioeconomic Pathways, SSPs) presented in the recent United Nations Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (IIPCC AR6, 2021), that site conditions provide for adequate buffer with low risk of saltwater intrusion up until at least 2100. However, for a scenario of more extreme climate change (e.g. SSP5-8.5 low confidence scenario) there is significant potential for climate change to impact the lake by overtopping and/ or breaching of the lower lying lake outfall area located along the northwest portion of the ridge that separates Marcil Lake from Arctic Bay

Figure 2-3: Northwest Portion of Ridge Separating Marcil Lake from Arctic Bay

Regarding the five (5) main illustrative SSPs adopted by IPCC AR6 to contrast future climate scenarios it is understood that currently the most likely climate scenario that will be realized outward to 2100 is SSP2-4.5. Under this scenario the median sea level rise is projected to be 0.06 in 2050 and 0.13 m by 2100; the upper 83rd percentile of simulations within which there is a 66 % probability of the actual outcome occurring is 0.33 m by 2050 and 0.74 m by 2100. This magnitude of sea level rise is not expected to overtop the interpreted 4.5 m "critical" elevation representative of the lower maximum ridge elevation along Marcil Lake's perimeter. SSP2-4.5 assumed extreme sea level (ESL) events associated with high tide and storm surge are expected to increase the potential for impact with the possibility of marginal exceedances by 2050 and increasing through to 2100 and beyond. However, for the range of SSP2-4.5 scenarios (and most other scenarios) considered it is anticipated that the risk of overtopping could be mitigated through construction of coastal defenses such as an earthen berm constructed from local aggregate sources.

In addition to direct impact from lateral intrusion of seawater, permafrost thaw may increase this risk in the event of erosion of the barrier ridge particularly where present as glacial veneer deposits in low lying sections (e.g. lake outflow area). Permafrost thaw also has the potential to impact lake water quality by melting watershed sediments releasing previously frozen saline porewater and/or possible other naturally occurring parameters of concern. With increased warming in the region impacts due to permafrost could become the principal concern regarding potential for saline or other impacts to the overall freshwater quality of the Marcil Lake raw water source.

Recommendations to facilitate planning and address suspected or actual potential water quality impacts include:

- Enhanced site assessment
- Development and implementation of a regular and consistent raw water monitoring program
- Establishment of a community based Arctic Bay Climate Change Committee is also recommended to support site assessment initiatives that can be considered (e.g. geotechnical and geomorphologic characterization of the Marcil Lake barrier shoreline; tide, storm surge and sea level rise monitoring/ characterization; permafrost and active layer monitoring; and raw water and watershed inflow monitoring).This information could be reviewed by the Arctic Bay Climate Change Committee supported by outside technical specialists and used to guide adaptation and possible mitigation measures that may be warranted should future climate change conditions suggest the lake water quality will be impacted.

3 Service Conditions for Water Treatment Processes

Service conditions and water treatment processes were evaluated and discussed in the "Technology Assessment and Service Conditions Report" (EXP, 2022) – findings and recommendations from that report have been summarized and developed in the following section.

3.1 Design Horizon

The design has been advanced based upon the assumption of a 20-year design horizon (end of design period in 2043).

3.2 Populations and Water Demands

Population projections have been provided using information prepared by the Nunavut Bureau of Statistics (2014). Non-residential water usage by a community tends to increase with increases in the population. To determine the theoretical total community water usage, the Residential Water Usage (RWU) is adjusted based on population to provide a Total Water Usage per Capita (TWUC). The Total Water Usage Per Capita, including residential and non-residential activities is estimated based on the equations in Table 3-1.

Table 3-1: Theoretical Total Community Water Usage (TWUC) Formula

Community Population	Total Water Use Per Capita (TWUC)
0 – 2,000	RWU x (1.0 + 0.00023 x Population)
2,000 – 10,000	RWU x [-1.0 + {0.323 x Ln(Population)}]

Annual historical water use records were reviewed between 2008 to 2020 to determine the actual average recorded daily demands. For Arctic Bay, average recorded daily demand between 2008-2020 was 76 lpcd. This recorded demand of 76 lpcd is low considering that typically, 90 lpcd is cited as the minimum residential water use for trucked services as per the Good Engineering Practices guidelines (2017).

Water use in northern contexts is sensitive to perceptions and reliability of water treatment and delivery. As the current water treatment plant has had challenges with delivery delays and capacity issues, it is likely that residents have moderated their water use. With a new, more efficient system, it is expected that community water use will rise, and future projections have taken this into consideration.

The 2020 Nunavut Draft Guideline Document "Water Treatment Plant Design" states a minimum per capita average day water consumption rate of 120 litres per capita per day (lpcd) for water treatment plant design for truck fill communities. Table 3-2 compares theoretical TWUC for each community with actual historical water use. From this comparison Table 3-2 also presents the proposed design demands.

Table 3-2: Projected Population and Water Demands

Parameter	Arctic Bay
Population (2023) *	956
Theoretical TWUC (2023)	110 lpcd
Population (2043)	1,184
Theoretical TWUC (2043)	115 lpcd
Actual Water Use (2008-2020)	76 lpcd
Design Consumption Rate	**120 lpcd**
Annual Design Consumption Rate (2043)	**51,859 m^3/year**

* *Population projections and projected growth rates based on data and projections from the Nunavut Bureau of Statistics (2014 and 2021), with regression equations extended from 2035 to 2043 as required*

3.3 Peaking Factors

Peak day demands are calculated using the proposed design daily water demand value of 120 lpcd multiplied by a peaking factor.

As discussed in the "Technology Assessment and Service Conditions Report" (EXP, 2022) and the SWTT (Phase 4), a peak day peaking factor of 2.5 is deemed appropriate.

3.4 Firefighting Flows and Associated Requirements

Per the Good Engineering Practice guidelines, to provide sufficient water supply for fire flow, either a minimum storage volume of 60 m^3 can be provided for firefighting purposes, or a raw water bypass of the water treatment plant could be used. Likewise, the NWT Fire Marshal requires a minimum firefighting flow of 1000 L/min for 60 minutes. To reduce onsite storage and heating requirements, water used for firefighting purposes will be provided using a bypass of the water treatment plant, so that trucks can be filled through truck fill arms at a minimum rate of 1000 L/min. This eliminates the need for additional onsite firefighting storage.

As such intake pumps will be adequately sized to deliver the emergency bypass rate of 1000 L/min (or the peak day design flow for the WTP if it exceeds 1000 L/min). Intake pumps should also have the capability to efficiently run at design flows which are less than 1000 L/min through the use of a variable frequency drive (VFD).

Per the SWTT Phase 4 report, raw water bypassing the water treatment plant for firefighting purposes will be chlorinated. This is consistent with Good Engineering Practice guidelines and the approach taken in the NWT, which states that chlorination be maintained in cases where water used for firefighting purposes bypasses the WTP. As such an injection point will be incorporated that will allow chlorination while filling a truck from the bypass.

These approaches are consistent with what is used by the NWT and is deemed appropriate for firefighting flows/storage. Following discussions with the GN, for the purposes of this Business Case report, the proposed water supply for fire flow will be provided through a raw water bypass (1000L/min). However, preference for firefighting requirements should be confirmed with the Fire Marshall prior to detailed design.

3.5 Design Flow

It is proposed that the treatment process will turn on/off once a day to produce the required amount of water, with approx. 12 hours of continuous run time to meet the production needs of the community. This is not the operational method for the potable water storage tank operation, as there will be continuous recirculation of the water, continuous heat addition (as required) and continuous free chlorine measurement. Note that the SWTT (Phase 6) noted that design treated water production must be achieved in no more than 18 hours of service. However, a 12-hr operational time is recommended to reduce treated water storage requirements.

Table 3-3: WTP Design Flows

Parameter	Arctic Bay WTP
WTP Operational hours/day	12
Average Daily Demands (L/day)	142,080
Peak Daily Demand (L/day)	355,200
Design WTP Flow (L/min)	**493**

3.6 Climate

Environment Canada does not provide Canadian Climate Normals (1971-2000) for Arctic Bay. The closest station for which climatic normals data was identified is in Nanisivik, Nunavut which is approximately 20 km to the southeast. In view of the close proximity of the communities, it is felt that the climatic data reported for Nanisivik is applicable for Arctic Bay. The following is climatic information drawn from the Climatic Normals (1971-2000) for Nanisivik.

- Annual daily average temperature -15.2°C
- February daily average temp -30.3°C
- February daily minimum average temp -33.1°C
- Lowest observed temp -53.0°C
- Maximum hourly wind speed 141 km/h

Based upon the above, it is concluded that the freeze protection systems must be capable of protection of the proposed water storage and associated piping to an ambient temperature of -50°C.

4 Water Treatment Train Process

4.1 Water Quality Requirements

Arctic Bay relies on surface water for their drinking water supply, and thus must meet the minimum treatment requirements as described in the GCDWQ. At a minimum, the GCDWQ states that all surface water must be treated using a multi-barrier approach (at least filtration and disinfection) to achieve a minimum of 3-log reduction (99.9%) of Giardia and Cryptosporidium, and 4-log reduction (99.99%) of viruses.

As discussed in the "Technology Assessment and Service Conditions Report" (EXP, 2022), historical water quality sampling records were reviewed, and the following approach has been used for the development of the water treatment train options:

- Required minimum treatment of filtration and disinfection, per GCDWQ
    - The GN (Department of Health) has issued an updated order (GN Turbidity Results Decision Tree – May 13, 2020) noting that filtered water turbidity should consistently be under 1 NTU
- Minimum overall 3-log reduction of Giardia and Cryptosporidium and 4-log reduction of viruses
- Primary disinfection shall include both ultraviolet light (UV) and chlorination
    - Disinfection log removal credits for Giardia and Cryptosporidium shall be achieved by UV
    - Disinfection log removal credits for viruses shall be achieved by chlorination
- **Treatment for reduction of dissolved organics (DBP precursors) is required to meet regulatory and anticipated requirements for DBPs.**

Table 4-1: Arctic Bay Water Treatment Objectives

Key Parameters	Unit	Source Water	Treatment Objectives
Turbidity	NTU	1 - 5	≤ 0.1 (99% of time) <0.3 (maximum)
Protozoa	Log Reduction	-	At least 3-log (up to 5.5 log)
Viruses	Log Reduction	-	At least 4-log
TOC/DOC	mg/L	1-10	<3 mg/L to reduce DBP formation
TDS	mg/L	8-29	<500
pH	pH units	6.7 - 7.3	7 - 10.5
CSMR *	ratio	1.0 - 2.5	< 0.5
Alkalinity ($CaCO_3$) *	mg/L	8 - 10	$CaCO_3$ > 50 mg/L

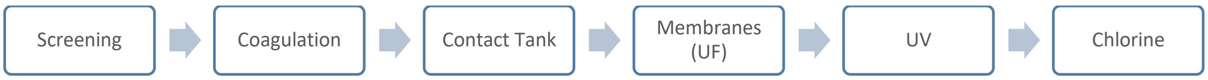
**** corrosion control and fluoridation options to be confirmed with the GN-CGS***

4.2 Proposed Water Treatment Train

4.2.1 Overview

As discussed in the "Technology Assessment and Service Conditions Report" (EXP, 2022), the preferred treatment train (Train #3a) for the new Arctic Bay WTP includes the following process:

- *Train # 3a: Membrane Filtration (UF), with coagulation and contact tank*



The train include chemical injection points for coagulant and pH adjustment (provisional as-required), basket inlet strainer (200-750 microns), contact tank, membrane filtration train (UF) with additional spare trains, duty and standby UV reactors, hypochlorite injection, and sufficient treated water reservoir volume to accommodate the required CT for virus inactivation.

The schematic for the preferred treatment train for Arctic Bay (Train#3a) is shown below.

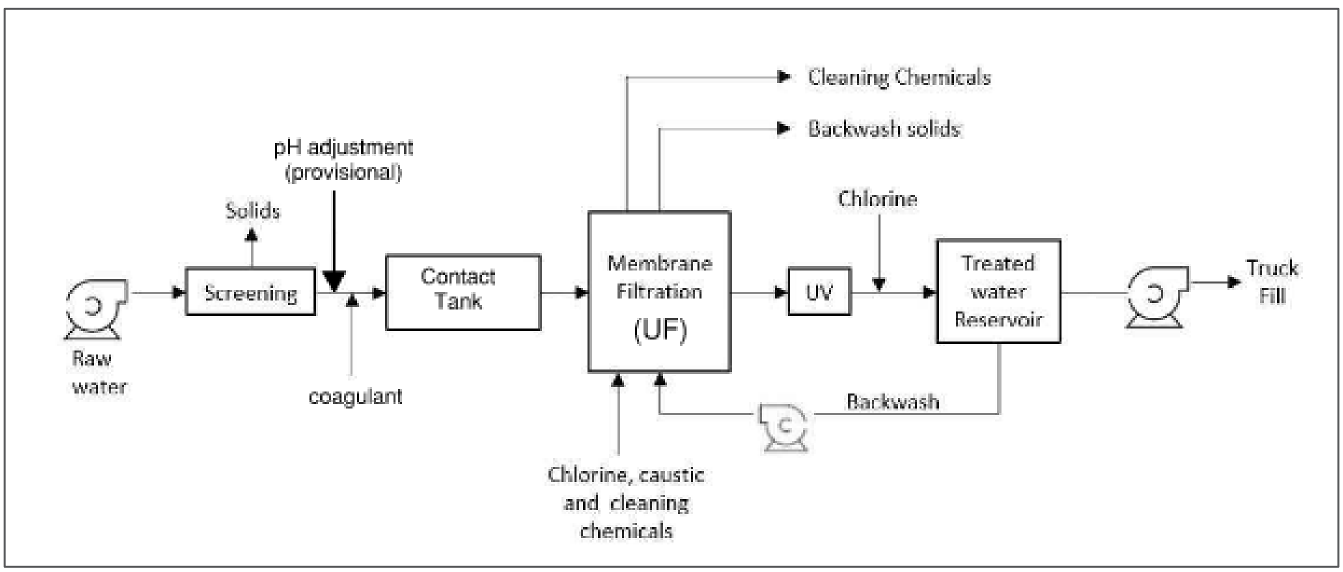


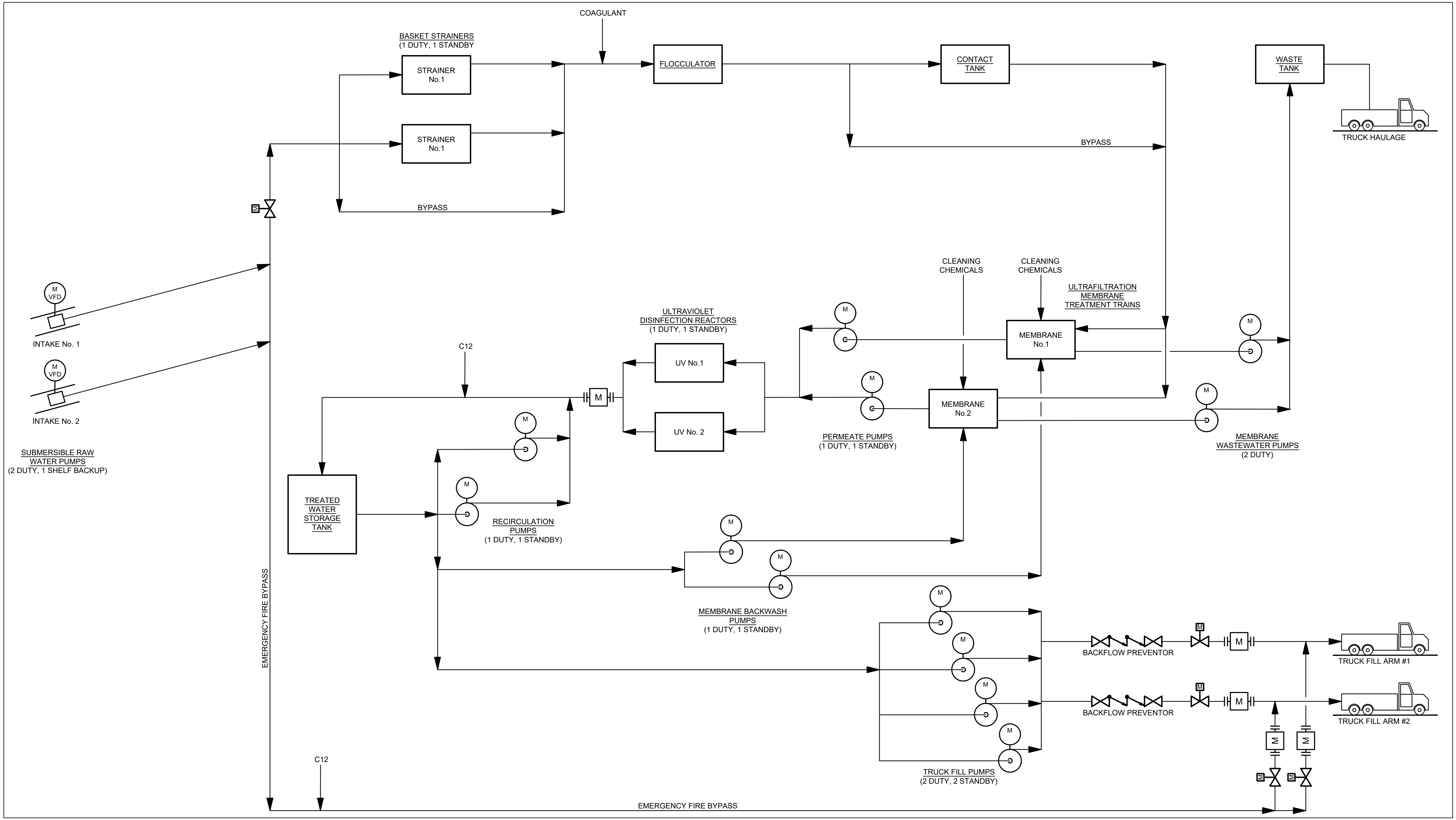
Figure 4-1: Proposed Treatment Train (Arctic Bay)

4.2.2 Process Flow Diagram

A Process Flow Diagram (PFD) for the proposed WTP at Arctic Bay has been provided in Figure 4-2.

4.2.3 Preliminary Sieve

It is proposed that a basket inlet strainer (200-750 microns) be used for debris and as a roughing filter prior to entering the contact tank. The inlet strainers are to be sized at 100% WTP flow. Cleaning of the sieves will be a scheduled operations and maintenance activity.



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DESIGN C.K.	ARCTIC BAY TREATMENT	SCALE N.T.S.	
DRAWN M.M.A.		SKETCH NO	
DATE MAY 2022	PROCESS FLOW DIAGRAM	FIG 4.2	
FILE NO ———			

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4.2.4 Coagulation and Flocculation

Coagulation is required for the removal of dissolved organic content (DOC) as well as improving membrane operation. The train will be designed to allow for sufficient coagulant contact time with the inclusion of a contact tank. An inline static mixer will be used upstream of the contact time to minimize additional mechanical mixing and energy costs. The contact tank design will be dependent on whether a pressurized or submerged ultrafiltration is used. If a pressurized UF unit is preferred, the contact tank will be pressurized from the raw water intake pumps to minimize additional pumping. If a submerged UF unit is preferred, the contact tank can be elevated (and open to atmospheric pressure) to allow gravity-flow into the submerged UF tanks. Chemical metering pump(s), electrical power, inputs to the automation and provision floor space will be provided to accommodate the addition of coagulant and pH adjustment chemicals.

In recent discussions with the NWT, contact tanks were installed in their systems to help deal with seasonal high turbidity (reservoir filling and runoff events) and future changes in raw water quality – it was noted that to date, most plants do not run the contact tanks on a regular basis as their membrane plants have been operating performing well using direct membrane filtration.

4.2.5 Ultrafiltration

Consistent with the SWTT and "Technology Assessment and Service Conditions Report" (EXP, 2022), ultrafiltration will be provided. It is anticipated that this strategy in combination with coagulation will provide effective and reliable turbidity and DOC reductions.

Most membrane systems backwash automatically at the end of each production cycle or based on set runtimes. Backwash pump flow rate is typically 1.1 to 1.5 times the filtrate flow rate but varies for each system. The ability to provide chlorine injection (chemically enhanced backwash) during backwash will be included in the design as a response to biological fouling. The use of chlorine injection will be based upon operational experience. It is expected that CIP maintenance using sodium bisulfite (SBS) and citric acid will take place at least once every 1-3 months. Backwash from the membranes will be sent to a waste holding tank, which will be periodically trucked to a disposal location (lagoon).

The membrane filtration train should be designed to include at least one redundant membrane train (N+1) so that the plant can meet daily production with any one train in backwash or offline. The inclusion of a few additional membrane modules is insignificant to the cost of the overall treatment system. The membrane trains will include differential pressure transmitters and flow meters on the inlet of the filtrate lines. PVDF is the preferred membrane material due to its superior characteristics related to chemical tolerance, fouling resistance and cleanability.

4.2.6 Disinfection – UV and Chlorination

Disinfection will be accomplished in two ways. The primary method will be accomplished using Sodium/Calcium Hypochlorite and the secondary will be achieved through Ultraviolet disinfection. Chlorine will be applied downstream of the UV disinfection. Chlorine solution will also be injected into the recirculation loop for the treated water storage to ensure an appropriate chlorine concentration in the water prior to loading the delivery trucks.

The chlorine/hypochlorite will have two mixing vessels, one for batch mixing and the second to act as a day tank for the blended chemical to be supplied out of. Both small tanks will be equipped with mixers to keep the hypochlorite in suspension. Chlorine contact time (CT) will be provided in the treated water storage tanks. Requirement for disinfection by chlorine is 4-log virus inactivation with a CT value of 12 mg/L· min at 0.5°C and pH 6-9. A free chlorine residual of 1.0 mg/L will be used for CT calculations and assumes that the storage tank will have a baffling factor of 0.1. This yields a CT time of 120 minutes. CT volume will be calculated for peak flows.

The ultraviolet (UV) configuration will be such that 2x100% treatment will be possible during the highest flow and lowest UVT (based on the worst-case raw water ultraviolet transmittance). The 2 units will have the ability to operate in either series or parallel as this is the most robust approach. It is not recommended to cycle them with a PLC as this overcomplicates the system and does not provide a significant savings in energy costs. Additional sampling throughout the year to characterize seasonal raw water UVT trends is recommended.

4.2.7 Fluoridation

GN-CGS has requested that fluoridation of drinking water be considered as a component of the standard water treatment train. Add-ons for fluoridation skids can be added onto the treatment train as required.

The use of fluorosilicic acid which is typically used in large-scale systems is not recommended due to dangerous chemical handling and storage requirements. Small scale systems can use solid sodium fluoride salt, which requires a dissolution/saturation tank and dosing system very similar to a calcium hypochlorite disinfectant system. The saturated sodium fluoride solution strength is approximately 10% of the strength of fluorosilicic acid but is a less severe solution for handling. Sodium fluoride is shipped as a solid, which is beneficial considering shipping and handling concerns to remote communities. Sodium fluoride is not aggressive compared to fluorosilicic acid; however, there are significant health and safety issues related to occupational exposure by inhalation of dusts, ingestion, and contact with skin. Safety shower and eye wash stations must be included wherever sodium fluoride is used. Separation must be made between other chemicals with acidic or oxidizing properties to avoid the generation of hydrogen fluoride gas. For this reason, a separate room within the WTP is likely required to house the fluoride storage and feed equipment.

Based on the information above, a sodium fluoride system will be provided as an optional chemical feed system and developed during the detailed design stage.

4.2.8 Corrosion Control

Add-ons for corrosion control (calcite filter or direct chemical addition) can be added onto the treatment train as required.

As discussed in the "Technology Assessment and Service Conditions Report" (EXP, 2022), the raw water is highly aggressive and has a high corrosion potential. The additional of corrosion inhibitors will not be considered due to intensive O&M requirements (accurate dosing, difficult pH control, safety concerns, special handling and feed equipment). Calcite filters are effective but requires significant footprint requirements.

If corrosion control is deemed necessary by the GN, the recommended approach would be pH and alkalinity adjustments via direct addition of various chemicals. As pH adjustment will likely be required as part of the coagulation process, direct chemical addition is an appropriate option. It is likely more cost-effective than calcite filters but requires more accurate dosing as the raw water is low in alkalinity making pH control more challenging. Provision for additional chemical feed pump(s) and ancillary equipment will be provided.

4.2.9 Automation

The automation strategy is intended to provide a balance between best available technology and the full capability of manual operation without the assistance of automation. Turbidimeters will be provided on the discharge of each membrane module and an online-chlorine analyzer will monitor free chlorine residual in the treated water. The WTP will turn on and off based on water levels in the treated water storage tank. A plant wide PLC system will provide control for the following.

- Filter backwash
- Chlorine addition
- UV disinfection start-up, shut-down and integration with water treatment

Backwash of filters will be initiated by the automation system in response to the following conditions.

- On a timed basis or at the end of each production cycle
- Excessive differential pressure across the filters
- Excessive turbidity following the filters

The capability to log instrumentation will be incorporated into the automation system. The ability to communicate from a remote site, as a tool for operator and trouble-shooting assistance, will be provided. The capability of manual operation of all functions of the treatment plant will be integrated into the design.

The following functions will operate on a stand-alone basis, independent of the PLC controlled automation. These functions do not require integration into the PLC based system to achieve full functionality. The decision to excludes these functions from the automation reflects the general principle of simplification, where possible.

- Truck fill start and stop
- Sump and sewage pump operation
- Raw water refilling operation
- Fuel system operation
- Heating system operation

Instrumentation, alarms, and process controls will be developed over the course of the detailed design.

4.3 Trucking Schedules and Number of Trucks

Current and future trucking demands were estimated in the "Technology Assessment and Service Conditions Report" (EXP, 2022) and are as follows:

Arctic Bay

- Total Cycle Time per truck load (fill, time, travel time, discharge time) = ~135 min/load
- 2020 (current trucking schedule)
  - 2 trucks at 12,000 L capacity (1 or 2 duty, 1 backup)
  - 6 days/week, 8 hours/day
  - Approx. 9 total return trips (loads) per day
- 2043 (future trucking schedule)
  - Based on 6-day delivery – approx. 14 loads/day
    - **4 duty trucks (12,000L capacity/truck) are required to meet demands in 2043**

4.4 Truck Arms and Truckfill Stations

According to the Good Engineering Practices, where there are more than two hauling trucks in use, a maximum of 20 minutes between trucks is suggested. Based on capacity and anticipated truck delivery schedules, the number of truck arms required at Arctic Bay is two (2) truck arms. The GN-CGS has a preference of two (2) truck arms to provide additional redundancy and to permit simultaneous loading of two trucks.

The same number of active (duty) truck fill pumps, plus one for redundancy (standby) should be provided for each truck arm. All truck fill pumps are to be capable of providing pumping rate of at least 1000 L/minute. Each truck fill station (2 total) will support one truck fill arm that extends from the WTP building. The arm shall be fully supported and include appropriate freeze protection. The truck arm will comprise of a 90° elbow that directs flow perpendicular towards the truck refilling hatch. The piping shall terminate above the truck hatch, with an additional sliding pipe that be lowered and retracted into the truck hatch for the filling operation.

The truck fill stations will also include an elevated access platform with stairs to allow operators safe access to the top of the tanker trucks. The platform will be adjustable to drop onto the top of the truck tank and shall have safety railings on all sides. The walkway is to be designed to allow the operator to reach the tank hatch and complete all filling activities from the walkway.

4.5 Raw Water Intakes

It was indicated that the GN-CGS preferred dual intakes to provide redundancy. The main issue with maintaining dual intakes is sedimentation and keeping both intakes clean and operational. However, this risk can likely be managed by cycling the intakes to manage sedimentation risks and providing spare pumps and additional freeze protection equipment. Additionally, water purge (ability to backflow water down the intake pipe) and air scour/burst systems for screen cleaning and ice mitigation are to be incorporated into the design as these are important process to help manage sedimentation and deep ice/freezing issues with the intakes.

Based on discussions with the GN-CGS, for a dual intake system, a total of three intake pumps are to be provided (two duty, 1 shelf back) and should have the capability to efficiently run at design flows which are less than 1000 L/min through the use of a variable frequency drive (VFD).

4.6 Intake Freeze Protection

Most northern communities use heat trace for intake freeze protection. Alternatively, some communities use tempered water (25°C) down the carrier pipe for freeze protection. However, the tempered water approach is not recommended as it requires an additional boiler unit with adequate storage and the use of unchlorinated water.

Dual heat trace (duty/standby) on each intake is recommended, along with heat trace controller fault alarms to indicate a failure of the duty heat trace and initiate the standby heat trace if the temperature falls below the setpoint. The addition of an air scour system can help mitigate ice/freezing risks if the intake is susceptible to deep ice. This approach has been used successfully at Rankin Inlet.

5 Raw Water, Treated Water and Process Wastewater Storage

5.1 Raw Water Storage – Marcil Lake

5.1.1 Storage Requirements

Based on the Hydrology and Water Balance assessment conducted by EXP (2022), Arctic Bay will use the existing natural lake (Marcil Lake) for the raw water supply and raw water storage. With an anticipated total winter storage (2043) of approximately 14,500,000 m^3, no capacity upgrades are required to meet the community's needs over the 20-year design horizon.

Submersible raw pumps will be installed within a carrier pipe at the dual intakes to extract raw water from Marcil Lake to the proposed WTP.

5.2 Treated Water Storage Tanks

5.2.1 Storage Requirements

Treated water storage is a very important element of this project. Treated water storage permits the activities of truck loading to be separate from treated water production. The separation of these processes will permit the filling of trucks at a rate that is independent of rate of production of treated water. Separation of the processes also provides the opportunity to treat water over the full working day, instead of the practice (used at existing truckfill plants) that entails a start and stop of the treatment process for each truck.

The treated water storage volume of 400 m^3 as estimated in the table below will be provided in a single steel tank approximately 11 m in diameter and 7 m in height. These dimensions are to be refined over the course of detailed design and with further discussions with tank suppliers. The treated water in the tank will be heated. The water temperature is not known but will likely be maintained between 5^{o}C and 10^{o}C.

Table 5-1: Treated Water Storage Volumes

Parameter	Arctic Bay
WTP Operational hours/day	12
Average Daily Demands (L/day)	142,080
Peak Daily Demand (L/day)	355,200
Design WTP Flow (L/min)	493
Truck Arms	2
Peak Flow for CT Calculation (L/min)	**2,000**
Firefighting Volume (m^3) *	-
Equalization Volume (m^3) **	118
CT Volume (m3) ***	240
Emergency Storage (m^3) $^+$	-

Plant Use Storage (m³) ++	36
Dead Volume (m³) +++	-
Total Treated Storage Volume (m³)	**394**

* *Firefighting volume provided through bypass*
** *Good Engineering Practices equalization volume = (projected max daily demand) - (8 hours of WTP design production)*
*** *Contact time = 120 minutes using CT value = 12 mg/L· min, free chlorine residual of 1.0 mg /L, baffling factor of 0.1*
\+ *Assume no emergency storage required*
++ *Assume plant use = 10% of design WTP flow*
+++ *Assumes no dead volume*

5.2.2 Alternative Tank Construction Methods

Water storage tanks are commonly constructed using bolted steel sections or as welded steel tanks. As the treated water tanks are an essential infrastructure component, a steel welded tank is recommended. Provided that a proper foundation is provided, it is expected that a steel-welded tank will be more robust than a bolted tank given the harsh environment and extreme (-50°C) temperature requirements of Arctic Bay. Leakage from bolted tanks could be challenging to deal with, as this would require removal of a portion of the cladding and insulation to repair. There is substantial expertise in Nunavut with the construction of welded steel tanks.

5.2.3 Freeze Protection

Both passive and active freeze protection of the treated water storage tank will be required. The passive freeze protection will take the form of insulation, protected by a cladding system. Spray-on polyurethane insulation with a steel cladding system is proposed. This has been successfully applied in Cape Dorset and Baker Lake.

Active freeze protection of the treated water storage will be achieved through circulation of the tank contents through a heat exchanger located within the WTP building. The boiler system will provide the heat input into the heat exchanger.

Over winter, it is imperative that the tanks maintain some water volume (minimum 30%) to ensure proper freeze protection of the tank and associated equipment.

5.2.4 Foundation

As per the Geotechnical Report and geothermal analysis (EXP, 2022), it is considered that these tanks may be set on inground engineered fill pads with insulation under the tank to minimize degradation of the permafrost. The thickness of the insulation required is a function of the sizes of the tanks, water temperature in the tanks, geotechnical, environmental conditions, and design of the tanks, etc. Geothermal analysis has concluded that the treated water storage tanks may be set on 1.2 m thick above-ground engineered fill pad underlain by 100 mm of insulation. The geothermal modelling of the treated water tank showed that thermosyphons would not be required if 100 mm thick insulation is used. Hence, the placement of 100 mm of rigid insulation is sufficient to maintain frozen ground conditions under the treated water storage tank operated at +10°C year-round.

5.3 Process Wastewater Storage Tanks

5.3.1 Storage Requirements

It is recommended to size the working wastewater volume (mainly filter backwash water) to hold a volume of no less than 7 days to account for trucking disruptions. The volume of process wastewater has been conservatively estimated at 10% of the WTP design flow to account for UF membrane backwashing and additional CIP and process upset waste volumes. Providing a slightly larger tank provides flexibility in the frequency of trucked wastewater servicing. Process wastewater volumes are estimated in the table below.

The process wastewater storage volume of 249 m^3 will be provided in a single steel tank approximately 8 m in diameter and 6 m in height. These dimensions are to be refined over the course of detailed design. The wastewater in the tanks will be heated. The wastewater temperature is not known but will likely be maintained between 5^{o}C and 10^{o}C.

Table 5-2: Process Wastewater Storage Volumes

Parameter	Arctic Bay
Process Wastewater Storage (m^3) for 7 days	249

5.3.2 Alternative Tank Construction Methods

Tanks are commonly constructed using bolted steel sections or as welded steel tanks. However, bolted steel tanks have become more common as they have significant advantages including lower capital costs. Steel welded tanks require skilled welders to construct the tank, the tank needs to be coated after installation, and routine maintenance includes scheduled recoating and sandblasting of the inner walls. Given the extreme (-50°C) temperature requirements, a steel welded tank is the preferred tank to use on this site for the process wastewater tank. However, bolted tanks for the process wastewater may also be feasible if required.

5.3.3 Freeze Protection

Both passive and active freeze protection of the treated water storage tank will be required. The passive freeze protection will take the form of insulation, protected by a cladding system. Spray-on polyurethane insulation with a steel cladding system is proposed.

Active freeze protection of the wastewater storage will be achieved through the provision of a heat exchanger within the tank (i.e. immersed heater). Typically, this requires that the heat exchange is always immersed – this unusable (dead) volume needs to be accounted for when confirming dimensions of the tank. Circulation of the tank contents through an external heat exchanger was discarded as a concept due to the risk of clogging of the heat exchanger. The risk of contamination of the treated water via the wastewater storage heat exchanger is viewed as minimal, as the heating medium provided to this heat exchanger is glycol, heated by the boiler system. It is anticipated that any leakage from the system, such as might occur at a heat exchanger, would lead to a leakage of glycol out of the system, due to the pressure within the glycol circuit.

Appropriate operating levels, freeboard and dead volumes to account for immersion heaters, inlet and outlet elevations are to be considered when confirming the dimensions of the storage tanks.

5.3.4 Foundation

The same comments provided above for the treated water storage tanks are equally applicable for the process wastewater storage tanks. The Geotechnical Report and geothermal analysis (EXP, 2022) has concluded that the process wastewater storage tanks may be set on 1.2 m thick above-ground engineered fill pad underlain by 100 mm of insulation. The geothermal modelling of the process wastewater tank showed that thermosyphons would not be required if 100 mm thick insulation is used.

6 Water Treatment Plant – Service Conditions Summary

A summary of the service conditions for the proposed WTP at Arctic Bay is given in Table 6-1 below.

Table 6-1: Service Conditions Summary

Category	Parameter	Arctic Bay WTP - Design Input
Population	Population (2023)	956
	Population (2043)	1,184
Demands and Design Flows	Design Consumption Rate	120 lpcd
	Peaking Factor	2.5
	Peak Daily Demand (2043)	355,200 L/day
	WTP Production Time Per Day	12 hours/day
	WTP Design Flow	493 L/min
	Fire Flow Bypass	1000 L/min
	Truckfill Flow (Total for 2 arms)	2 x 1000 = 2000 L/min
Intake	# of Raw Water Intakes	2
	# of Raw Water Pumps	3 (2 duty, 1 spare)
	Intake Freeze Protection	Dual heat trace (duty/standby)
Truck Fill	# of Truck Arms	2
	# of Truckfill Pumps	4 (2 duty, 2 spare)
Raw Water Inlet Strainers	# of Basket Strainers	2 (1 duty, 1 spare) sized @ 500 L/min
Contact Tank	Contact Time	10-30 mins depending on required flocculation/coagulation time
Membrane Filtration	# of trains	N+1 or N+2
	Membrane Recovery Rate	>95%
UV	# of UV reactors	2 @ 100% design capacity
Chlorination	CT Time *	120 minutes
Iron and Manganese	Iron and Manganese Treatment	Not required
Corrosion Control (provisional)	Corrosion Control Treatment	Direct chemical addition
Fluoridation (provisional)	Fluoridation	Fluoridation skid
Treated Water Storage	Firefighting Volume	N/A (fire flow provided through bypass)
	Equalization (EQ) Volume	118 m^3
	CT Volume	240 m^3
	Emergency Volume	N/A
	Plant Use Volume	36 m^3
	Dead Volume	-
	Total Treated Water Storage	394 m^3
	Tank Freeze Protection	Recirculation
Wastewater Storage	Wastewater Volume	249 m^3
	Tank Freeze Protection	Immersed heater
Raw Water Storage	Type of raw water storage	Existing reservoir (Marcil Lake)
	Capacity upgrade required?	Not required

** Contact Time = 240 minutes using CT value = 12 mg/L· min, free chlorine residual of 1.0 mg /L, baffling factor of 0.1*

7 Building Components

7.1 Applicable Codes and Standards

Design will be in accordance with requirements of following codes and standards, and to requirements of local authority having jurisdiction. Where conflict occurs, the most stringent shall apply.

- National Building Code of Canada 2015 edition, errata, revisions and supplements.
- CSA-A23.1-14/A23.2-14, Concrete Material and Methods of Concrete Construction / Methods of Test for Concrete.
- CSA-A23.3-14, Design of Concrete Structures.
- CSA-S16-14, Limit States Design of Steel Structures.
- CAN/CSA-S136-16, North American Specification for the Design of Cold Formed Steel Structural Members.
- Good Building Practice Guidelines, Gov. of Nunavut, 2nd Edition, 2005
- Good Engineering Practice for Northern Water and Sewer Systems, 2nd Edition, 2017

7.2 Foundations

As per the recommendations from the Geotechnical Report (EXP, 2022), it is anticipated that the WTP be set on spread and strip footings or on slabs on a 1.2 m in-ground engineered fill pad underlain by rigid insulation (100 mm). Thermosyphon horizonal evaporator loops 25 mm in diameter and 60 m long with consistent spacing of 1 m would prevent or minimize degradation of the permafrost under the foundations. Thermosyphons are not required under the storage tanks. It should be noted that the thermosyphon system is a proprietary design and build activity. Therefore, construction of the pad and material specification would also have to comply to the requirement of the design-build engineer.

7.3 Structure

Design loads are to be in accordance with the 2015 edition of the National Building Code of Canada (NBCC) for Arctic Bay. The Importance Category = ‘Post Disaster’.

The building structure will be a steel framed system which is well suited and commonly used in the north. As noted in the SWTT reports, the GN-CGS has noted that the new WTP is to be a modular (prefabricated) building. It is proposed that the framing will consist of metal roof deck supported by steel frames spanning the narrow dimension of the building which will support insulated metal roof panels. The wall structure will consist of horizontal cold formed girts supporting insulated metal exterior wall panels. The floor will consist of steel channel framing along with floor structure described in the next building envelope subsection. The lateral load resisting system will consist of braced steel frames.

7.4 Building Envelope

For the purposes of the schematic design, the following building envelope components have been proposed. Further development of these components will be completed over the course of the detailed design.

- Walls
    - Pre-finished insulated metal panels
    - Air barrier
    - RSI 8.13/R46 insulation
    - Structural cold formed girts
- Roof
    - Pre-finished insulated metal panels
    - Air barrier
    - RSI 8.13/R46 insulation
- Floor
    - With regard to modular construction and corrosion resistance, the floor will be constructed of metal deck installed at time of fabrication along with temporary plywood over for protection during fabrication. Channel 'housekeeping pads' will be constructed over the framing to allow for equipment installation during the fabrication process.
    - Final floor structure to be developed in the design stage (concrete, epoxy, etc.)
    - Steel channel joists.
    - Sprayed insulation
    - Weather barrier.
    - Pre-finished metal cladding.
    - RSI 8.13/R46 insulation.

7.5 Support Systems

7.5.1 Mechanical

For the purposes of the schematic design, the following section proposes preliminary mechanical components. Further development of these components will be completed over the course of the detailed design.

7.5.1.1 Applicable Codes and Standards

At a minimum, the following codes and practice standards are to be incorporated into the design.

- National Fire Code of Canada, 2015
- National Plumbing Code of Canada, 2015
- Installation Code for Oil Burning Equipment – CSA 139 Series
- Ventilation for Acceptable Indoor Air Quality – ASHRAE 62.1 – 2016
- Good Building Practice Guidelines, Gov. of Nunavut, 2nd Edition, 2005
- Good Engineering Practice for Northern Water and Sewer Systems, 2nd Edition, 2017

7.5.1.2 Fire Protection

The building will be equipped with portable fire extinguishers as required by code. No sprinkler system will be provided.

7.5.1.3 Plumbing

Potable water will be supplied to the building from the treated water tank. Insulated PEX domestic water piping will distribute potable water throughout the facility. A hydronically-heated domestic water heater/storage tank will be provided to provide domestic hot water to the facility.

Sanitary drainage will be pumped utilizing a macerating pump from facility fixtures and will drain into a sanitary storage tank. The sanitary storage tank will have a pump-out line to building exterior for tank discharge by a local truck.

Water closet is to be floor mounted, vitreous china, flush valve, low water use (4.8 litres per flush). Lavatory is to be stainless steel. Faucet shall have flow restrictors to ensure low water use.

An emergency shower/eyewash complete with thermosetting mixing valve will be provided as a safety measure for personnel working with chemicals.

7.5.1.4 Heating

As per the SWTT, the GN-CGS has requested that boilers be located in a separate dedicated room. Three oil fired boilers are proposed in the boiler room. Two boilers will run continuously, and the third boiler will exist for redundancy. Each boiler shall have a dedicated circulator pumping into a main hot water header. Boilers will be sized in the detailed design stage once building footprints are confirmed.

Boilers will have stand-alone controls but will be monitored and sequenced by the plant PLC system. It is further proposed that non-toxic glycol heat exchange fluid be used in the boilers.

Fuel oil for the boilers will be stored on site in an exterior tentative double wall storage tank. The fuel tank is to be sized to provide for the fuel autonomy requirements, as set out in Good Building Practices as published by GNWT (2017). Fuel will be fed into the boilers via an interior, double-walled day tank. A duplex transfer system complete with stand-alone controls will be provided. Fuel tanks to be installed on containment pads to prevent the accidental release of diesel.

The hot water header will feed a glycol heat exchanger to supply space heating via unit heaters located throughout the facility and hydronic heating coils located at supply air intakes. Unit heaters are operated by stand-alone thermostats. This glycol loop will also supply a packaged heat trace unit to provide heat tracing for the truck fill arms, raw water tanks, treated water tank, sanitary storage tank and associated treatment processes.

The hot water header will also feed a second hot water - treated water heat exchanger to provide heat to the treated water tank circulation loop to prevent freezing and the truck fill line.

All pumps and heat exchangers will be 100% duty with 100% standby for full redundancy.

7.5.1.5 Ventilation and Air Conditioning

The facility shall be continuously ventilated through a heat recovery ventilator at a rate of 0.5 air changes per hour (ACH) normally. Heating coils will be used in the return air duct to prevent heat recovery ventilator core freeze up. Ventilation rate shall increase to 0.8 ACH during occupancy. Ventilation shall increase in the event of excess chlorine gas being sensed in the facility. Supply air shall be heated by a hydronic heating coil.

The boiler room shall have its own dedicated outdoor air inlet to provide cooling and combustion air via supply fan and modulated by control dampers. Exhaust outlets shall by modulated by control dampers.

Intake hoods shall have a minimum vertical length of 600 mm to ensure contaminants including insects and snow do not enter the ventilation system. Hoods must be mounted high enough such that the hoods do not become blocked by snow. A review of snow drifting patterns at this location must be done before hood placement. Insect screens shall not be installed on outdoor air intakes to avoid being blocked by insects and snow.

A separate area will be provided for mixing and pumping equipment for chlorine and other chemicals (i.e. coagulants and provisional fluoride chemicals). The chemical room is to be ventilated and designed to operate under negative pressure so that the atmosphere of the room is exhausted to the outside and will not migrate to other areas of the building. Fluoride storage and equipment requirements will be developed once criteria is confirmed.

As per the SWTT, the GN-CGS has noted a preference to include a diesel-powered generator located in a separate, heated enclosure. Ventilation requirements for the generator enclosure are to be confirmed during the detailed design.

7.5.2 Electrical

For the purposes of the schematic design, the following section proposes preliminary electrical components. Further development of these components will be completed over the course of the detailed design.

7.5.2.1 Applicable Codes and Standards

The WTP will be designed to meet the electrical requirements of the following standards:

- Canadian Electrical Code Cdn.1-2015.
- Institute of Electrical and Electronics Engineers (IEEE).
- National Building Code of Canada 2015 (NBC).
- National Electrical Manufacturer’s Association (NEMA).
- Electrical and Electronic Manufacturer’s Association of Canada (EEMAC).
- Illuminating Engineering Society (IES).

The electrical design will be done in close cooperation with other disciplines, the client, the GN and in accordance with all local laws, rules and regulations.

7.5.2.2 Electrical Service

The primary electrical source for the new WTP will be from the QEC grid with a secondary (backup) source provided by a generator. The new WTP will require a 347/600V, 3-phase power supply. The utility connection will be via a standard electrical mast mounted on the exterior of the building and fed from utility-supplied, pole-mounted transformers.

7.5.2.3 Service Entrance Equipment and Distribution

The WTP facility will be equipped with a 200A, 347/600V, wall-mounted, fused main disconnect. This disconnect will supply power to the entire facility. The main disconnect will feed a free-standing motor control centre (MCC) which in turn will feed the additional power distribution equipment. The equipment will include the following:

- One (1) surge suppressor (TVSS)
- One (1) 347/600V, 100A, 3 Ø panelboard.
- One (1) 120/208V, 100A, 3 Ø panelboard.
- One (1) 37.5kVA, 600V-120/208V dry-type transformer.
- Harmonic filters and controls as required

The 347/600V panelboard will feed all mechanical and process devices requiring an un-switched 347/600V power connection. The 120/208V panelboard will be used to provide power to all lighting, receptacles, control and instrumentation systems.

7.5.2.4 Motor Control Centre

The WTP will be equipped with a 400A, 347/600V, 3Ø, 4-wire motor control centre (MCC). All of the 347/600V and 120/208V electrical equipment in the WTP system will be fed from the MCC.

The panelboards and transformer mentioned in the previous section, as well as all of the system motor starters and variable frequency drives (VFD's) will be embedded into the MCC. Each motor starter and VFD will be equipped with panel-mounted hand-off-auto (HOA) switches to allow operation of the motors in case of a control system failure.

7.5.2.5 Emergency Power System

The WTP system will have a 347/600V, 3-phase diesel generator integrated into the electrical distribution system to provide standby emergency power during utility power outages. As per the SWTT, the GN-CGS has noted a preference to include a diesel-powered generator located in a separate, heated enclosure.

The generator will supply emergency power to the entire WTP system via a 200A, 347/600V automatic transfer switch (ATS). The system will have sufficient fuel storage capacity to operate the generator at full load for 24 hours. Generator sizing calculations will be completed during the detailed design stage.

Status information related to the generator and the ATS will be tied to the WTP PLC-based control system and integrated into the alarm notification component of the plant SCADA system. In addition, all louvre actuators associated with generator operation will be controlled automatically, based on temperature, by the plant PLC-based control system. Provisions will also be in place in the plant SCADA system to allow the operator to individually position the louvres manually (or automatically as described above).

An uninterruptable power supply (UPS) will be provided for the PLC based control system. This will assure continuing operation of the control system following a loss of electrical supply.

7.5.2.6 Lighting

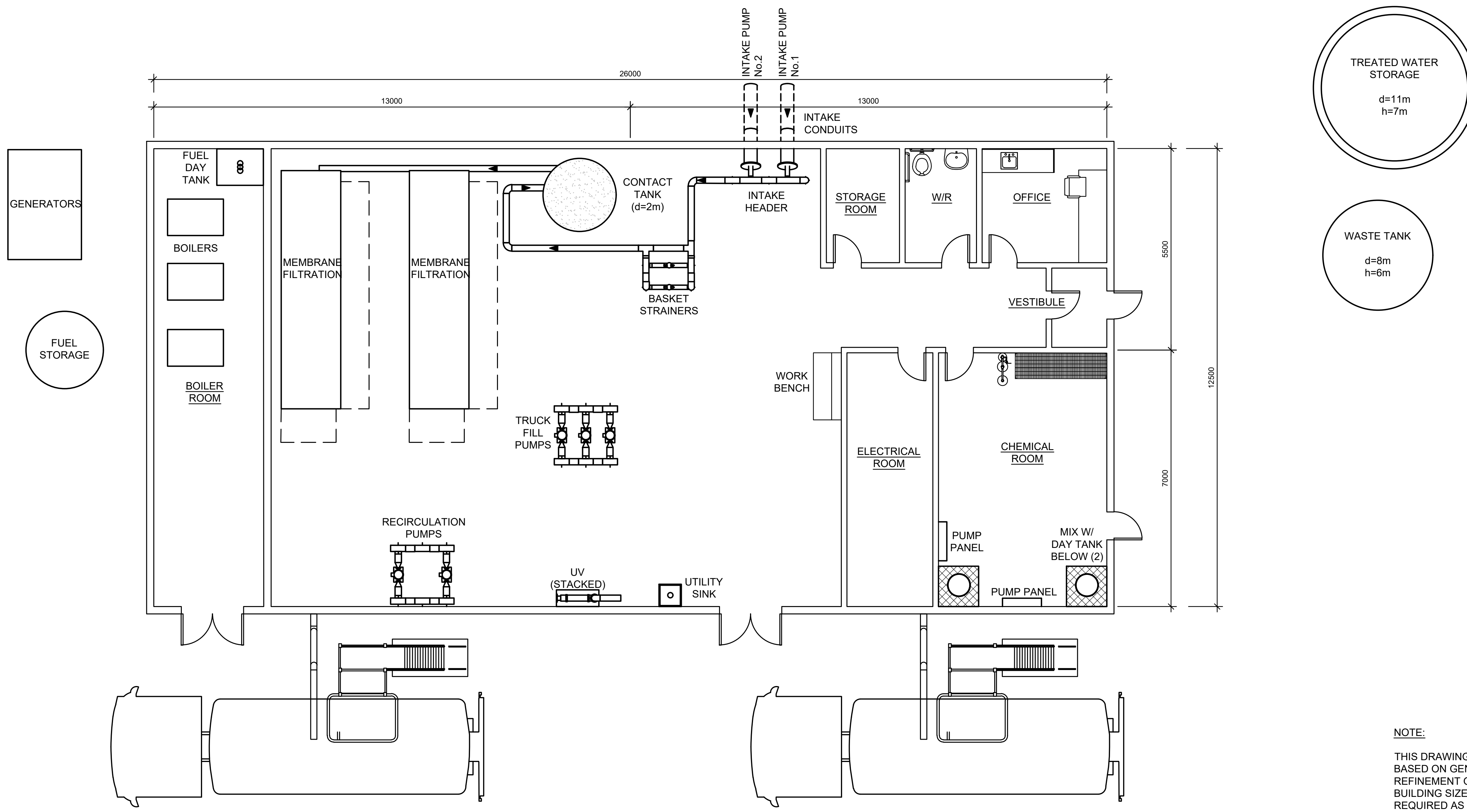
Lighting in the WTP will be 120V LED type. Vapour-proof 1 x 4 LED fixtures will be used throughout the interior of the building. LED wall pack type fixtures will be used on the exterior of the building. Exterior building entrances and building interior will be illuminated to IES standards. Sufficient capacity will be built into the size of the 120/208V panelboard to accommodate additional site lighting, if required.

Emergency egress lighting will be provided as required by the latest edition of the National Building Code. Emergency egress lighting will automatically come on if normal power fails.

Exit lighting will be provided as required by the National Building Code 2015. They will be LED type, metallic housing and be supplied from emergency back-up battery inverter power.

7.6 Building Footprints

For the purposes of the schematic design and business case, a building footprint has been conservatively estimated at 26 m x 13 m to account for provisional processes such as fluoridation and corrosion control and to allow space for additional rooms as required (storage rooms, working areas, maintenance requirements for submerged vs. pressurized membranes, etc.). The building also includes a combined space for office and laboratory, washroom, entry vestibule, truck fill station and platforms. A proposed building layout for the WTP has been provided in Figure 7-1 below. Building footprints and layouts will be developed in subsequent design stages with further refinement of the process equipment/requirements.



NOTE:

THIS DRAWING REPRESENTS A CONCEPTUAL LAYOUT BASED ON GENERAL EQUIPMENT SIZING ONLY. REFINEMENT OF THE LAYOUT DRAWING INCLUDING BUILDING SIZE, TANK SIZE AND CONFIGURATION WILL BE REQUIRED AS PART OF NORMAL ENGINEERING DESIGN, BASED ON ACTUAL EQUIPMENT MANUFACTURER SELECTIONS, ROUTING OF PIPING, MAINTENANCE ACCESS FOR EQUIPMENT, AND OTHER FACTORS.

exp Services Inc. 100-2650 Queensview Drive Ottawa, ON K2B 8H6 www.exp.com	DESIGN C.K. DRAWN M.M.A.	ARCTIC BAY – CONCEPTUAL	SCALE 1:125
	DATE MAY 2022 FILE NO ___	WTP BUILDING LAYOUT	SKETCH NO FIG 7-1

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8 Site Location and Screening of Sites

8.1 Scouting Study for Potential Sites

Satellite imagery was used in the scouting study to identify potential locations for the new WTP. Eight (8) potential sites for the new WTP were identified at locations along the existing 9.2 km access road between the community core and the existing WTP at Marcil Lake as shown on Figure 8-1. Sites were screened on their distances to the raw water source (Marcil Lake), their distance from the community, and available space requirements for a new WTP. Additional constraints that were incorporated included waste facility setbacks, airport zoning setbacks, topographic considerations and community land-use/parcel plans.

From these eight sites, Site 5, Site 6 and Site 7 were eliminated from further consideration due to land use conflicts, significant freezing risks due to length of raw water transmission line, excessive slopes on the site and constructability considerations. A summary of the initial scouting study has been provided in Appendix A.

8.2 Field Visits and Community Input - Screening of Sites

Site visits by representatives of EXP and GN-CGS and discussions with the Hamlet's community council were undertaken in Fall 2021 for the five (5) remaining sites. From the field investigations and discussions with the Hamlet, Site 2 and Site 8 were eliminated from further consideration:

- Site 2 is located at the end of the runway, on the opposite side of the road from the airport and waterway. This is a very steep area that has already had gravel extracted from it. There are concerns about potential contamination issues as is unused/broken equipment parked here. This is a steep location with a blind hill/corner on the main road to the airport. Considerable efforts to provide suitable driveway construction/line of site would be required. This site is located at a high point and is very exposed. From a constructability perspective, this site is not ideal, specifically for tank construction.
- Site 8 was eliminated due to land-use conflicts. The council noted that this site is next to the lot designated for the new school and would not be suitable for the new WTP. Installation of the transmission pipeline would be challenging, and the site has a significant cross-grade. The council also noted a concern with potential vandalism if the new WTP was built at this site which is located right in the middle of the Hamlet.

R.P.P. K.R. JOHNSON ALBERTA PROFESSIONAL PLANNERS INSTITUTE REGISTERED PROFESSIONAL PLANNER AB/NT/NU

Hamlet of Arctic Bay - Scouting Study for Potential Water Treatment Plant Sites

Prepared by: Ken Johnson, RPP, P.Eng and Chris Keung, MASc. (Revision 2: August 27, 2021)

Notes: Refer to Table entitled "Hamlet of Arctic Bay Scouting Study for Potential Water Treatment Plant Sites" for additional information on the Scouting Study

exp.

FIGURE 8-1

8.3 Preferred Sites – Site 1, Site 3 and Site 4

Following screening from the site visit and input from community council, the three (3) preferred sites that were considered for additional field investigations (topographic survey, geotechnical assessments, Phase 1 Environmental Site Assessments) were Site 1, Site 3 and Site 4. These are the preferred sites that will be considered for the new WTP as shown in Figure 8-2.

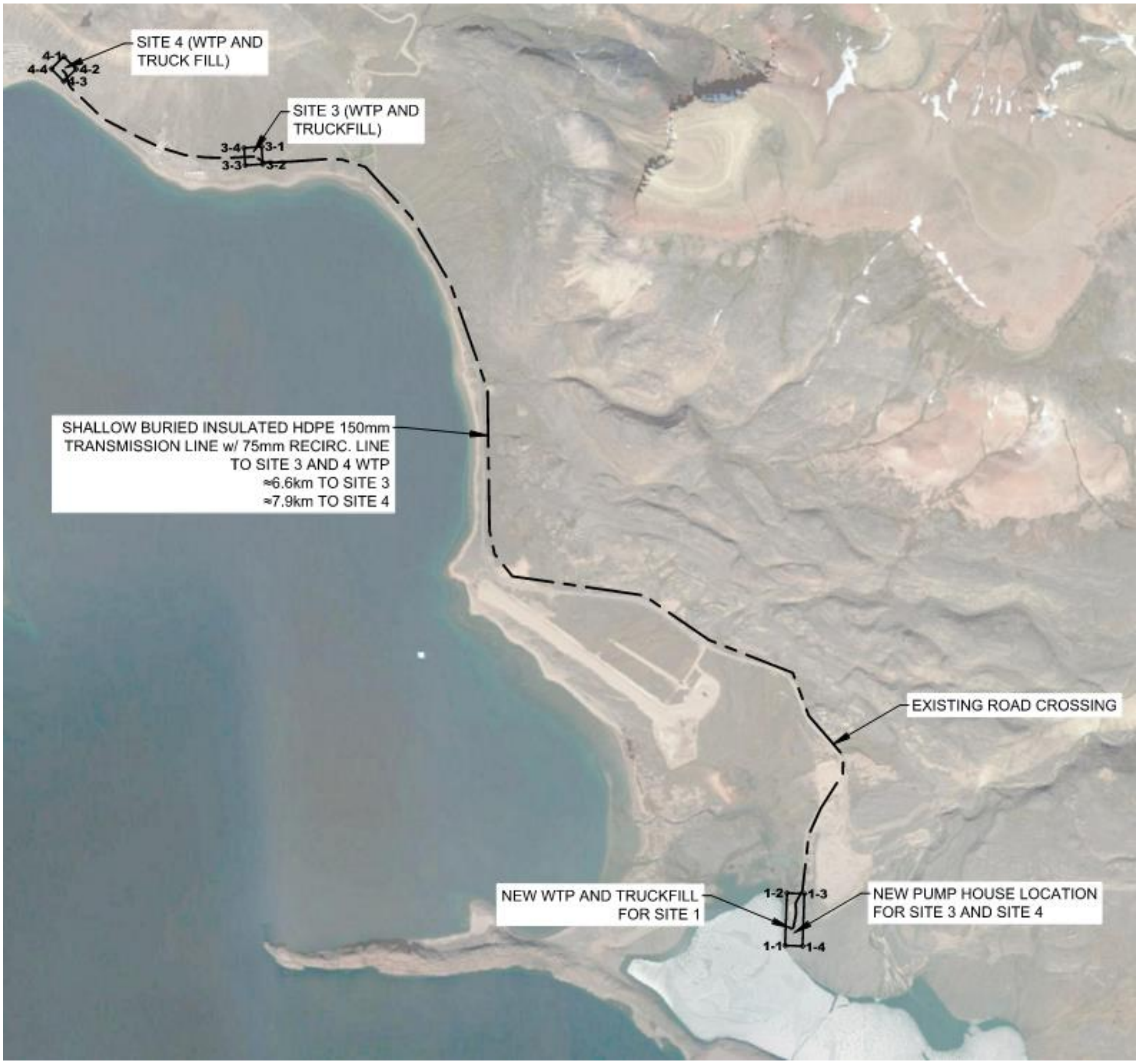


Figure 8-2: Preferred Sites for New WTP

Siting options for these three (3) preferred WTP sites will be discussed in the next section.

9 Siting Options for Site 1, Site 3 and Site 4

9.1 Siting Options Overview

- Site 1 – Site 1 is located adjacent to the existing WTP and the existing lake reservoir (Marcil Lake), southeast of an Environment Canada weather station (which is located west of the existing pumphouse – on the left side of Figure 9-1). The weather station shares power from the existing pumphouse. The site is fairly flat lying with the ground surface elevations varying from 6 m el. to 8 m el. except for the northeast corner where the ground surface rises to 11 m. The site is located approximately 30 m east of the lakeshore. The extent of talik under the lake or in its vicinity is currently not known.

Figure 9-1: Site 1

- Site 3 – Site 3 is located next to the new Power Plant which is currently under construction by QEC. It is located approximately 6.6 km north of Marcil Lake reservoir and approximately 1.3 km south of the community. The ground surface elevations at the site vary from 12.5 m el. at the southwest corner to 27.5 m el. at the northeast corner. The site slopes down to the southwest at a slope of 8° approximately. As the slope is relatively steep, the earthworks at the site are expected to be more extensive as is reported to be the case at the Power Plant site. A long hill is located behind the site and would necessitate integrating drainage plans directly into the design on the eastern edge of the community.

Figure 9-2: Site 3

- Site 4 – Site 4 is located adjacent to the community on the road to the existing Water Treatment Plant and is approximately 7.9 km (along the existing access road) from Lake Marcil reservoir. The ground surface elevations vary from 17 m el. to 36 m el. The site slopes down steeply to the southwest at an inclination of 5.9H:1V approximately. A hill is located along the north property boundary. The council also noted a concern with potential vandalism if the new WTP was built at this site within the community.

Figure 9-3: Site 4

9.2 Siting Options – Construction Components

A new WTP at Site 1 (existing WTP site at Marcil Lake) would require the following construction components:

i. WTP Building at Site 1 (process, mechanical, electrical)
ii. Storage Tanks (treated water, wastewater)
iii. Dual intakes for raw water (complete with intake screen, heat trace and submersible well pumps)
iv. Site Development (site grading, foundation work and truck turnaround area)
v. Electrical (connection from existing services)

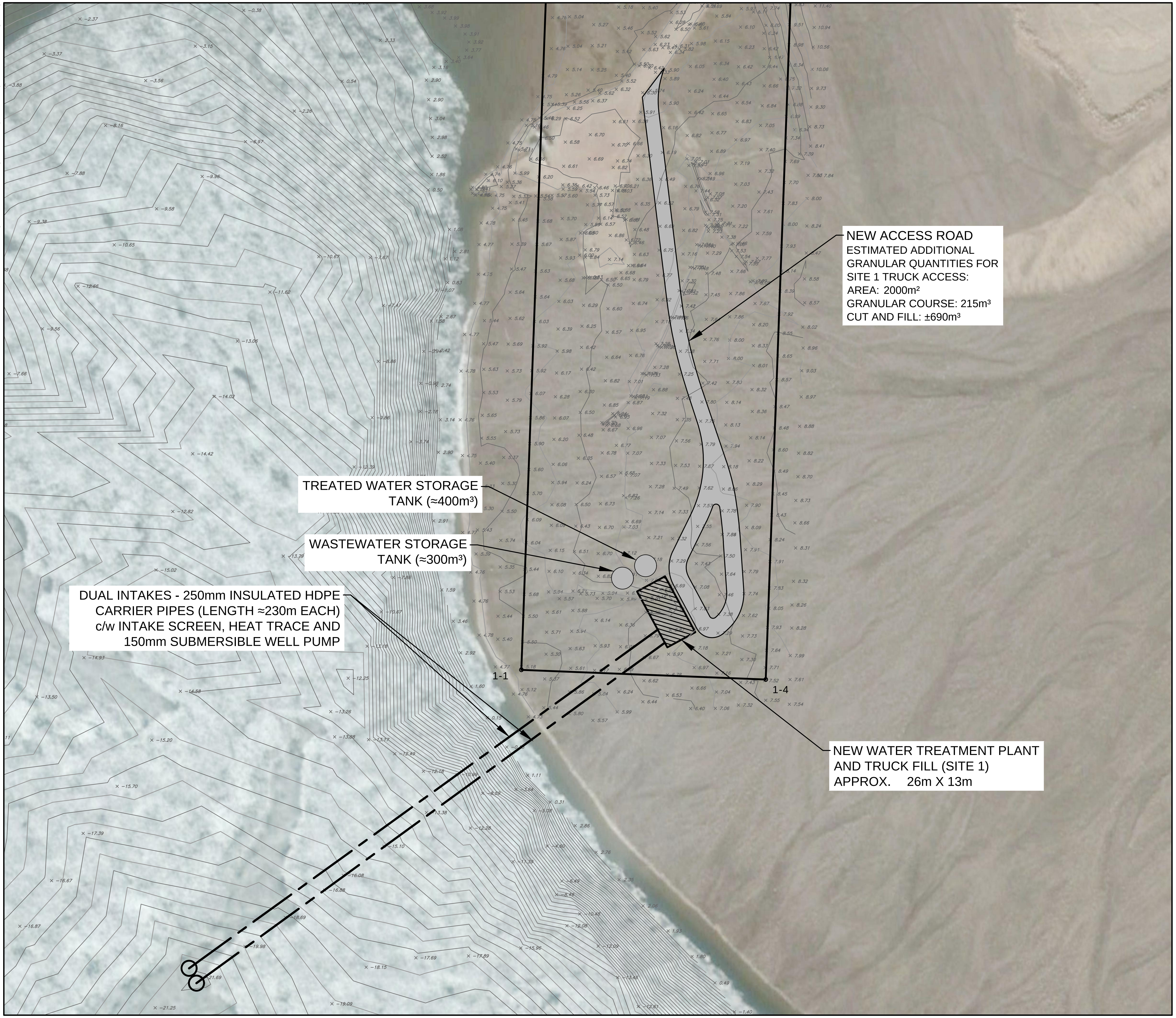
Site 3 and Site 4 are located closer to the community along the access road and in general, have similar constructability considerations. Both sites would require a new WTP/truckfill at their designated sites, an additional building (pump house at Marcil Lake) and raw water transmission line. A new WTP at Sites 3 or 4 would require the following construction components:

i. New pump house at Marcil Lake (process, mechanical, electrical)
ii. Transmission line from pump house to WTP, and associated recirculation line
    a. 6.6 km transmission line from Marcil Lake to Site 3
    b. 7.9 km transmission line from Marcil Lake to Site 4
iii. WTP Building at Site 3 or Site 4 (process, mechanical, electrical)
iv. Storage Tanks (treated water, wastewater)
v. Dual intakes for raw water (complete with intake screen, heat trace and submersible well pumps)
vi. Site Development (site grading, foundation work and truck turnaround area)
vi. Electrical (connections from existing services)

The proposed WTP will use Marcil Lake as its water source. Installation depth of the new intakes is recommended at a depth greater than 20 m. This would allow installation of the intake to take place on the western portion of Marcil Lake minimizing construction efforts and length of the intake (approx. 250 m) while still providing adequate storage operational volumes. The deepest part of Marcil Lake (depth approx. 35 m) is located further south and east and would require significant efforts to install an intake at this location (length of intake approx. 900 m).

9.3 Conceptual Site Plans – Site 1, Site 3 and Site 4

Site plans have been developed for Site 1, Site 3 and Site 4 and are shown in the following figures (Figure 9-4 to Figure 9-8). These conceptual designs are based on the water treatment service conditions and building components described in the previous sections. The site plans detail the proposed access road, truck turnaround areas and estimated layout footprints for the WTP.



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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:1500 — 0, 30, 60 m

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY SITE 1 WTP AND TRUCKFILL CONCEPTUAL DESIGN

Project No. FRN-21016638-A0

Dwg. No. **FIGURE 9-4**

Rev. No. 0

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Dwg Standards Ckd By:

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Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY - SITE 3 & SITE 4 RAW WATER TRANSMISSION LINE CONCEPTUAL DESIGN

Project No.

FRN-21016638-A0

Dwg. No. **FIGURE 9-5**

Rev. No. 0

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Designed By:	CK
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Scale: 1:1500	0 30 60 m

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY SITE 3 AND 4 PUMP HOUSE CONCEPTUAL DESIGN

Project No.
FRN-21016638-A0

Dwg. No.	Rev. No.
FIGURE 9-6	0

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Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY TOPOGRAPHIC SURVEY SITE 3

Project No. FRN-21016638-A0

Dwg. No. **FIGURE 9-7**

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Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:1000 — 0, 20, 40 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
TOPOGRAPHIC SURVEY
SITE 4

Project No.
FRN-21016638-A0

Dwg. No.
FIGURE 9-8

Rev. No.
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9.4 Wind Blowing and Snow Drifting Studies – Site 1, Site 3 and Site 4

A Wind Blowing and Snow Drifting Assessment was completed by SLR Consultants for the proposed WTP layouts at Sites 1, 3 and 4. Sixteen years of wind records from Environment Canada indicate that prevailing annual winds occur from the northwest, west-northwest, and southeast directions. Winds greater than 23 km/hr are most common from the southeast, south-southeast and northwest directions and are the wind directions that were considered for the assessment. Snowfall data from the Nanisivik Airport (16 km from Arctic Bay) indicated an average of 191 cm snow, annually.

Results from the Wind Blowing and Snow Drifting Assessment and discussions with SLR were used to provide preliminary orientations for the WTP building, access roads and storage tanks to minimize heavy snow drift formation and minimize snow removal efforts. Main conclusions from the Wind Blowing and Snow Drifting Assessment at Arctic Bay include:

- Strong winds greater than 23 km/hr, with or without snow, occur for less than 7% of the time during winter – thus, snow drifting may not be a significant issue, so much as snow accumulation.
- In terms of wind and snow drifting, the preferred location is Site 4, followed by Site 3, followed by Site 1.
- Site 3 and Site 4 has an additional pump house building at Marcil Lake which will require snow removal efforts
- At Site 1, to reduce snow removal efforts, it is recommended to place the main access doors on the east side of the building. The base of the west tank stairs should be located on the north side of the tank, while the base on the east tank stairs should be located on the northeast side of the tank.
- At Site 3, to reduce snow removal efforts, it is recommended to place the main access doors on the south side of the building. Secondary access doors should be placed on the east façade. The base of the tank stairs should be located on the southwest side of each tank.
- At Site 4, to reduce snow removal efforts, it is recommended to place the main access doors on the south side of the building. Secondary access doors should be placed on the east façade. The base of the tank stairs should be located in the middle of the southwest side of each tank.

9.5 Geotechnical – Site 1, Site 3, and Site 4

Geotechnical reports have been provided in Appendix D. The Geotechnical investigations and associated reports (EXP, 2021 & 2022) have revealed that from a geotechnical perspective, Site 1 is most favorable, followed by Site 3, with Site 4 being the least favorable, in terms of suitability for construction of the WTP building and storage tanks for the following reasons:

- The geotechnical conditions are best for Site 1, with its site underlain by well drained sand and gravel to sandy gravel with few ice crystals or lenses. Site 3 and Site 4 have randomly distributed layered soils. The soils for Site 3 have more ice crystals and lenses compared to Site 1, and Site 4 has more ice crystals and lenses than Site 3 and Site 1. Site 4 also has surficially disturbed material or fill which was encountered from 1 m to 4 m depth – this material is not suitable for construction and would have to be excavated and disposed of.
- The site topography and grade differences also favour Site 1. Site 1 is nearly flat, with a gentle gradient of 39.7H:1V, while Site 3 has steeper site slopes, ~7.7H:1V, and Site 4 has even steeper site slopes, ~5.9H:1V. Site 1's elevation is between 6 m to 8 m approximately (grade difference of 2 m) except for the northeast corner where the ground surface rises to elevation 11 m. For Site 3, ground surface elevation varies from 12.5 m to 27.5 m (grade difference of 15 m).

For Site 4, ground surface elevation varies from 17 m to 36 m (grade difference of 19 m). For both Site 3 and Site 4, the sites slope down from northeast to southwest.

- Construction of the WTP building and storage tanks would require the same type of foundations at all three sites:
    - WTP building would require spread and strip footings set at a shallow depth set on an inground engineered fill pad incorporating insulation and thermosyphons. Based on the geothermal analysis, the required thickness of granular bed and insulation is 1.2 m and 100 mm, respectively. Geothermal analysis revealed that thermosyphons under the WTP building with horizontal evaporator loops 25 mm in diameter and 60 m long with consistent spacing of 1 m would prevent or minimize degradation of the permafrost under the foundations.
    - The treated water storage tank and the wastewater storage tank will be founded on slabs set on an inground engineered fill pad overlain with rigid insulation (thermosyphons are not required under the storage tanks). Based on the geothermal analysis, the required thickness of insulation is 100 mm.
- The Phase I and II ESAs completed at Site 1, Site 3 and Site 4 did not identify any areas of potential environment concern.

9.6 Site Development (Grading and Drainage) – Site 1, Site 3 and Site 4

Site 1 is relatively flat, only requiring nominal site grading for construction of the proposed foundations on level ground. Both Sites 3 and Site 4 have significant slopes requiring site grading to obtain relatively flat area for construction of the water treatment plant, treated water storage and wastewater storage tank. For all three sites, site grading can likely be undertaken by excavating material from the higher ground and backfilling low-lying areas, with the exception of surficially disturbed material for Site 4 (from 1 m to 4 m depth) which is not considered to be suitable for construction purposes. Otherwise, whether the on-site material can be used for construction of engineered fill pads would depend on its gradation and would require additional testing. The municipality has various quarries located along the access road – the quantity and quality of these local granular sources is currently unknown and would require additional investigation/testing.

Satisfactory performance of the foundation system would be contingent on eliminating or minimizing surface and subsurface water flow under the structure. For Site 3 and Site 4, drainage ditches would likely be required along the north and east sides of the site to prevent surface and subsurface flow of water from the higher ground under the structure. Site 1 may likewise require drainage ditches or cut offs to prevent subsurface water flow under structures to prevent degradation of the permafrost. Drainage ditches would have to be deep enough to intercept all the subsurface water during spring freshet. All downspouts from the building should be directed to discharge at least 4 m from the perimeter of the building or preferably should discharge to the perimeter drainage ditches.

The finished grade around the buildings would require sloping away from the structure at a grade of at least four percent to prevent ponding of the surface water around the foundations of the structure.

10 Fire Protection Considerations

10.1 Fire Protection – General

Trucked water supply for fire protection has been a continuing concern for the community and the Government of Nunavut. As part of the ongoing discussions, EXP has completed an assessment of fire protection considerations associated with each of the proposed sites. Site 1 is located at the existing site and is the furthest from the community. Site 3 and Site 4 are located closer to the community but will require a raw water transmission line and additional pump house. Raw water transmission lengths and maximum trucking distances for the three sites are provided in Table 10-1 below.

Table 10-1: Raw Water Transmission Line Lengths and Trucking Distances

Site	Raw Water Transmission Line to WTP	Longest Trucking Distance (WTP to Furthest House)
1 (existing site, by Marcil Lake)	0 km	10.3 km
Site 3 (partway between community and existing site)	6.7 km	3.6 km
Site 4 (in community)	7.9 km	2.4 km

10.2 Fire Routing Analysis

A fire routing analysis was completed to assess whether moving the WTP/truckfill closer to the community would significantly improve the firefighting response and ability to respond to a fire event. Commentary on this analysis is provided below.

- In the event of a fire, time is passed between the initial fire alert by someone, the alarm/klaxon going off, the community fire department gathering, dressing up and the fire truck leaving the firehall.
    - 10 minutes or longer would not be out of the ordinary. While there are several variables at play, e.g., ignition source, type/age of building materials, travel time within the community, the experience is more often than not that by the time the fire truck arrives on scene it's too late to evacuate or save the building and attention turns to preventing the spread of fire to adjacent buildings.
    - The fire truck tank will empty on average in about 5 or 6 minutes at the fire scene then wait for refill from water trucks.
    - These variables differ for each community and should be verified with the community Fire Marshall.
- The intent of moving the WTP/truckfill closer to the community is to presumably shorten the duration for the water truck relay to fill the fire truck tank.
    - There are a few constants.
        1. Fill time at truckfill station with the only variable being the size of the water truck. Assuming water trucks are 12,000 L/truck, this equates to approximately 15 minutes (drive up, climb truck, position hose, press start button on panel, fill truck (1,000 L/min), switch off pump, drive away). Winter fill times are slower than summer.
        2. Connect time, water truck to fire truck at incident location and startup for filling. Typically using kamlock fittings – assume 2 minutes on average, winter filling time slower than summer.

iii. Time to fill the fire truck – depends on the pump discharge capacity of the water truck but typically, it is a small pump used to fill building tanks. Assume 5 minutes (SAO or Fire Marshall should confirm).
iv. Water truck speed: faster going empty, slower when full – conservative average = 30km/hr.

- Number of water trucks
  - It is our understanding that Arctic Bay currently has 2 duty trucks @ 12,000 L/truck.
  - Based on estimated future demand, at least 4 trucks will be required to meet trucking demands in 2043.

10.2.1 Fire Scenario 1: Worst-Case Scenario (Full Round Trip)

The total routing time for the worst-case scenario where all the water trucks are empty and are required to travel from the community to the new WTP and back to the community (full round trip) was calculated as shown in the following table.

- Site 1 (Existing Site) water truck route: 20.6 km round trip, 30 km/hr
- Site 3 water truck route: 7.2 km round trip, 30 km/hr
- Site 4 water truck route: 4.8 km round trip, 30 km/hr

Table 10-2: Fire Scenario 1 - Worst Case Scenario - All Trucks Empty and Require Full Round Trip

Parameter	Site 1 (20.6 km trip)	Site 3 (7.2 km trip)	Site 4 (4.8 km trip)
Fill time at truckfill (1000 L/min)	15 min		
Connect time (water truck to fire truck)	2 min		
Time to fill fire truck/onion tank *	5 min		
Travel Time	41 min	15 min	10 min
Total Time (for each load to replenish fire truck)	**63 min**	**37 min**	**32 min**

* water trucks may be fitted with a 4 ½" outlet with fittings that are compatible with the fire department – this would allow the fire truck to directly draw from the water truck

10.2.2 Scenario 2: Available Truck at Truckfill Station (One-Way Trip)

The total routing time for another scenario where all the water trucks are empty but at least one truck is already at the new WTP (one-way trip) was calculated as shown in the following table.

- Site 1 (Existing Site) water truck route: 10.3 km round trip, 30km/hr
- Site 3 water truck route: 3.6 km round trip, 30km/hr
- Site 4 water truck route: 2.4 km round trip, 30km/hr

Table 10-3: Fire Scenario 2 -- All Trucks Empty but are Waiting at Truckfill Station (i.e. one-way trip)

Parameter	Site 1 (20.6 km trip)	Site 3 (7.2 km trip)	Site 4 (4.8 km trip)
Fill time at truckfill (1000 L/min)	15 min		
Connect time (water truck to fire truck)	2 min		

Time to fill fire truck/onion tank	5 min		
Travel Time	21 min	8 min	5 min
Total Time (for each load to replenish fire truck)	**43 min**	**30 min**	**27 min**

10.3 Fire Routing Considerations

Considering the distances and constants, for the worst-case (Scenario 1 - no water trucks available and requires full round-trip), Site 3 reduces the refilling relay by about 26 minutes and Site 4 by about 31 minutes compared to Site 1. For a more likely scenario where at least one of the trucks is at the truckfill station (one-way trip), Site 3 reduces the refilling relay by about 13 minutes and Site 4 by about 16 minutes compared to Site 1.

In our opinion, irrespective of the site, the reduction in routing time is only marginal and insufficient for the truck relay to provide water in a timely manner to fill the fire truck which by this time has been empty for approximately 26 minutes (or 21 minutes for Scenario 2 when only a one-way trip is required). Another factor that must be considered for fire protection is potential interruptions in water supply. One of the main concerns with a transmission line is freezing risks. Site 3 and Site 4 would require a relatively long transmission line where there is significant risk of freezing and prolonged interruptions in water supply.

Effective fire response is highly dependent on whether water trucks are full and available within the community at the time of the initial response. One of the recommendations provided in the 1993 NWT Fire Protection Study (Heinke & Marianayagam, 1993) is to keep water delivery trucks full during off-delivery hours and to store the trucks full in the community parking garage (or in the fire hall). During water trucking operational hours, increasing the total number of water trucks on duty and implementing some scheduling procedures increases the chances that the water trucks are staggered and increases the probability that water trucks are full and available within the community.

11 Cost Estimates

11.1 Capital Costs

Opinions of probable cost estimates (Class D) were developed by a Professional Quality Surveyor (Altus) by identifying the main cost components required for the proposed WTP at Site 1, Site 3, and Site 4. The main capital cost components are as follows:

- Capital costs
    - Building and Site Development Costs
        - Site 1 – WTP building
        - Site 3 and Site 4 – WTP building, pump house and raw water transmission line (6.6 km and 7.9 km for Site 3 and Site 4, respectively)
    - Access Road and truckfill turnaround area costs
    - Storage Tanks (treated water storage, process wastewater)
    - Process equipment
    - Mechanical equipment including tank freeze protection
    - Electrical
    - Include decommissioning of existing WTP
    - General requirements (freight and accommodations)
    - Contingencies (design, escalation)

Contingencies were included to help account for differences in costs due to site location, as well as account for any unknown costs which cannot be predicted at this early project phase. Class D cost estimates have been provided in Appendix C. The Class D estimates for total construction capital costs for the three sites were:

- Site 1 – $13,147,000
- Site 3 – $28,237,000
- Site 4 – $30,943,000

11.2 Annual Operations and Maintenance (O&M) Costs

Order-of-magnitude O&M estimates were developed by a Professional Quality Surveyor (Altus). Costs are in 2022 Canadian Dollars. Detailed O&M cost estimates are provided in Appendix C. The following assumptions have been made to develop the O&M estimates:

- Water treatment plant runs – 12 hours/day, 5 days/week
- Operating labour (WTP operation, truck deliveries, wastewater collection, snow removal and road maintenance as required)
        - 5 full time employees – 8 hours/day, 5 days/week
        - 1 supervisor – 8 hours/day, 2 days/week
        - 52 weeks, 12 months

- Truck delivery fuel
  - Assume 4 trucks at 12,000 L capacity
    - Deliveries – 5 days/week, 8 hours/day
    - Fuel consumption = ~200 L of diesel for one truck per day
    - Diesel cost = $2.00/L
    - Annual truck fuel cost = $104,000/truck/year x 4 trucks = $416,000/year
- Energy (WTP Building)
  - Electrical consumption (from SWTT Cost Estimate, 2021)
    - process load is estimated at 75 kW (SWTT Cost Estimate 2021), operating at 12 hours/day, electrical process load = 900 kWh per day. At 5 days/week, annual electrical process load = 234,000 kWh
    - other electrical usage will be small (area lighting, fans, misc. equipment). Annual misc. electrical load = 20,000 kWh
    - Electrical cost ($1.15/kWh), inclusive of demand and consumption charges
    - Total annual electrical cost = $292,000/year
  - Heating fuel (from SWTT Cost Estimate, 2021)
    - Estimated that the WTP building will use approximately 1000 Million British Thermal Units (MBTU) and assuming diesel cost of $35.24/MBTU, annual heating cost for the WTP = ~$40,000/year
- Chemical costs are estimated at $40,000/year
- Training costs are estimated at $10,000/year
- Regulatory and Routine water testing (from SWTT Report, 2021) = $84,000
- Replacement of membranes (required on 5-year basis) – assumed cost of $75,000 in replacement years
- Certified operator to run the facility for initial startup and provide operator training for 6 months – assumed $300,000
- UV Lamp Replacement – assumed $5,000 (every 4 years)
- Truck replacement x four (4) included in lifecycle – assumed cost of $65,000 in purchase years

The proposed WTP at Site 3 and Site 4 would require an additional raw water transmission line and pump house. Additional O&M considerations for Site 3 and Site 4 include:

- Additional energy costs for transmission line heating and recirculation (Site 3 and Site 4)
  - Reheat water for the transmission pipeline
    - Calculated heat loss across the length of the pipe (ambient ground temperature = -15°C, k = 0.024 W/mC for polyurethane insulation, water temp in = 4°C)
      - Site 3 heat loss (average) = ~80,000 W
        - Total Heat input (annual) = 700,800 kWh = 2,391 MBTU/year
        - Total heating cost (annual) = 2,391 MBTU x $35.24 = $85,000/year
      - Site 4 heat loss (average) = ~90,000 W
        - Total Heat input (annual) = 788,400 kWh = 2,690 MBTU/year
        - Total heating cost (annual) = 2,690 MBTU x $35.24 = $95,000/year
  - Recirculation electrical energy (Sites 3 and 4)
    - Assuming recirc pump (30m pumping head @ 2L/s), annual electrical consumption = ~14,000 kWh/year

    - @$1.15/kWh
    - Total electrical cost for recirculation (annual) = $16,000/year
- Site 3 and Site 4 – freeze up events or winter pipe maintenance for the transmission pipeline – assumed $50,000 every 3 years

The annual O&M estimates for the three sites were:

- Site 1 – $1,899,304/year
- Site 3 – $2,031,984/year
- Site 4 - $2,043,809/year

11.3 Life Cycle Costs

The total 30-year cost for major repair and rehabilitation works was estimated at:

- Site 1 – $6,236,701
    - Annual average = $207,890/year
- Site 3 – $7,877,107
    - Annual average = $262,570/year
- Site 4 –$8,282,518
    - Annual average = $276,084/year

Assumptions and allowances made in the development of the lifecycle portion of this estimate include: design and pricing contingency of 10% is included; oncosts of 20% included to account for isolated lifecycle projects; and project management fee of 15%. Detailed life cycle cost breakdowns are provided in Appendix C.

12 Options Evaluation Scheme

12.1 Methodology and Ranking Criteria

Site 1, Site 3 and Site 4 will be compared based on appropriate scoring and weightings to determine the preferred site for the new WTP at Arctic Bay. The evaluation will consider factors of Technical, Compliance, Operational, Socio-Economic and Economic Feasibility. Within these factors sub-criteria have been developed to evaluate the three potential sites and is provided in the table below.

The evaluation applies a weighting to the specific criteria items. The weighting used is 1 through 10, with 10 being the strongest weighting for a given criteria. The sites are then scored according to the criteria from 1 through 10, with 10 being the highest score. The relative weights of the objectives are based upon an objective perspective on this project. Relative weighing and scoring will be reviewed and discussed with the GN-CGS and community council.

Table 12-1: Options Evaluation - Ranking Criteria

No	Criteria	Information	Weighting Factor
1	Capital Costs	Capital cost is the estimate of the opinion of the probable cost of each option based upon a planning level estimate (Class D). This is a preliminary estimate which, because of limited site information, and indicates the approximate magnitude of the cost of the proposed option. A low capital cost is the desired objective.	9
2	O&M Costs	Operations and maintenance cost is an estimate of operations and maintenance costs of each option and has been completed as part of the Class D cost estimate. A low operations and maintenance cost is the desired objective.	9
3	Ease of Constructability	Constructability refers to the anticipated ease with which the construction may advance for a given option. Notable considerations include site development works (earthworks, site preparation and drainage improvements), geotechnical, construction of access road and electrical works to connect to the QEC grid. An easily constructed facility is the desired objective.	10
4	Community Acceptance and Aesthetic Impact	Community acceptance refers to the preference of each option from community residents. Notable considerations include potential land-use conflicts and proximity issues (human activities, natural and cultural features). Also includes aesthetic impact that each option may have on community residents. High community acceptance and low aesthetic impact is the desired objective.	8
5	Service Life / Sustainability	Service life is the overall anticipated operating lifespan of a facility from the time of its original construction. A long service life is the desired objective.	6
6	Environmental Risk	Environmental risk refers to the potential environmental events such as flooding, landslide and other climate-change related impacts (permafrost settlement). A low environmental risk is the desired objective.	7
7	Performance Risk	Performance risk refers to the ability for an option to maintain continuous operations of the WTP (and existing WTP) while meeting all compliance requirements. A low performance risk is the desired objective.	7
8	Space for Future Expansion	Future expansion refers to the ease of expansion that each option will accommodate at some point in the future. An option that has space for future expansion is the desired objective.	4
9	Operations and Maintenance	Simple operations and maintenance refer to the level of effort required for the operators and maintenance staff. Routine maintenance must be within the abilities of local	8

		maintenance staff and resources of the community, without the need for specialized equipment or tools. Maintenance is not burdensome. Simple operations and maintenance is the desired objective.	
10	Public Safety	Minimizes traffic from water delivery trucks including safety of operators or maintenance staff. No hazardous structures or facilities to which the public can access.	6
11	Fire Protection Considerations	Fire protection refers to the preferred option to improve firefighting response and ability to respond to fire events.	8

12.2 Options Evaluation

Table 12-2 provides some discussion comparing Site 1, Site 3 and Site 4 according to the ranking criteria.

Table 12-2: Options Evaluation - Comparison

No	Criteria	Site 1	Site 3	Site 4
1	Capital Costs	Capital costs for Site 1 was estimated at $13,147,000. Site 1 will be assigned a score of 10.	Capital costs for Site 3 was estimated at $28,237,000. Site 3 has a significantly higher capital cost compared to Site 1 due to the additional components (raw water transmission line and pump house). Site 3 will be assigned a score of 5.	Capital costs for Site 4 was estimated at $30,943,000. Site 4 has a significantly higher capital cost compared to Site 1 due to the additional components (raw water transmission line and pump house). Site 4 will be assigned a score of 3.
2	O&M Costs	O&M costs for Site 1 was estimated at $1,899,304/year. Site 1 will be assigned a score of 10.	O&M costs for Site 3 was estimated at $2,031,984/year. Site 3 has a significantly higher capital cost compared to Site 1 due to the additional components (raw water transmission line and pump house). Site 3 will be assigned a score of 7.	O&M costs for Site 4 was estimated at $2,043,809/year. Site 4 has a significantly higher capital cost compared to Site 1 due to the additional components (raw water transmission line and pump house). Site 4 will be assigned a score of 5.
3	Ease of Constructability	Well-known site, existing power and road infrastructure that can be utilized. The proposed WTP will be located south of the existing Environment Canada weather station. Best geotechnical conditions – relatively flat (40H:1V) and contains few ice crystals and lenses. This is the best site for ease of constructability and geotechnical conditions Site 1 will be assigned a score of 8.	Additional components to construct include a raw water transmission line (6.7 km) and pump house at Marcil Lake. Worse geotechnical conditions – site has significant slope (8H:1V) and requires significant site grading. Soils contain more ice crystals and lenses than Site 1. Site 3 will be assigned a score of 5.	Additional components to construct include a raw water transmission line (7.9 km) and pump house at Marcil Lake. Worst geotechnical conditions – steepest site slopes (6H:1V) and requires site grading. Soils contain the most ice crystals and lenses and surficially disturbed material which is not suitable for construction and would have to be excavated and disposed of. Site 4 will be assigned a score of 3.

4	Community Acceptance and Aesthetic Impact	Site 1 is located at the existing WTP site at Marcil Lake. The community is familiar with this location. Site 1 will be assigned a score of 8.	Site 3 is located closer to the community in the industrial area. This site is located next to the new QEC power plant and fuel tanks. Public perception of locating a new WTP next to these facilities (potential of contamination) may not be favourable. Site 3 will be assigned a score of 5	Site 4 is located at the edge of the community. Council has indicated that vandalism is a concern at this location. Site 4 will be assigned a score of 7.
5	Service Life/Sustainability	It is anticipated that the reduced efforts to maintain only one building at Site 1 will improve service life/sustainability compared to Site 3 and Site 4. Site 1 will be assigned a score of 8.	There are concerns with the additional efforts to maintain an additional pump house building and long transmission line. There is significant risk of freeze up and settlement issues caused by permafrost degradation of the transmission line which may require premature repairs/replacement. Site 3 and Site 4 will both be assigned a score of 5.	
6	Environmental Risk	Site 1 will be assigned a score of 8.	As noted above there are concerns about permafrost degradation which may cause settlement issues with the transmission pipeline. Migration of existing contaminants due to permafrost degradation is another concern. This risk is highest at Site 3 (industrial area with close proximity to fuel tanks/power plant) followed by Site 4 (within community) followed by Site 1 (undeveloped area). Site 3 will be assigned a score of 4. Site 4 will be assigned a score of 6.	
7	Performance Risk	The risk of prolonged interruptions is expected to be the lowest at Site 1. At Site 1 only one building needs to be operated and maintained. Site 1 will be assigned a score of 8.	The transmission line has significant risk of freezing which can lead to prolonged interruptions in water supply. The longer the transmission line, the higher the risk of freezing. Site 3 will be assigned a score of 5. Site 4 will be assigned a score of 4.	
8	Space for Future Expansion	Site 1 has ample room to expand on all sides. All sites are equally suitable for future expansion and will each be assigned a score of 5.	Site 3 is located besides the new QEC power plant being constructed. It appears that there is ample room to expand towards the east. However, the slope is also quite steep and would require significant site grading. All sites are equally suitable for future expansion and will each be assigned a score of 5.	Site 4 has ample room to expand to the east or west. However, the slope is quite steep and would require significant site grading. All sites are equally suitable for future expansion and will each be assigned a score of 5.
9	Operations and Maintenance	Site 1 is the best site to minimize O&M efforts – one location to operate and maintain equipment. Site 1 will be assigned a score of 8.	Site 3 and Site 4 will require significantly more O&M than Site 1 as there are 2 buildings and a transmission pipeline to operate and maintain. Although, snow accumulation/drifting impacts at the WTP/truckfill building are expected to be less at Site 3 and Site 4 compared to Site 1, the entire length of the road to Marcil Lake will still require snow clearing to maintain access to the pump house. Thus, total snow removal efforts are expected to be more burdensome at Site 3 and Site 4.	

			Additional effort will be required for unfreezing/thawing of the transmission pipeline. Site 3 and Site 4 will be assigned a score of 4.	
10	Public Safety	Site 1 is located at Marcil Lake and is far away from the community. There are no notable concerns regarding public safety. Site 1 will be assigned a score of 8.	Site 3 will see increased trucking activity and vehicle traffic within the industrial area. Site 3 will be assigned a score of 7.	Site 4 is most susceptible to unauthorized access/vandalism, increased trucking activity and vehicle traffic directly within the community. Site 4 will be assigned a score of 6.
11	Fire Protection Considerations	Site 1 has the longest refilling routing time. However, Site 1 has the most-reliable water supply and the lowest risk of prolonged supply interruptions. Site 3 and Site 4 reduce the refilling routing time but there is considerable risk with freezing of the pipeline and prolonged supply interruptions. There are benefits and drawbacks at each site. In our opinion, the risk of water interruptions outweighs the benefits of marginally improving routing time. Water truck availability and response time can be improved through operational procedures (increasing duty water trucks, storing full trucks within community, scheduling routes, etc.). All sites will be assigned a score of 5 as there are benefits and drawbacks at each site.		

Table 12-3 provides a summary of the scoring summary between Site 1, Site 3 and Site 4 according to the ranking criteria.

Table 12-3: Options Evaluation – Scoring Summary

No	Criteria	Weighting	Site 1 Rating	Site 1 Score	Site 3 Rating	Site 3 Score	Site 4 Rating	Site 4 Score
1	Capital Costs	9	10	*90*	5	*45*	3	*27*
2	O&M Costs	9	10	*90*	7	*63*	5	*45*
3	Ease of Constructability	10	8	*80*	5	*50*	3	*30*
4	Community Acceptance and Aesthetic Impact	8	8	*64*	5	*40*	7	*56*
5	Service Life/Sustainability	6	8	*48*	5	*30*	5	*30*
6	Environmental Risk	7	8	*56*	4	*28*	6	*42*
7	Performance Risk	7	8	*56*	5	*35*	4	*28*
8	Space for Future Expansion	4	5	*20*	5	*20*	5	*20*
9	Operations and Maintenance	8	8	*64*	4	*32*	4	*32*
10	Public Safety	6	8	*48*	7	*42*	6	*36*
11	Fire Protection Considerations	8	5	*40*	5	*40*	5	*40*
	TOTAL	(820)		***656***		***425***		***386***

12.3 Site Recommendation – Site 1

Based upon the Options Evaluation using criteria categories related to technical, compliance, operational, socio-economic and economic considerations, Site 1 is the recommended site for the new WTP at Arctic Bay.

The main considerations for the recommendation of Site 1 over Site 3 and Site 4 are related to “Ease of Constructability”, “Performance Risk” and “Operations and Maintenance”. A new WTP at Site 1 would provide the most reliable water supply system, require less effort to operate and maintain as it does not include a transmission pipeline or additional pump house building, and would require less effort to develop the site as the location is relatively flat. From a financial perspective, Site 1 has a significantly lower capital and O&M costs compared to Site 3 and Site 4.

The Hamlet Council of Arctic Bay has raised a concern about the fire protection offered with maintaining the water treatment at the current location outside of the community. The concern is associated with the travel time for water tracks to fill and return to the community and the public safety issues associated with this response time. EXP has reviewed this public safety concern and suggests that the truck filling response time will only be marginally improved with locating the water treatment facility closer to the community. The public safety concern must be weighed against the risk of prolonged water supply interruptions and freezing concerns associated with a long water supply transmission line to the sites closer to the community (Site 3 and Site 4). By eliminating the need to operate and maintain a long transmission line, Site 1 provides the community with the most reliable water supply option. Improving water truck availability and response time can be addressed through adapting operational procedures (increasing duty water trucks, increasing community fire trucks, storing full trucks within community during off-hours, scheduling routes to ensure staggering of water truck deliveries, etc.), and providing supplemental storage in the community. Discussions with the Nunavut Fire Marshal are necessary to provide additional information on the public safety concerns associated with fire suppression response times.

12.4 Fire Marshall and Hamlet Council Input – Addition of 75 m^3 Fire Fighting Storage Tank

As per discussions regarding the Hamlet’s Council Meeting and Decision regarding the WTP location (August 17, 2022), the Hamlet and Fire Marshall support the new WTP at Site 1 with the provision that an independent storage tank (75 m^3) used for fire-fighting flows be located within the community limits.

As such, the recommended site for the new WTP at Arctic Bay is Site 1. Additionally, this recommendation includes the provision of a 75 m^3 treated water storage tank (firefighting storage) within the community.

The treated water storage volume of 75 m^3 (used solely for firefighting purposes) will be provided in a single steel tank approximately 4.5 m in diameter and 4 m in height. These dimensions are to be refined following site investigations and through the detailed design. The treated water in the tank will be heated. The water temperature is not known but will likely be maintained between 5^{o}C and 10^{o}C. A steel welded tank is recommended. Provided that a proper foundation is provided, it is expected that a steel-welded tank will be more robust than a bolted tank given the harsh environment and extreme (-50°C) temperature requirements of Arctic Bay.

Both passive and active freeze protection of the treated water storage tank will be required. The passive freeze protection will take the form of insulation, protected by a cladding system. Spray-on polyurethane insulation with a steel cladding system is proposed. Active freeze protection of the treated water storage will be achieved through circulation of the tank contents through an independent heat exchanger. The boiler system will provide the heat input into the heat exchanger. Over winter, it is imperative that the tanks maintain some water volume (minimum 30%) to ensure proper freeze protection of the tank and associated equipment. The storage tank will require a boiler system and ancillary mechanical equipment that will require a designated heated shelter.

Geotechnical investigations and geothermal analyzes are required to determine the geotechnical/foundation requirements for the tank. Based on these investigations and analyzes, it can be determined if additional geotechnical/foundation considerations (i.e. thermosyphons) are required.

Location of the firefighting storage tank is still to be determined. This requires an additional site visit and discussions with city officials (Council and Fire Marshall). As shown in Figure 12-1, sites that were considered in the initial scouting study can be revisited for potential sites for the firefighting storage tank. Additional sites can be investigated following site visits and discussions with the community. Proximity to the new Fire Hall is to be considered.

Figure 12-1: Potential Firefighting Storage Tank Locations

As the 75 m^3 storage tank is to be used solely for firefighting purposes, it is recommended that operation and maintenance of this tank fall under the Fire Department. To eliminate the risk of contaminating the drinking water distribution, it is imperative that the storage tank only be used for firefighting operations and not for drinking water trucking. Ideally, the outlet of the tank could be locked with the responsibility of the keys belonging to the Fire Department.

The estimated capital cost for this additional 75,000L tank is approximately $200,000. This is dependent on the site conditions and foundation/geotechnical requirements following site investigations.

13 Summary and Recommendations

13.1 Summary and Recommendations

2. The main objective of this Business Case Report is to summarize the findings and work undertaken as part of this project. The scope of this project included the following:
    i. Initial field visit and potential site selection for the new WTP
    ii. Technical investigations
        i. Hydrological, Bathymetric and Water Balance Study including Climate Change (Saline Intrusion) Screening Study
        ii. Geotechnical Investigations
        iii. Environmental Site Assessment (Phase 1 and partial Phase 2)
        iv. Land Topographic Survey and Bathymetry Survey
        v. Wind Blowing and Snow Drifting Study
    iii. Review of existing conditions, water quality information, water quality requirements, hydrological information and proposed water treatment process trains
        i. Development of service conditions including anticipated population growth, demands and regulatory requirements over a 20-year design horizon
        ii. Development of water treatment plant components including raw water extraction, treatment, water storage requirements, fire flow requirements, power considerations, building components and geotechnical requirements.
    iv. Development of schematic designs for the preferred site locations
    v. Preparation of Class D cost estimates including capital, operations and maintenance (O&M) and life-cycle costs for the preferred sites
    vi. Options Evaluation for the preferred sites
    vii. Site recommendation for the new WTP at Arctic Bay

3. The proposed Treatment Train at Arctic Bay is:

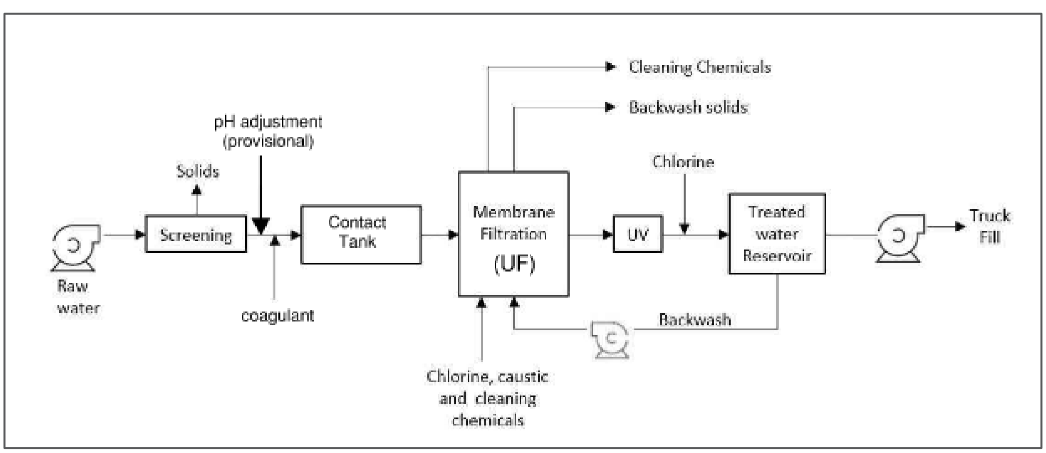


Figure 13-1: Proposed Treatment Train at Arctic Bay WTP

4. A summary of the service conditions for the proposed WTP at Arctic Bay is given in Table 13-1 below.

Table 13-1: Service Conditions Summary

Category	Parameter	Arctic Bay WTP - Design Input
Population	Population (2023)	956
	Population (2043)	1,184
Demands and Design Flows	Design Consumption Rate	120 lpcd
	Peaking Factor	2.5
	Peak Daily Demand (2043)	355,200 L/day
	WTP Production Time Per Day	12 hours/day
	WTP Design Flow	493 L/min
	Fire Flow Bypass	1000 L/min
	Truckfill Flow (Total for 2 arms)	2 x 1000 = 2000 L/min
Intake	# of Raw Water Intakes	2
	# of Raw Water Pumps	3 (2 duty, 1 spare)
	Intake Freeze Protection	Dual heat trace (duty/standby)
Truck Fill	# of Truck Arms	2
	# of Truckfill Pumps	4 (2 duty, 2 spare)
Raw Water Inlet Strainers	# of Basket Strainers	2 (1 duty, 1 spare) sized @ 500 L/min
Contact Tank	Contact Time	10-30 mins depending on required flocculation/coagulation time
Membrane Filtration	# of trains	N+1 or N+2
	Membrane Recovery Rate	>95%
UV	# of UV reactors	2 @ 100% design capacity
Chlorination	CT Time *	120 minutes
Iron and Manganese	Iron and Manganese Treatment	Not required
Corrosion Control (provisional)	Corrosion Control Treatment	Direct chemical addition
Fluoridation (provisional)	Fluoridation	Fluoridation skid
Treated Water Storage	Firefighting Volume	N/A (fire flow provided through bypass)
	Equalization (EQ) Volume	118 m^3
	CT Volume	240 m^3
	Emergency Volume	N/A
	Plant Use Volume	36 m^3
	Dead Volume	-
	Total Treated Water Storage	394 m^3
	Tank Freeze Protection	Recirculation
Wastewater Storage	Wastewater Volume	249 m^3
	Tank Freeze Protection	Immersed heater
Raw Water Storage	Type of raw water storage	Existing reservoir (Marcil Lake)
	Capacity upgrade required?	Not required

5. An initial scouting study to identify potential sites was completed. Eight (8) potential sites for the new WTP were identified. From these eight sites, Site 5, Site 6 and Site 7 were eliminated from further consideration due to land use conflicts, significant freezing risks due to length of raw water transmission line, excessive slopes on the site and constructability considerations.

6. Following site visits by representatives of EXP and GN-CGS and discussions with the Hamlet's community council, Site 2 and Site 8 were also eliminated from further consideration due to constructability concerns, contamination concerns and land-use conflicts.

7. Following the screening process, the three preferred sites for the new WTP were Site 1, Site 3 and Site 4. Additional technical assessments (Hydrological & Water Balance Study, Geotechnical Investigations, Phase 1 Environmental Site Assessment, Topographic and Bathymetry Survey, Wind Blowing and Snow Drifting Study) were completed for the three preferred sites.
    - Site 1 – located adjacent to the existing WTP and the existing lake reservoir (Marcil Lake).
    - Site 3 – located next to the new Power Plant which is currently under construction by QEC. It is located approximately 6.6 km north of Marcil Lake reservoir and approximately 1.3 km south of the community.
    - Site 4 – located adjacent to the community on the road to the existing Water Treatment Plant and is approximately 7.9 km (along the existing access road) from Lake Marcil reservoir.

8. Based on the hydrology analysis and bathymetric survey, the existing water source (Marcil Lake watershed) and reservoir (Marcil Lake) is adequate to meet the needs of the community for the 20-year design horizon without supplementary pumping or capacity upgrades to the reservoir. The size of the Marcil Lake watershed is extremely large at 12,660 Ha and is expected to provide significant volumes of water to recharge Marcil Lake. Marcil Lake has substantial reserve storage volume that can easily accommodate the community's water supply needs. The deepest part of Marcil Lake is 35 m and has an estimated useable operational storage of approximately 14,500,000 m^3.
    i. Results of the Climate Risk / Saline Intrusion potential screening for Marcil Lake suggest that for the "normal" (i.e. median) climate change projection scenarios, that site conditions provide for adequate buffer with low risk of saltwater intrusion up until at least 2100. However, for a scenario of more extreme climate change (e.g. SSP5-8.5 low confidence scenario) there is significant potential for climate change to impact the lake by overtopping and/ or breaching of the lower lying lake outfall area located along the northwest portion of the ridge that separates Marcil Lake from Arctic Bay.

9. The proposed WTP will continue using Marcil Lake as the primary water source for the community of Arctic Bay – no additional upgrades to the existing road infrastructure or capacity upgrades to the reservoir are anticipated.

10. The proposed WTP shall be provided in a modular building approximately 26 m x 13 m.

11. The scope of the new WTP includes site development, new WTP (building, process, electrical, mechanical), dual raw water intakes, storage tanks (treated, wastewater) and transmission/recirculation line from pump house to WTP (only for Site 3 and Site 4).

12. Capital cost estimates (Class D) were prepared for all three sites. The capital costs for Site 3 and Site 4 are significantly higher than Site 1 due to the additional transmission pipeline and pump house building. The estimated capital costs for the three sites are:
    - Site 1 capital costs = $13,147,000
        - A provision of $200,000 is included for the in-town firefighting storage tank (75m^3)
        - Thus, the Site 1 total capital costs = $13,347,000
    - Site 3 capital costs = $28,237,000
    - Site 4 capital costs = $30,943,000

13. Operations & Maintenance (O&M) costs were prepared for all three sites. The O&M costs for Site 3 and Site 4 are significantly higher than Site 1 due to the additional efforts to operate and maintain the transmission pipeline and pump house building. The estimated O&M costs for the three sites are:
    - Site 1 annual O&M costs = $1,899,304/year
    - Site 3 annual O&M costs = $2,031,984/year
    - Site 4 annual O&M costs = $2,043,809/year

14. The total 30-year lifecycle costs for major repair and rehabilitation works are estimated at:
    - Site 1 – $6,236,701
        - Annual average = $207,890/year
    - Site 3 – $7,877,107
        - Annual average = $262,570/year
    - Site 4 –$8,282,518
        - Annual average = $276,084/year

15. An Options Evaluation was completed for the three preferred sites (Site 1, Site 3, Site 4). The criteria included a comparison based upon: capital costs; O&M costs; ease of constructability; community acceptance and aesthetic impact; service life/sustainability; environmental risk; performance risk; space for future expansion; operations and maintenance; public safety; and fire protection considerations. The evaluation applied weighting to specific criteria items. The sites were then scored according to the criteria.

16. The results from the Options Evaluation:
    - Site 1 – Total score = 656
    - Site 2 – Total score = 425
    - Site 3 – Total score = 386

17. Based upon the Options Evaluation, it is recommended that Site 1 be used as the site for the new WTP at Arctic Bay and advanced toward detailed design and implementation. Out of the three potential locations, a new WTP at Site 1 would provide the most reliable water supply system, require the least amount of effort to operate and maintain as it does not include a transmission pipeline or additional pump house building, and would require the least amount of effort to develop the site as the location is relatively flat.

18. As per discussions regarding the Hamlet's Council Meeting and Decision regarding the WTP location (August 17, 2022), the Hamlet and Fire Marshall support the new WTP at Site 1 with the provision that an independent storage tank (75 m^3) used for fire-fighting flows be located within the community limits.
    i. The treated water storage volume of 75 m^3 (used solely for firefighting purposes) will be provided in a single steel tank approximately 4.5 m in diameter and 4 m in height. A steel welded tank with both passive and active freeze protection is recommended.
        i. Additional site visits, geotechnical investigations and discussions with community officials (Council and Fire Marshall) is required to finalize site location for the firefighting storage.
        ii. The estimated capital cost for this additional 75 m^3 tank is approximately $200,000. This will be dependent on the site conditions and foundation/geotechnical requirements following site investigations.

14 Legal Notification

This report was prepared by EXP Services Inc. for the account of the Government of Nunavut.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. EXP Services Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this project.

Appendix A – Scouting Study

1. **Scouting Study for Potential Water Treatment Plant Sites (EXP) – Arctic Bay (Revision 2: August 27, 2021)**

Hamlet of Arctic Bay - Scouting Study for Potential Water Treatment Plant Sites

Prepared by: Ken Johnson, RPP, P.Eng and Chris Keung, MASc. (Revision 2: August 27, 2021)

Notes: Refer to Table entitled "Hamlet of Arctic Bay Scouting Study for Potential Water Treatment Plant Sites" for additional information on the Scouting Study

REGISTERED PROFESSIONAL PLANNER
R.P.P.
K.R. JOHNSON

Hamlet of Arctic Bay - Scouting Study for Potential Water Treatment Plant Sites
Prepared by: Ken Johnson, RPP, P.Eng and Chris Keung, MASc. (Revision 2: August 27, 2021)

exp.

Notes: Refer to Table entitled "Hamlet of Arctic Bay Scouting Study for Potential Water Treatment Plant Sites" for additional information on the Scouting Study

HAMLET OF ARCTIC BAY SCOUTING STUDY FOR POTENTIAL WATER TREATMENT PLANT SITES

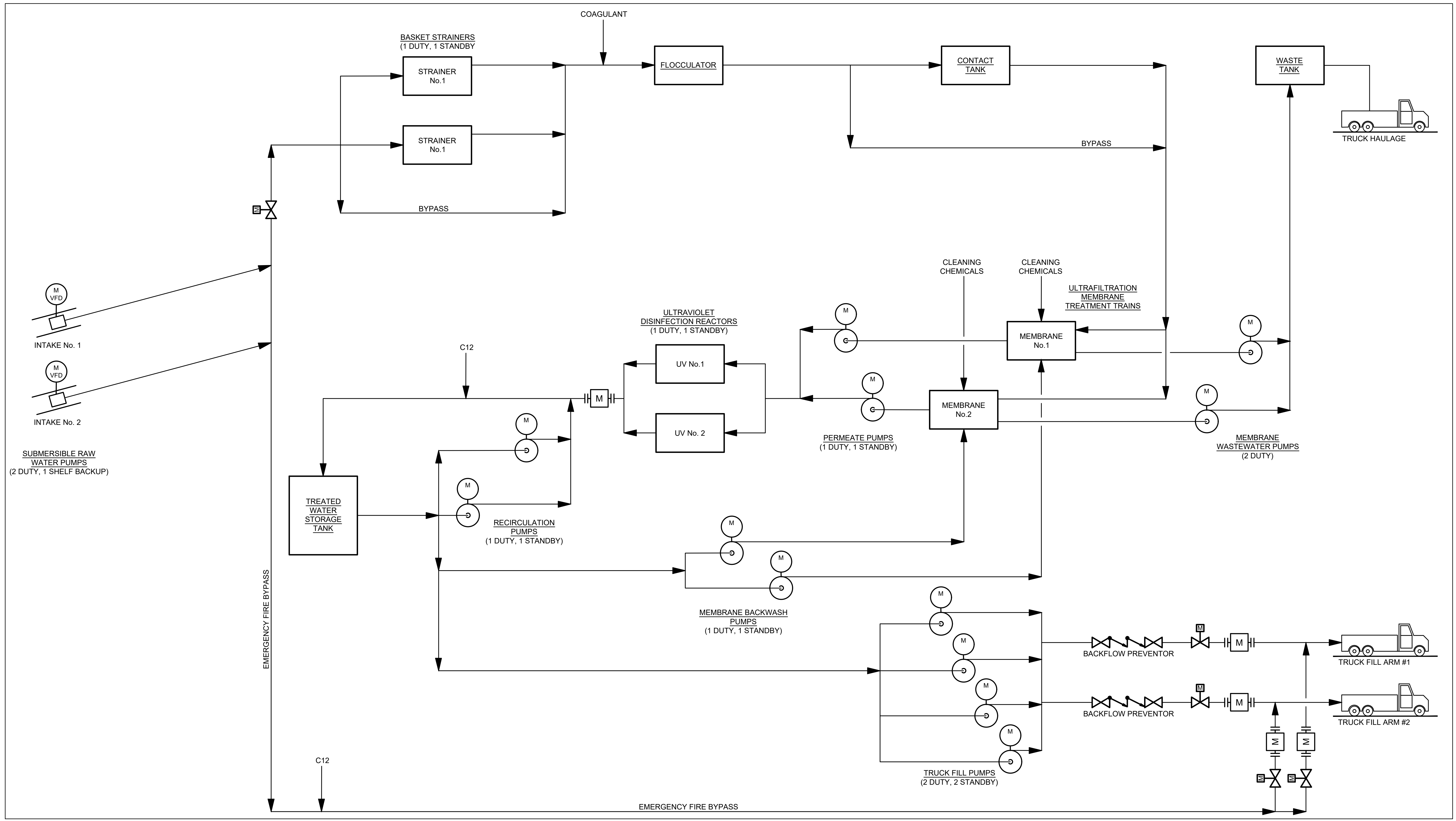
Legend	
(green)	Short-Listed Sites
(pink)	Screened Sites

Site No	Water Source	Raw Water Supply Method	Raw Water Supply Distance to WTP	Trucking Distance to Core Community	Additional Considerations	Trucked Delivery To Community (< 3km)	No Raw Water Supply Line Required	Reduced Freeze Risk (Supply line less than 3km)	Minimzed Disturbance to Community (Public Health and Safety considerations)	No Land Use Conflicts	Slope flatter than 10H:1V	TOTAL
1 (existing)	Marci Lake	Treat at Source	0 km	9.2 km	- sufficient space at existing site to maintain existing WTP during construction - site is relatively flat		✓	✓	✓	✓	✓	5
2	Marci Lake	piped raw water supply or bulk haul	3.3 km	5.9 km	- at edge of airport (relatively well-maintained road) - freeze risk of raw water supply line			✓	✓	✓	✓	4
3	Marci Lake	piped raw water supply or bulk haul	6.7 km	2.5 km	- located near industrial area - potential site of new power plant? -significant freeze risks due to length of raw water supply (piped option) - significant trucking efforts and raw water storage footprint for raw water delivery (bulk haul option)	✓			✓	✓	✓	4
4	Marci Lake	piped raw water supply or bulk haul	7.9 km	1.3 km	- located just east of main core community -significant freeze risks due to length of raw water supply (piped option) - significant trucking efforts and raw water storage footprint for raw water delivery (bulk haul option)	✓			✓	✓		3
5	Marci Lake	piped raw water supply or bulk haul	9.2 km	0 km	- located in core community on access road leading up to the lagoon -significant freeze risks due to length of raw water supply (piped option) - significant trucking efforts and raw water storage footprint for raw water delivery (bulk haul option) - existing ground not relatively flat	✓				✓		2
6	Marci Lake	piped raw water supply or bulk haul	8.8 km	0.4 km	- within community use site (future fire hall site) -significant freeze risks due to length of raw water supply (piped option) - significant trucking efforts and raw water storage footprint for raw water delivery (bulk haul option)	✓						1
7	Marci Lake	piped raw water supply or bulk haul	8.4 km	0.8 km	- within community use site (currently Innujaq School) -significant freeze risks due to length of raw water supply (piped option) - significant trucking efforts and raw water storage footprint for raw water delivery (bulk haul option)	✓					✓	2
8	Marci Lake	piped raw water supply or bulk haul	9.1 km	0.1 km	- just east of Future Elder's Center (within Open Space) -significant freeze risks due to length of raw water supply (piped option) - significant trucking efforts and raw water storage footprint for raw water delivery (bulk haul option)	✓				✓		2

** 5.8km to airport (relatively well-maintained road)
** regardless, road to pumphouse (Marci Lake) will have to maintained
** exclude site 7 - site of Innujaq School. Exclude site 5 - slope of existing ground, site 6 - land use conflicts

Appendix B – Schematic Design Figures

1. **Process Flow Diagram (EXP) – Arctic Bay (May 2022)**
2. **Conceptual WTP Building Layout (EXP) – Arctic Bay (May 2022)**
3. **Conceptual Design and Site Layouts (EXP) for Site 1, Site 3 and Site 4 – Arctic Bay (May 2022)**



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DESIGN C.K.	ARCTIC BAY TREATMENT	SCALE N.T.S.
DRAWN M.M.A.		SKETCH NO
DATE MAY 2022	PROCESS FLOW DIAGRAM	FIG 4.2
FILE NO ___		

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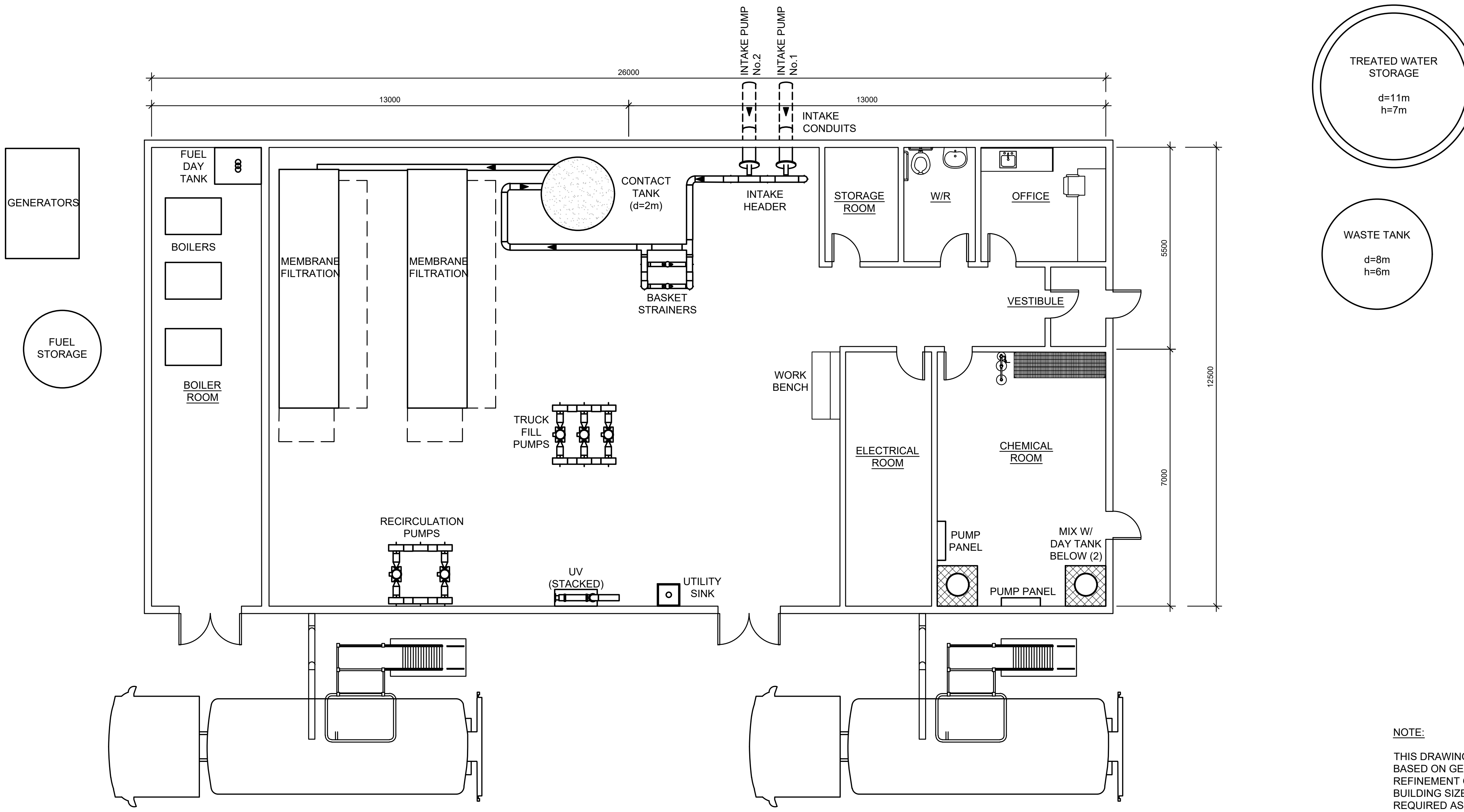
Last Saved: Mar 15, 2022 4:20 PM Last Plotted: May 24, 2022 11:08 AM Plotted by: Billiald



NOTE:

THIS DRAWING REPRESENTS A CONCEPTUAL LAYOUT BASED ON GENERAL EQUIPMENT SIZING ONLY. REFINEMENT OF THE LAYOUT DRAWING INCLUDING BUILDING SIZE, TANK SIZE AND CONFIGURATION WILL BE REQUIRED AS PART OF NORMAL ENGINEERING DESIGN, BASED ON ACTUAL EQUIPMENT MANUFACTURER SELECTIONS, ROUTING OF PIPING, MAINTENANCE ACCESS FOR EQUIPMENT, AND OTHER FACTORS.

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DESIGN C.K.	ARCTIC BAY – CONCEPTUAL		SCALE 1:125
DRAWN M.M.A.			SKETCH NO
DATE MAY 2022	WTP BUILDING LAYOUT		FIG 7-1
FILE NO ___			

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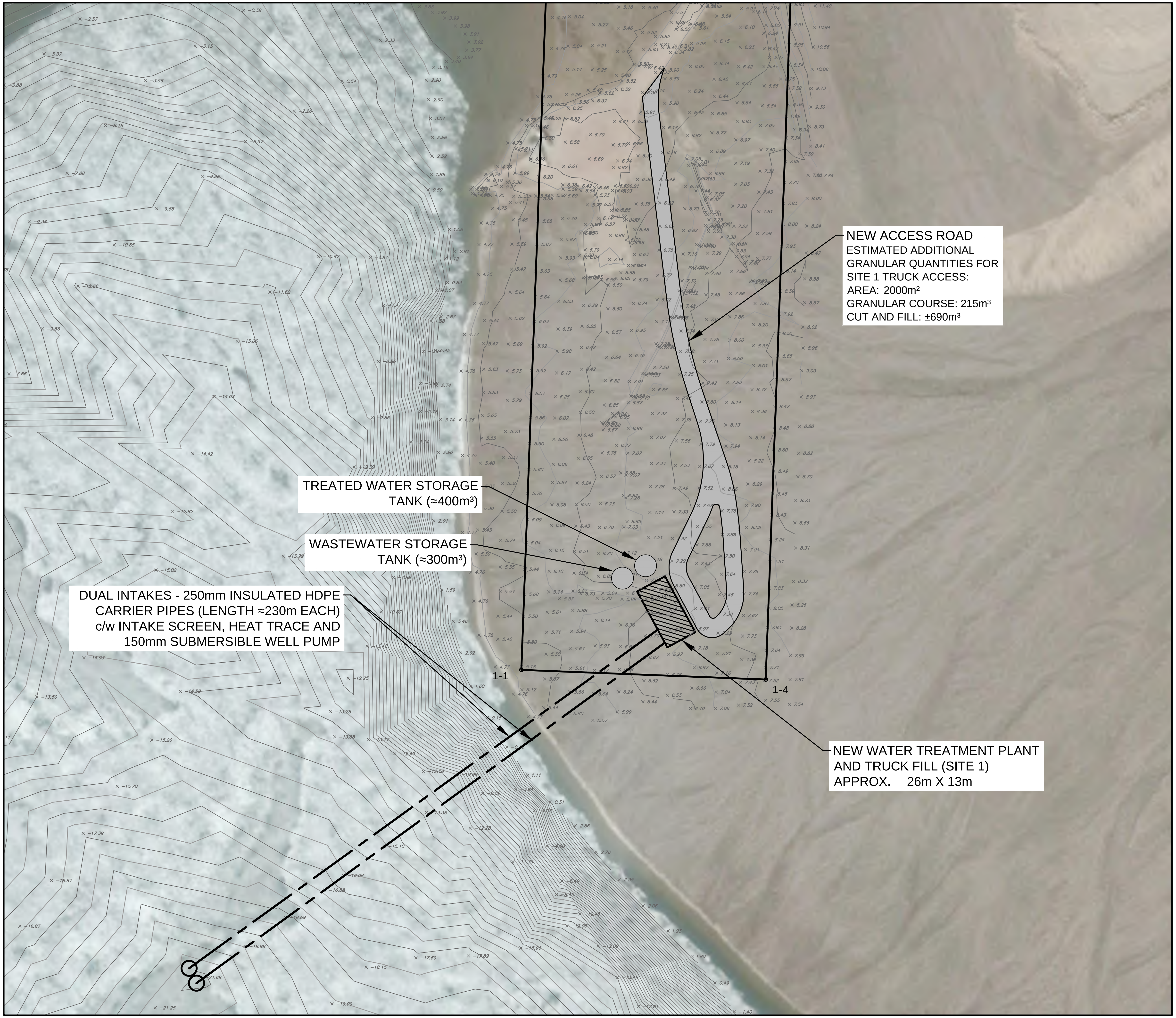

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No.	Issue	Date

N

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:1500 — 0, 30, 60 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
SITE 1 WTP AND
TRUCKFILL
CONCEPTUAL DESIGN**

Project No.

FRN-21016638-A0

Dwg. No.

FIGURE 9-4

Rev. No.

0

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No.	Revision	Date

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Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:25000 — 0 500 1000 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY - SITE 3 & SITE 4 RAW WATER TRANSMISSION LINE CONCEPTUAL DESIGN

Project No.

FRN-21016638-A0

Dwg. No.

FIGURE 9-5

Rev. No.

0

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No.	Revision	Date

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Dwg Standards Ckd By:	
Designed By:	CK
Design Checked By:	
Scale: 1:1500	0 30 60 m

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY SITE 3 AND 4 PUMP HOUSE CONCEPTUAL DESIGN

Project No.

FRN-21016638-A0

Dwg. No.	Rev. No.
FIGURE 9-6	0

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No.	Revision	Date

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Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:1000 0 20 40 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
TOPOGRAPHIC SURVEY
SITE 3**

Project No.
FRN-21016638-A0

Dwg. No.
FIGURE 9-7

Rev. No.
0

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:1000 (0 – 20 – 40 m)

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY TOPOGRAPHIC SURVEY SITE 4

Project No.

FRN-21016638-A0

Dwg. No.

FIGURE 9-8

Rev. No.

0

Appendix C – Cost Estimates

1. **Arctic Bay Water Treatment Plan Class D Estimate (Altus Group) – Capital Costs (March 15, 2022)**
2. **Arctic Bay Water Treatment Plan Annual Maintenance and 30 Year LifeCycle Estimate (Altus Group) – (May 12, 2022)**

ARCTIC BAY WATER TREATMENT PLANT
CLASS D ESTIMATE

13130.101307

PREPARED FOR:

EXP

Suite 100 - 2650 Queensview Drive, Ottawa, ON, K2B 8H6

PREPARED BY:

Altus Group - Cost & Project Management

2020 4th Street SW, Suite 310, Calgary, AB, T2S 1W3
Phone: (403) 508-7770
Issued Date: R1 - March 15, 2022

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March 15, 2022 Project No.: 13130.101307

EXP
Suite 100 - 2650 Queensview Drive
Ottawa, ON
K2B 8H6

Attention: Christopher Keung

Re: Arctic Bay Water Treatment Plant, Class D Estimate R1

Dear Christopher,

We submit for your review our Class D Estimate, at Q1 2022 in accordance with the terms of our engagement.

The estimate includes all direct and indirect construction costs and general conditions, as well as contractor's overheads and profit. The provisions for contingencies are based on the information provided and defined within the body of this report.

The estimate includes the following contingencies, which are defined within the body of this report.

- 15% for design and pricing contingency
- 0% post-contract contingency - EXCLUDED
- 8% for escalation contingency

It should be noted that this report is not intended for general circulation, publication or reproduction for any other person or purpose without express written permission to each specific instance.

Furthermore, this report was written for the exclusive use of EXP and Government of Nunavut and is not to be relied upon by any other party. Altus Group Limited does not hold any reporting responsibility to any other party.

Should you have questions related to this report please do not hesitate to contact the undersigned.

Yours truly,

ALTUS GROUP LIMITED

David Jollimore, PQS
Senior Cost Consultant

David Crane

David Crane, PQS, MRICS
Senior Director

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REPORT CONTENTS

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1 Introduction

1.1 Scope

This estimate consists of a modular Arctic Bay Water Treatment Plant project located in Arctic Bay, Nunavut.

Scope of work includes one modular water treatment plant, decommissioning of existing plant, one waste water storage tank, one treated water storage tank, a new pump house, and associated site/utility work to service the water treatment plant. This estimate provides pricing for three site options (site 1, 3 and 4).

The Construction Estimate is intended to provide a realistic budget based on the information provided. The estimate reflects our opinion as to the fair market value for the construction of this proposed project and is not intended to predict the lowest bid.

The estimate includes all direct and indirect construction costs consistent with the information available. Certain exclusions and qualifications may apply; please refer to the detail within the estimate report.

1.2 Area / Project Statistics

The areas have been measured in accordance with the Canadian Institute of Quantity Surveyors (CIQS) Standard Method of Measurement. Detailed areas and project statistics are included in Appendix A.

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2 Project Details

2.1 General Information

From the information provided, we have measured quantities where possible and applied unit rates considered competitive for a project of this nature, based on historical and current cost data for this type of project. Where design information was limited, we have had discussions with the relevant design disciplines and/or made assumptions based on our experience with projects of a similar type, size, and standard of quality.

2.2 Location

The location cost base for this estimate is Arctic Bay, Nunavut.

2.3 Measurement and Pricing

The estimate has been derived using generally accepted principles on method of measurement as per the Canadian Institute of Quantity Surveyors Elemental Cost Analysis and/or Method of Measurement of Construction Works.

The rates used and developed for this estimate where applicable include labour and material, equipment, and subcontractor's overheads and profit. Pricing is based on our experience with similar projects, or quotes provided by subcontractors as noted within the estimate.

The unit rates in this estimate are indicative of current market conditions and do not account for periods of extreme market volatility, or escalation during construction, unless noted otherwise in the estimate. These unit rates can be considered current and accurate for the current period.

This estimate is not intended to be a prediction of the lowest bid and assumes competitive bidding for all aspects of the work.

A Class D Estimate, has an accuracy range with an expected variance of -30% - +50%.

2.4 Environmental Sustainability

The estimate incorporates design elements consistent with Green Standards as identified within the design information. Although the design and pricing incorporates energy efficient and sustainable elements, actual certification with a regulatory body is not necessarily included. Premium costs could be applicable relating to additional site management required and submission of necessary documentation.

2.5 Taxes

The Goods and Services Tax (GST) has been excluded from this estimate.

2.6 General Requirements and Fees

The fee for the General Contractor is included. The general requirements are based on our assumptions of the anticipated construction approach and schedule.

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2 Project Details

2.7 Procurement Methodology

We have assumed that the project would be procured with a General Contractor approach under a CCDC standard form of contract.

We have assumed a minimum of three bids would be received for all trade categories to establish competitive bidding and tender results. The estimate is a determination of fair market pricing and not a prediction of lowest bid in any trade category. Please note that should the above minimum bidding conditions not occur on this project, construction bids received could vary significantly from the estimated costs included within this report.

2.8 Schedule / Phasing

The project has been priced to be completed as a single phase. The unit rates in our estimate are based on construction activities occurring during normal working hours and proceeding within a non-accelerated schedule.

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3 Scope Assumptions and Exclusions

3.1 Construction Budget Assumptions

1. Tender date of Q1 2023
2. Project duration of 2 months
3. Materials such as liner. textiles, etc. are assumed to be barged to site from major port
4. Assumed at fill/granular material will be locally sourced
5. Contractor is assumed to come from Iqaluit
6. Local accommodations are available, no camp required
7. Material quantities based on architect's/engineer's quantities, when provided
8. Decommissioning of existing water treatment plant
9. Water treatment building dimensions 26m x 13m
10. Two filler stations

3.2 Construction Budget Exclusions

The following items are excluded from the estimate:

1. Land and associated costs
2. Utility connection costs/charges
3. Soft costs and professional fees
4. Development and Building Permits
5. Legal fees
6. Marketing/promotion
7. Realty taxes, levies, insurance
8. Operating expenses
9. Interest/finance charges
10. Remedial work to existing buildings/structures/property (unless noted)
11. Premiums for removal/treatment of contaminated soil
12. Vibration/noise control premiums
13. DAF
14. Owner supplied FF&E (except as noted)
15. Municipal off site services connection
16. Construction contingency
17. COVID-19 contingency
18. GST

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4 Contingencies

4.1 General

The effective use of contingencies in construction cost planning requires a clear understanding of estimating risks in both a project specific and general construction market sense. The appropriate level of contingency is dependent on the amount of information available, knowledge of the design teams' methods and philosophy, the timing of the estimate preparation relative to the project design and construction schedule, and the anticipated complexity of the construction work.

4.2 Design and Pricing

A design and pricing contingency of 15% has been included in the estimate.

This contingency covers the design and pricing evolution during the remaining design stages of the project. Please note this contingency is not intended to cover additional scope or additional functional program requirements.

4.3 Escalation

An escalation contingency of 8% has been included in the estimate. This contingency is intended to address anticipated changes in construction costs due to market fluctuations between the date of this report and the anticipated tender date of Q1, 2023.

4.4 Construction Contingency (Post-Contract)

A construction contingency has been excluded from the estimate. It is the intention of this contingency to cover post-contract change orders.

4.5 COVID-19

The COVID-19 pandemic has the potential to materially impact the project construction budget beyond the estimate provided herein and outside of "standard" project contingencies. This estimate does not include any potential COVID-19 related impact costs. We recommend that EXP / Government of Nunavut assess each project individually and apply an appropriate contingency.

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5 General Statement of Liability

5.1 Probable Costs and Ongoing Cost Control

Altus Group Limited does not guarantee that tenders or actual construction costs will not vary from this estimate. Acute market conditions, proprietary specifications, or competition/collaboration among contractors may cause tenders to vary from reasonable estimates based on normal and abnormal competitive conditions.

Altus Group Limited recommends the owner and/or design team review the cost estimate report including line item descriptions, unit prices, allowances, assumptions, exclusions, and contingencies to ensure the appropriate design intent has been accurately captured within the report.

It should be noted that the cost consultants are not qualified to confirm that construction work and design is in accordance with approved plans and specifications.

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6 Estimate Documentation

6.1 Documentation

Page Count	Description	Date Received
69	2021.12.20-Technology ASsessments for New Water Treatment Facilities_DRAFT	February 10, 2022
5	Arctic Bay Schematic Design Figures.pdf	February 10, 2022
1	1-Arctic Bay - CONCEPTUAL FOOTPRINTS	February 10, 2022

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7 List of Appendices

7.1 Class D Estimate

A. Project Statistics

B. Executive Summary

C. Elemental Summary & Details - Water Treatment Plant Modular Building

D. Elemental Summary & Details - Processing Equipment & Tanks

E. Elemental Summary & Details - Site Option 1 (Existing)

F. Elemental Summary & Details - Site Option 3

G. Elemental Summary & Details - Site Option 4

I. Provisional Pricing

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Project Statistics

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FLOOR DETAILS

GFA FLOOR DETAILS

Arctic Bay WTP Modular Building	Enclosed Area (m²)	Void (m²)	GFA (m²)	GFA (sf)	Perimeter (m)	Height (m)	Wall (m²)
L1 GFA	338	-	338	3,638	78	3.60	281
B Sub-Total	338		338	3,638	78	3.60	281

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Executive Summary

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	Site Option 1			Site Option 3			Site Option 4		
Building Component	Area (m2)	Unit Rate	Total	Area (m2)	Unit Rate	Total	Area (m2)	Unit Rate	Total
Modular Building WTP	338 m2	$19,058 /m2	$6,441,706	338 m2	$19,058 /m2	$6,441,706	338 m2	$19,058 /m2	$6,441,706
Processing Equipment	1 sum	$3,098,509	$3,098,509	1 sum	$3,098,509	$3,098,509	1 sum	$3,098,509	$3,098,509
Site Development	9,420 m2	$122 /m2	$1,148,045	9,416 m2	$1,425 /m2	$13,416,418	9,424 m2	$1,657 /m2	$15,616,513
Pre-contingency Subtotal (GFA)	338 m2	$31,622 /m2	$10,688,260	338 m2	$67,919 /m2	$22,956,633	338 m2	$74,428 /m2	$25,156,728
Design & Pricing Contingency (15.0%)			$1,603,239			$3,443,495			$3,773,509
Design Contingency Subtotal (GFA)	338 m2	$36,365 /m2	$12,291,499	338 m2	$78,107 /m2	$26,400,128	338 m2	$85,592 /m2	$28,930,237
Escalation Contingency (8.0%)			$855,061			$1,836,531			$2,012,538
Construction Contingency (0.0%)			Excluded			Excluded			Excluded
Total Construction Cost (GFA)	338 m2	$38,895 /m2	$13,146,560	338 m2	$83,540 /m2	$28,236,659	338 m2	$91,547 /m2	$30,942,775
GST			Excluded			Excluded			Excluded
Total Construction Cost	338 m2	$38,896 /m2	$13,147,000	338 m2	$83,541 /m2	$28,237,000	338 m2	$91,547 /m2	$30,943,000

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Elemental Summary & Details - Water Treatment Plant Modular Building

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ELEMENTAL SUMMARY
ARCTIC BAY WTP MODULAR BUILDING

$6,956,000
ARCTIC BAY WTP MODULAR BUILDING
TOTAL

$20,580/m² TOTAL /m² | 338 m²
$1,912/sf TOTAL /sf | 3,638 sf COMP. GFA

Element	GFA Ratio	Element Quantity	Element Unit Rate	Cost Total	$ Total /m2 GFA	%
A SHELL				1,932,145	5,716 /m2	27.8%
A1 Substructure				719,296	2,128 /m2	10.3%
A11 Foundations	1.00	338 m2	2,128 /m2	719,296	2,128 /m2	10.3%
A2 Structure				648,689	1,919 /m2	9.3%
A21 Lowest Floor Construction	1.00	338 m2	1,574 /m2	532,112	1,574 /m2	7.6%
A23 Roof Construction	1.00	338 m2	345 /m2	116,576	345 /m2	1.7%
A3 Exterior Envelope				564,160	1,669 /m2	8.1%
A31 Walls Below Grade	0.36	123 m2	500 /m2	61,500	182 /m2	0.9%
A32 Walls Above Grade	0.87	295 m2	550 /m2	162,360	480 /m2	2.3%
A33 Windows & Entrances	0.05	18 m2	1,144 /m2	20,600	61 /m2	0.3%
A34 Roof Covering	1.00	338 m2	573 /m2	193,700	573 /m2	2.8%
A35 Projections	1.00	338 m2	373 /m2	126,000	373 /m2	1.8%
B INTERIOR				185,971	550 /m2	2.7%
B1 Partitions & Doors				44,027	130 /m2	0.6%
B11 Partitions	0.60	203 m2	155 /m2	31,427	93 /m2	0.5%
B12 Doors	0.02	6 no.	2,100 /no.	12,600	37 /m2	0.2%
B2 Finishes				73,008	216 /m2	1.0%
B21 Floor Finishes	1.00	338 m2	125 /m2	42,250	125 /m2	0.6%
B22 Ceiling Finishes	1.00	338 m2	16.00 /m2	5,408	16 /m2	0.1%
B23 Wall Finishes	1.20	406 m2	62.50 /m2	25,350	75 /m2	0.4%
B3 Fitting & Equipment				68,936	204 /m2	1.0%
B31 Fitting & Fixtures	1.00	338 m2	204 /m2	68,936	204 /m2	1.0%
C SERVICES				1,453,633	4,301 /m2	20.9%
C1 Mechanical				669,447	1,981 /m2	9.6%
C11 Plumbing & Drainage	1.00	338 m2	1,031 /m2	348,424	1,031 /m2	5.0%
C12 Fire Protection	1.00	338 m2	4.89 /m2	1,653	5 /m2	0.0%
C13 HVAC	1.00	338 m2	815 /m2	275,370	815 /m2	4.0%
C14 Controls	1.00	338 m2	130 /m2	44,000	130 /m2	0.6%
C2 Electrical				784,186	2,320 /m2	11.3%
C21 Service & Distribution	1.00	338 m2	1,429 /m2	482,980	1,429 /m2	6.9%
C22 Lighting, Devices & Heating	1.00	338 m2	246 /m2	83,185	246 /m2	1.2%
C23 Systems & Ancillaries	1.00	338 m2	645 /m2	218,021	645 /m2	3.1%
D SITE & ANCILLARY WORK				355,000	1,050 /m2	5.1%
D2 Ancillary Work				355,000	1,050 /m2	5.1%
D21 Decommissioning	0.00	1 sum	125,000 /sum	125,000	370 /m2	1.8%
D22 Alterations	1.00	338 m2	680 /m2	230,000	680 /m2	3.3%
Net Construction Estimate				$3,926,749	11,618 /m2	56.5%
Z GENERAL REQUIREMENTS & ALLOWANCES				1,851,064	5,477 /m2	26.6%
Z1 General Requirements & Fee				550,332	1,628 /m2	7.9%
Z11 General Requirements and Fee		30.0 %		1,178,275	3,486 m2	16.9%
Z12 Freight and Accommodations		10.8 %		550,332	1,628 m2	7.9%
Total Construction Estimate (Excluding Contingencies)				$5,655,356	16,732 /m2	81.3%
Z2 Contingencies				1,300,732	3,848 /m2	18.7%
Z21 Design and Pricing Contingency		15.0 %		848,303	2,510 m2	12.2%
Z22 Escalation Contingency		8.0 %		452,428	1,339 m2	6.5%
Z23 Construction Contingency				EXCLUDED		
GST				EXCLUDED		
TOTAL CONSTRUCTION COST				$6,956,088	20,580 /m2	100%

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		Quantity	Unit Rate ($)	Total ($)
	A1 Substructure			
	A11 Foundations			
	Preparation			
B.A11.1	Clearing and grubbing	338 m2	3.50	1,183
B.A11.2	Rough grading	338 m2	8.00	2,704
	Strip Footings			
B.A11.3	Perimeter Strip Fdns. - 900x300mm	78 m	1,038.38	80,993
	Trench excavation and removal from site	390 m3	21.00	8,190
	Granular backfill - supply & place (by machine)	327 m3	85.00	27,790
	Formwork - strip footings	47 m2	220.00	10,296
	35 MPa, C1 (5000Psi) - supply	22 m3	1,250.00	27,641
	Place concrete	22 m3	60.00	1,327
	Black reinforcing steel - labour, material, and accessories	1,369 kg	4.20	5,749
	Foundation Walls			
B.A11.4	Foundation Walls - 250x2000mm high	78 m	1,930.20	150,556
	Formwork - foundation stub wall	312 m2	220.00	68,640
	35 MPa, C1 (5000Psi) - supply	41 m3	1,250.00	51,188
	Dampproofing to foundation walls	156 m2	55.00	8,580
	Place concrete	41 m3	60.00	2,457
	Black reinforcing steel - labour, material, and accessories	3,510 kg	4.20	14,742
	50mm (2") rigid insulation (R10)	117 m2	42.30	4,949
	Other A11 Foundations			
B.A11.5	Excavation, backfill and insulation to thermosyphon system	338 m2	470.00	158,860
	Bulk excavation in earth and remove from site	676 m3	27.00	18,252
	Granular backfill	608 m3	95.00	57,798
	200mm hi-load 60 rigid insulation	338 m2	240.00	81,120
	Below-grade vapour retarders	338 m2	5.00	1,690
B.A11.6	Thermosyphon system To building	1 sum	325,000.00	325,000
	TOTAL FOR A11 FOUNDATIONS	338 m2	2,128 /m2	$719,296

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		Quantity	Unit Rate ($)	Total ($)
A2 Structure				
A21 Lowest Floor Construction				
	Slab on Grade			
B.A21.1	Slab on Grade - 150mm Thick	338 m2	598.03	202,132
	Bulk excavation in earth and remove from site	676 m3	27.00	18,252
	Granular backfill	625 m3	95.00	59,404
	35 MPa, C1 (5000Psi) - supply	53 m3	1,250.00	66,544
	Place concrete	53 m3	60.00	3,194
	Concrete finishing - steel trowel finish	338 m2	16.00	5,408
	38mm (1-1/2")rigid insulation (R7.5)	338 m2	50.00	16,900
	38mm (1-1/2")rigid insulation (R7.5)	338 m2	50.00	16,900
	Below-grade vapour retarders	338 m2	5.00	1,690
	Black reinforcing steel - labour, material, and accessories	3,296 kg	4.20	13,841
	Structural Framing - Metal Deck to WTP			
B.A21.2	Modular building floor system, assumed plywood	338 m2	60.00	20,280
B.A21.3	Structural steel framing	16,900 kg	6.50	109,850
B.A21.4	Misc. Details	1,690 kg	7.50	12,675
B.A21.5	Floor Assembly	600 m2	311.96	187,175
	200mm Mineral wool batt insulation	600 m2	50.00	29,996
	38mm Rigid insulation	600 m2	40.00	23,997
	AVB	600 m2	22.00	13,198
	Resilient strapping	600 m2	25.00	14,998
	Prefinished metal liner panel	600 m2	175.00	104,986
	TOTAL FOR A21 LOWEST FLOOR CONSTRUCTION	338 m2	1,574 /m2	$532,112

		Quantity	Unit Rate ($)	Total ($)
A2 Structure				
A23 Roof Construction				
	Structural Steel Floor Framing at WTP Roof			
B.A23.1	Steel framing (all-in)	13,520 kg	6.50	87,880
B.A23.2	Misc. connections and details	1,352 kg	7.50	10,140
B.A23.3	38mm metal deck	338 m2	54.90	18,556
	TOTAL FOR A23 ROOF CONSTRUCTION	338 m2	345 /m2	$116,576

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		Quantity	Unit Rate ($)	Total ($)
	A3 Exterior Envelope			
	A31 Walls Below Grade			
	Building Skirting			
B.A31.1	Allowance for skirting to building Assumed 1.5m high	123 m2	500.00	61,500
	TOTAL FOR A31 WALLS BELOW GRADE	123 m2	500 /m2	$61,500
	A3 Exterior Envelope			
	A32 Walls Above Grade			
	Metal Panels - Building			
B.A32.1	Prefinshed metal panels - stud back-up	295 m2	550.00	162,360
	TOTAL FOR A32 WALLS ABOVE GRADE	295 m2	550 /m2	$162,360
	A33 Windows & Entrances			
	Windows			
B.A33.1	Glazing Allowance Allow 6 windows at 1m2 per	4 no.	750.00	3,000
	Exterior Louvres			
B.A33.2	Fixed louvers Allowance	1 sum	5,000.00	5,000
	Hollow Metal Exterior Doors			
B.A33.3	Hollow metal exterior doors - Single	2 no.	2,300.00	4,600
B.A33.4	Hollow metal exterior doors - Double	2 pair	4,000.00	8,000
	TOTAL FOR A33 WINDOWS & ENTRANCES	18 m2	1,144 /m2	$20,600

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		Quantity	Unit Rate ($)	Total ($)
	A3 Exterior Envelope			
	A34 Roof Covering			
	Roof Covering to Building - Building			
B.A34.1	Insulated metal roof panels	338 m2	550.00	185,900
	Roof Accessories			
B.A34.2	Allowance for roof accessories	1 sum	2,500.00	2,500
B.A34.3	Roof hatches	1 no.	3,500.00	3,500
B.A34.4	Steel ladder	1 no.	1,800.00	1,800
	TOTAL FOR A34 ROOF COVERING	338 m2	573 /m2	$193,700
	A3 Exterior Envelope			
	A35 Projections			
	Canopies			
B.A35.1	Canopy Allowance	2 ea.	15,000.00	30,000
	Areaway Walls and Gratings			
B.A35.2	Galvanized metal grating stairs and landing To double doors	2 no.	30,000.00	60,000
B.A35.3	Galvanized metal grating stairs and landing To single doors	2 no.	18,000.00	36,000
	TOTAL FOR A35 PROJECTIONS	338 m2	373 /m2	$126,000
	B1 Partitions & Doors			
	B11 Partitions			
	Steel Stud and Drywall Partition Assemblies			
B.B11.1	Demising partition	203 m2	128.17	26,019
	92mm (3-5/8") s/studs 406mm (16") o/c to walls	203 m2	45.50	9,227
	89mm (3-1/2") sound attenuation batt.	203 m2	22.40	4,543
	15.9mm (5/8") fire rated (type 'X') drywall to walls	203 m2	16.20	3,285
	Tape & finish (Level 4 finish) to walls	203 m2	14.00	2,839
	15.9mm (5/8") fire rated (type 'X') drywall to walls	203 m2	16.20	3,285
	Tape & finish (Level 4 finish) to walls	203 m2	14.00	2,839

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		Quantity	Unit Rate ($)	Total ($)
	B1 Partitions & Doors			
	B11 Partitions			
	Misc. Metals, Rough Carpentry, Sealing etc.			
B.B11.2	Rough carpentry - above grade	338 m2	10.00	3,380
B.B11.3	Allow for sealing, caulking and firestopping	338 m2	6.00	2,028
	TOTAL FOR B11 PARTITIONS	203 m2	155 /m2	$31,427
	B12 Doors			
	Hollow Metal Interior Doors			
B.B12.1	Hollow metal interior doors - Single	6 lvs	2,100.00	12,600
	TOTAL FOR B12 DOORS	6 no.	2,100 /no.	$12,600
	B2 Finishes			
	B21 Floor Finishes			
	Hardeners, Sealers, and Other Surface Treatment			
B.B21.1	Epoxy coatings	338 m2	125.00	42,250
	TOTAL FOR B21 FLOOR FINISHES	338 m2	125 /m2	$42,250
	B22 Ceiling Finishes			
	Applied Ceiling Finishes			
B.B22.1	Interior paint to exposed ceiling soffit	338 m2	16.00	5,408
	TOTAL FOR B22 CEILING FINISHES	338 m2	16.00 /m2	$5,408

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		Quantity	Unit Rate ($)	Total ($)
B2 Finishes				
B23 Wall Finishes				
	Painting to Walls			
B.B23.1	Interior paint to walls	304 m2	50.00	15,210
	Assumed epoxy style			
	Wall Covering			
B.B23.2	Misc. wall protection	101 m2	100.00	10,140
	Allow 25% of partition walls			
	TOTAL FOR B23 WALL FINISHES	406 m2	62.50 /m2	$25,350
B3 Fitting & Equipment				
B31 Fitting & Fixtures				
	Platforms			
B.B31.1	Steel access platforms - allowance	1 no.	48,000.00	48,000
	Brackets			
B.B31.2	Misc. metals - above grade	338 m2	22.00	7,436
B.B31.3	Misc. grating to equipment	7 m2	1,000.00	7,000
	Cabinetwork and Casework			
B.B31.4	Cabinets - Kitchen Counter	2 m	1,000.00	2,000
	Shelving			
B.B31.5	Work Bench	2 m	1,500.00	3,000
	Washroom Accessories - Residential Grade			
B.B31.6	Washroom accessories to suites	1 sum	1,500.00	1,500
	TOTAL FOR B31 FITTING & FIXTURES	338 m2	204 /m2	$68,936

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		Quantity	Unit Rate ($)	Total ($)
	C1 Mechanical			
	C11 Plumbing & Drainage			
B.C11.1	Equipment	1 sum	41,500.00	41,500
	Equipment			
	Sanitary Waste Tank	1 no	13,500.00	13,500
	Domestic Water Tank	1 no	8,500.00	8,500
	Pressure Tank	1 no	2,500.00	2,500
	Hot Water Tank	1 no	1,500.00	1,500
	Fuel storage tanks and platform	1 sum	15,500.00	15,500
B.C11.2	Piping-Above Grade	1 sum	296,769.00	296,769
	Piping-Above Grade			
	Domestic cold water	60 m	125.00	7,500
	Domestic hot water	41 m	125.00	5,100
	Fuel piping	112 m	145.00	16,240
	Sanitary drain and vent-above grade	75 m	135.00	10,125
	Pipe insulation (Domestic)	121 m	22.00	2,661
	Pipe Insulation and heat trace - Carrier pipe	523 m	225.00	117,758
	Concrete ballast block and pipe support	105 no.	1,312.50	137,385
B.C11.3	Plumbing Fixtures	1 sum	10,155.00	10,155
	Plumbing Fixtures			
	Water closet tank-manual flush, low flow-non electronic faucet	1 no.	395.00	395
	Lavatory-counter top, low flow-non electronic faucet	1 no.	425.00	425
	Office sink	1 no.	750.00	750
	Utility sink	1 no.	750.00	750
	Emergency Shower	1 no.	2,400.00	2,400
	Eye Wash	1 no	750.00	750
	Floor drains	4 sum	350.00	1,400
	Non freeze wall hydrants	1 sum	2,000.00	2,000
	Emergency Shower	1 no	220.00	220
	Eye Wash	1 no	165.00	165
	Plumbing fixtures - installation only	1 sum	900.00	900
	TOTAL FOR C11 PLUMBING & DRAINAGE	338 m2	1,031 /m2	$348,424

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		Quantity	Unit Rate ($)	Total ($)
	C1 Mechanical			
	C12 Fire Protection			
B.C12.1	Building	1 sum	1,652.81	1,653
	Building			
	Fire extinguishers	1 sum	1,500.00	1,500
	Sprinkler and standpipe system control valves assembly c/w zone valves, heads, etc	1 sum	112.50	113
	Allowance for testing, balancing and certification	1 sum	40.31	40
	TOTAL FOR C12 FIRE PROTECTION	338 m2	4.89 /m2	$1,653

		Quantity	Unit Rate ($)	Total ($)
	C1 Mechanical			
	C13 HVAC			
B.C13.1	Heating Plant	1 sum	92,400.00	92,400
	High efficiency heating boilers, 107 MBH each	1 sum	20,200.00	20,200
	P-Building heating system pumps, VFD	2 no.	13,500.00	27,000
	HEX 1.1 and 1.2 Treated Water Tank	2 no.	8,500.00	17,000
	HEX 2/3 Heat exchanger, backwash tank	1 no.	8,500.00	8,500
	Allowance for glycol feed tank, chemical treatment, etc	1 no.	6,500.00	6,500
	Allowance for air separators, gauges, valves, etc	1 sum	5,500.00	5,500
	Allowance for boiler flue vent	1 sum	7,700.00	7,700
B.C13.2	Air Handlers and Fans - Building	1 sum	65,500.00	65,500
	MUA-Building make-up air unit direct fired	1 sum	60,000.00	60,000
	Building Exhaust Fan	1 sum	2,500.00	2,500
	EF-Mechanical and Electrical room exhaust fan	2 sum	1,500.00	3,000
B.C13.3	Piping-HVAC	1 sum	27,000.00	27,000
	Hot water piping supply and return	135 m	105.00	14,175
	Piping Insulation	135 m	95.00	12,825
B.C13.4	Common Area terminal devices - Building	1 sum	13,550.00	13,550
	Unit heaters-hydronic	4 no	2,200.00	8,800
	Entrance force flow heater-hydronic	2 no	1,500.00	3,000
	RHC -1	1 no.	750.00	750
	BB Coils	1 no	1,000.00	1,000
B.C13.5	Ductwork and Air Distribution	1 sum	21,920.00	21,920
	Galvanized steel ductwork	574 kg	30.00	17,220
	Diffusers, registers and grilles	1 sum	1,600.00	1,600
	Duct insulation	1 sum	3,100.00	3,100
B.C13.6	Miscellaneous	1 sum	55,000.00	55,000
	Allowance for emergency generator fuel oil system	1 sum	20,000.00	20,000
	Generator room ventilation system	1 sum	20,000.00	20,000
	Testing, balancing and Commissioning	1 sum	15,000.00	15,000
	Allowance for MCC - by Div. 16			Included Elsewhere
	TOTAL FOR C13 HVAC	338 m2	815 /m2	$275,370

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		Quantity	Unit Rate ($)	Total ($)
C1 Mechanical				
C14 Controls				
B.C14.1	Controls	1 sum	44,000.00	44,000
	Make-up air units	1 sum	15,000.00	15,000
	Heating / cooling plant	1 sum	15,000.00	15,000
	Generator and fuel system monitoring and controls	1 sum	4,500.00	4,500
	Fans, dampers	2 sum	1,500.00	3,000
	Process monitoring	1 sum	6,500.00	6,500
	TOTAL FOR C14 CONTROLS	338 m2	130 /m2	$44,000
C2 Electrical				
C21 Service & Distribution				
B.C21.1	Normal Power	1 sum	17,852.80	17,853
	Provide feeder connection of electrical service - Main service equipment provided by others	1 ls	4,366.80	4,367
	Modular allowance for Main Service switchboard	1 sum	13,486.00	13,486
B.C21.2	Emergency Power	1 sum	235,110.10	235,110
	Provide feeder connection for generator - Generator provided by others	1 sum	1,872.00	1,872
	Modular allowance for exterior pad mounted generator	1 sum	182,432.25	182,432
	Modular allowance for transfer switch and emergency distribution	1 sum	50,805.85	50,806
B.C21.3	Distribution - common area	1 m2	8,757.00	8,757
	Modular allowance for Branch panels	1 sum	8,757.00	8,757
B.C21.4	Motor Controls & Wiring	1 m2	184,860.00	184,860
	Wire & connect to mechanical equipment - None observed in structure - Assumed all mechanical connections and feeders are factory supplied	1 nil	0.00	Excluded
	Modular allowance for MCC	1 sum	56,316.00	56,316
	Modular allowance for Mechanical connections and feeders	1 sum	128,544.00	128,544
B.C21.5	Miscellaneous	1 sum	36,400.00	36,400
	Grounding	1 sum	3,500.00	3,500
	Misc. Heat Trace and controllers	1 sum	32,900.00	32,900
	TOTAL FOR C21 SERVICE & DISTRIBUTION	338 m2	1,429 /m2	$482,980

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		Quantity	Unit Rate ($)	Total ($)
	C2 Electrical			
	C22 Lighting, Devices & Heating			
B.C22.1	**Lighting**	1 sum	60,911.25	60,911
	Assumed that all electrical lighting, switching and receptacles on structure are included by factory installed structure provider	1 nil	0.00	Excluded
	Module - Interior lighting and branch wiring	1 no.	32,475.00	32,475
	Module - Tank lighting and branch wiring	1 no.	5,200.00	5,200
	Module - Exterior man and fill lighting	1 no.	5,600.00	5,600
	Modular - Exit signs, battery packs and remote heads	1 no.	11,960.00	11,960
	Modular - Exterior time clock and contactor	1 no.	2,080.00	2,080
	Modular interior lighting control	1 no.	3,596.25	3,596
B.C22.2	**Common Area Devices**	1 sum	22,274.00	22,274
	Assumed that all electrical lighting, switching and receptacles on structure are included by factory installed structure provider	1 nil	0.00	Excluded
	Modular - 15A/20A 125V duplex receptacle	20 no.	180.00	3,600
	Modular - 15A/20A 125V duplex receptacle, GFI	4 no.	230.00	920
	Modular - 15A 125V duplex receptacle, GFI, W/P - exterior of building and tanks	6 no.	459.00	2,754
	Modular - General branch wiring	1 no.	15,000.00	15,000
	TOTAL FOR C22 LIGHTING, DEVICES & HEATING	338 m2	246 /m2	$83,185

		Quantity	Unit Rate ($)	Total ($)
	C2 Electrical			
	C23 Systems & Ancillaries			
B.C23.1	**Fire Alarm System**	1 sum	38,441.00	38,441
	Modular - Fire alarm system and auto dialer - Requirements TBD	1 sum	38,441.00	38,441
B.C23.2	**Security System**	1 sum	41,600.00	41,600
	Allowance for security system including CCTV camera, access door devices, etc. - Requirements TBD	1 sum	41,600.00	41,600
B.C23.3	**Communications**	1 sum	44,740.00	44,740
	Allowance forTelephone and communication service and lines - Not included in module structure scope(s)	1 sum	3,400.00	3,400
	Modular -Communication cable tray	1 sum	8,100.00	8,100
	Modular - Communication outlet rough in	12 no.	135.00	1,620
	Cable drops	24 no.	285.00	6,840
	Plywood backboards	1 sum	835.00	835
	Racks, patch panels, etc.	1 sum	8,000.00	8,000
	Active hardware - Allowance	1 sum	8,665.00	8,665
	Rack mounted UPS and PDU's	1 sum	7,280.00	7,280
B.C23.4	**Miscellaneous**	1 sum	93,240.00	93,240
	Allowance for cut over and decommissioning of existing facility	1 sum	25,020.00	25,020
	Assistance with testing and commissioning - Coordinate with modular system provider	1 sum	13,680.00	13,680
	Modular - Setup, connections, testing and commissioning	1 sum	13,905.00	13,905
	Permits, Inspections and job costs	1 sum	40,635.00	40,635
	TOTAL FOR C23 SYSTEMS & ANCILLARIES	338 m2	645 /m2	$218,021

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		Quantity	Unit Rate ($)	Total ($)
	NET BUILDING COST (Excluding Site)	338 m2	10,567 /m2	$3,571,749

D2 Ancillary Work

D21 Decommissioning

B.D21.1	Decommission and removal from site - Existing Water Treatment Plant	1 sum	125,000.00	125,000
	TOTAL FOR D21 DECOMMISSIONING	1 sum	125,000 /sum	$125,000

D22 Alterations

B.D22.1	Allowance for onsite setup and connection, and commissioning of modular building	1 sum	230,000.00	230,000
	TOTAL FOR D22 ALTERATIONS	338 m2	680 /m2	$230,000
	NET BUILDING COST (Including Site)	338 m2	11,618 /m2	$3,926,749

Z1 General Requirements & Fee

Z11 General Requirements and Fee

B.Z11.1	General Requirement and Fee - Modular Builder	15%		706,965
B.Z11.2	General Requirements and Fee - General Contractor	10%		471,310
	TOTAL FOR Z11 GENERAL REQUIREMENTS AND FEE	30 %	39,267 /%	$1,178,275

Z12 Freight and Accommodations

B.Z12.1	Accommodations modular	240 night	375.00	90,000
B.Z12.2	Flights modular	16 no	2,000.00	32,000
B.Z12.3	Flights GC	8 no	2,000.00	16,000

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		Quantity	Unit Rate ($)	Total ($)
	Z1 General Requirements & Fee			
	Z12 Freight and Accommodations			
B.Z12.4	Accommodations GC	120 night	375.00	45,000
B.Z12.5	Freight from modular site to docks	1 sum	65,000.00	65,000
B.Z12.6	Freight to site	4,031,099	0.08	302,332
	TOTAL FOR Z12 FREIGHT AND ACCOMMODATIONS	11 %	51,050 /%	$550,332
	TOTAL CONSTRUCTION ESTIMATE (Excluding contingencies)	338 m2	16,732 /m2	$5,655,356
	Design and Pricing Contingency	15.00 %		848,303
	Escalation Contingency	8.00 %		452,428
	Construction Contingency			EXCLUDED
	TOTAL CONSTRUCTION ESTIMATE (Including contingencies)	338 m2	20,580 /m2	$6,956,088
	TOTAL CONSTRUCTION ESTIMATE (Excluding Taxes)	338 m2	20,580 /m2	$6,956,088

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Elemental Summary & Details - Processing Equipment & Tanks

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ELEMENTAL SUMMARY
PROCESSING EQUIPMENT AND TANKS

$3,672,000
PROCESSING EQUIPMENT AND TANKS TOTAL

$3,671,701/ TOTAL /m² | 1 m²

$341,113/sf TOTAL /sf | 11 sf COMP. GCA

Element	GCA Ratio	Element Quantity	Element Unit Rate	Cost Total	$ Total /sum GCA	%
B INTERIOR				1,444,111	1,444,111	39.3%
B3 Fitting & Equipment				1,444,111	1,444,111	39.3%
B32 Equipment	338.00	338 m2	4,273 /m2	1,444,111	1,444,111	39.3%
D SITE & ANCILLARY WORK				793,700	793,700	21.6%
D1 Site Work				793,700	793,700	21.6%
D11 Site Development	1.00	1 sum	104,000 /sum	104,000	104,000	2.8%
D12 Mechanical Site Services	1.00	1 sum	0.00 /sum	689,700	689,700	18.8%
Net Construction Estimate				$2,237,811	2,237,811	60.9%
Z GENERAL REQUIREMENTS & ALLOWANCES				1,433,891	1,433,891	39.1%
Z1 General Requirements & Fee				747,312	747,312	20.4%
Z11 General Requirements and Fee		22.0 %		492,318	492,318 sum	13.4%
Z12 Freight and Accommodations		9.3 %		254,994	254,994 sum	6.9%
Total Construction Estimate (Excluding Contingencies)				$2,985,123	2,985,123	81.3%
Z2 Contingencies				686,578	686,578	18.7%
Z21 Design and Pricing Contingency		15.0 %		447,768	447,768 sum	12.2%
Z22 Escalation Contingency		8.0 %		238,810	238,810 sum	6.5%
Z23 Construction Contingency				EXCLUDED		
GST				EXCLUDED		
TOTAL CONSTRUCTION COST				$3,671,701	3,671,701	100%

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		Quantity	Unit Rate ($)	Total ($)
B3 Fitting & Equipment				
B32 Equipment				
	Process Piping Equipment			
B.B32.1	Intake Pump	3 no.	15,500.00	46,500
B.B32.2	DAF Unit, Flocculator, Sledge Transfer Pump, Floc Mixer, Flash Mixer, Coag Mixing Tank, Liquid Polymer Make-down system, Coag dosing Skid Mag Flowmeter, Control Panel	1 sum	0.00	Excluded, not part of design
B.B32.3	Greensand Pkg, Blower Package, Pumps, Backwash Pumps	1 sum	640,000.00	640,000
B.B32.4	Ultraviolet Disinfection Reactor Units	1 sum	93,800.00	93,800
B.B32.5	Fluoridation injection system	1 sum	75,000.00	75,000
B.B32.6	Chlorination injection system	1 sum	95,000.00	95,000
B.B32.7	Truck Fill Pumps	3 no	4,500.00	13,500
B.B32.8	Labor to Install	1 sum	26,400.00	26,400
B.B32.9	Process Piping 1"	15 m	186.61	2,799
B.B32.10	Process Piping 2"	40 m	210.70	8,428
B.B32.11	Process Piping 4"	201 m	275.05	55,285
B.B32.12	Process Piping 6"	16 m	450.72	7,212
B.B32.13	250mm Carrier Pipes	523 m	475.00	248,601
B.B32.14	Allowance for Valves (Isolation, Check, Etc)	1 sum	73,723.99	73,724
B.B32.15	Allowance for Vic Fittings	1 sum	36,862.00	36,862
B.B32.16	Pipe Insulation (Process, Cladding for Tanks)	1 sum	21,000.00	21,000
	TOTAL FOR B32 EQUIPMENT	338 m2	4,273 /m2	$1,444,111
	NET BUILDING COST (Excluding Site)	1 sum	1,444,111	$1,444,111

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D11 Site Development			
	Tank setup			
	Site Furnishings			
B.D11.1	Truck Filler platforms	2 no.	20,000.00	40,000
B.D11.2	Steel Piles - Rock Socketed	16 no.	4,000.00	64,000
	TOTAL FOR D11 SITE DEVELOPMENT	1 sum	104,000 /sum	$104,000
	D1 Site Work			
	D12 Mechanical Site Services			
	Mechanical Site Services			
B.D12.1	Treated Water Reservoir (Backwash Storage Tank)	1 no	305,200.00	305,200
B.D12.2	Wastewater Storage Tank	1 no	330,000.00	330,000
B.D12.3	Submersible Mixer	1 no	17,100.00	17,100
B.D12.4	Raw Water Storage Tanks	1 sum	0.00	Excluded, not part of design
B.D12.5	Misc Steel	1 sum	7,500.00	7,500
B.D12.6	Labor to Install	1 sum	26,400.00	26,400
B.D12.7	Diesel driven pump, trailer mounted	1 sum	0.00	Excluded, not part of design
B.D12.8	Buchanan 6" hose	30 m	0.00	Excluded, not part of design
B.D12.9	Submersible Well Pump	1 no	3,500.00	3,500
	TOTAL FOR D12 MECHANICAL SITE SERVICES	1 sum	689,700 /sum	$689,700
	NET BUILDING COST (Including Site)	1 sum	2,237,811	$2,237,811
	General Requirements and Fee	22.00 %		492,318
	Freight and Accommodations	9.34 %		254,994
	TOTAL CONSTRUCTION ESTIMATE (Excluding contingencies)	1 sum	2,985,123	$2,985,123

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	Quantity	Unit Rate ($)	Total ($)
Design and Pricing Contingency	15.00 %		447,768
Escalation Contingency	8.00 %		238,810
Construction Contingency			EXCLUDED
TOTAL CONSTRUCTION ESTIMATE (Including contingencies)	1 sum	3,671,701	$3,671,701
TOTAL CONSTRUCTION ESTIMATE (Excluding Taxes)	1 sum	3,671,701	$3,671,701

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Elemental Summary & Details - Site Option 1 (Existing)

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ELEMENTAL SUMMARY

SITE DEVELOPMENT - SITE OPTION 1 (EXISTING)

$1,412,000

SITE DEVELOPMENT - SITE OPTION 1 (EXISTING) TOTAL

$150/m²
TOTAL /m²

$14/sf
TOTAL /sf

9,420 m²

101,400 sf
COMP. SCA

Element	SCA Ratio	Element Quantity	Element Unit Rate	Cost Total	$ Total /m2 SCA	%
D SITE & ANCILLARY WORK				860,637	91 /m2	60.9%
D1 Site Work				860,637	91 /m2	60.9%
D11 Site Development	1.00	9,421 m2	39.09 /m2	368,309	39 /m2	26.1%
D12 Mechanical Site Services	1.00	9,421 m2	26.39 /m2	248,601	26 /m2	17.6%
D13 Electrical Site Services	1.00	9,421 m2	25.87 /m2	243,727	26 /m2	17.3%
NET BUILDING COST (Including Site)				860,637	91 /m2	60.9%
Net Construction Estimate				$860,637	91 /m2	60.9%
Z1 General Requirements & Fee				287,408	31 /m2	20.4%
Z11 General Requirements and Fee		22.0 %		189,340	20 m2	13.4%
Z12 Freight and Accommodations		9.3 %		98,068	10 m2	6.9%
Total Construction Estimate (Excluding Contingencies)				$1,148,045	122 /m2	81.3%
Z2 Contingencies				264,050	28 /m2	18.7%
Z21 Design and Pricing Contingency		15.0 %		172,207	18 m2	12.2%
Z22 Escalation Contingency		8.0 %		91,844	10 m2	6.5%
Z23 Construction Contingency				EXCLUDED		
TOTAL CONSTRUCTION COST				$1,412,095	150 /m2	100%

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D11 Site Development			
	Preparation - Site 1			
Site.D11.1	Clearing and grubbing Allow 40% of existing site	9,420 m2	3.50	32,971
Site.D11.2	Rough grading Allow 40% of existing site	9,420 m2	6.00	56,522
Site.D11.3	Truck fill area Allows for excavation and backfill	1,420 m2	45.29	64,310
	Allowance for cut/ fill c/w compaction	490 m3	50.00	24,500
	Granular 150mm	150 m3	95.00	14,250
	Non woven geotextile	1,420 m2	18.00	25,560
	Preparation - Tanks			
Site.D11.4	Clearing and grubbing	158 m2	3.50	552
Site.D11.5	Rough grading	158 m2	6.00	946
Site.D11.6	Excavation, backfill and insulation to thermosyphon system See provisional pricing	1 note	0.00	Excluded
Site.D11.7	Allowance for thermosyphon system See provisional pricing	1 note	0.00	Excluded
	Paving and Surfacing Including Base - Site			
Site.D11.8	Granular 250mm thick Placed around the building	2,000 m3	95.00	190,009
	Fences, Gates, Rails, & Barriers			
Site.D11.9	Bollards	4 no.	2,000.00	8,000
	Signage			
Site.D11.10	Exterior signage allowance	1 sum	15,000.00	15,000
	TOTAL FOR D11 SITE DEVELOPMENT	9,421 m2	39.09 /m2	$368,309

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		Quantity	Unit Rate ($)	Total ($)
D1 Site Work				
D12 Mechanical Site Services				
Site.D12.1	250mm Carrier Pipes	523 m	475.00	248,601
	TOTAL FOR D12 MECHANICAL SITE SERVICES	9,421 m2	26.39 /m2	$248,601
D1 Site Work				
D13 Electrical Site Services				
Site.D13.1	Incoming Power	3,993 m2	29.30	117,005
	Allowance for utility provider - Assumes an additional pole will be required and overhead feeder to building	1 sum	41,164.20	41,164
	Secondary feeder from utility providers pole - assumed over head and ran to service mast provided by structure provider	1 sum	22,453.20	22,453
	Feeder from generator to Building	1 sum	7,488.00	7,488
	Feeders from building to tanks - Assumed not in modular providers scope	1 sum	45,900.00	45,900
Site.D13.2	Incoming Communications	3,993 m2	7.52	30,033
	Allowance for communication lines ran from Main overhead utility pole to structure	1 sum	12,537.00	12,537
	Communications - Interconnect from existing facility - To remain during construction	60 m	291.60	17,496
Site.D13.3	Site Lighting & Devices	3,993 m2	24.21	96,688
	Allowance for site lighting poles and branch not included by modular structure provider scope	2 no	15,577.20	31,154
	Heat trace for Intakes - Dual with two runs each intake	512 lm	128.00	65,534
	TOTAL FOR D13 ELECTRICAL SITE SERVICES	9,421 m2	25.87 /m2	$243,727
	NET BUILDING COST (Including Site)	9,420 m2	91.36 /m2	$860,637
	General Requirements and Fee	22.00 %		189,340
	Freight and Accommodations	9.34 %		98,068
	TOTAL CONSTRUCTION ESTIMATE (Excluding contingencies)	9,420 m2	122 /m2	$1,148,045
	Design and Pricing Contingency	15.00 %		172,207
	Escalation Contingency	8.00 %		91,844
	Construction Contingency			EXCLUDED
	TOTAL CONSTRUCTION ESTIMATE (Including contingencies)	9,420 m2	150 /m2	$1,412,095
	TOTAL CONSTRUCTION ESTIMATE (Excluding Taxes)	9,420 m2	150 /m2	$1,412,095

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Elemental Summary & Details - Site Option 3

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ELEMENTAL SUMMARY
SITE DEVELOPMENT - SITE OPTION 3

$16,502,000
SITE DEVELOPMENT - SITE OPTION 3 TOTAL

$1,753/m²
TOTAL /m²

$163/sf
TOTAL /sf

9,416 m²

101,353 sf
COMP. SCA

Element	SCA Ratio	Element Quantity	Element Unit Rate	Cost Total	$ Total /m2 SCA	%
D SITE & ANCILLARY WORK				11,361,450	1,207 /m2	68.8%
D1 Site Work				11,361,450	1,207 /m2	68.8%
D11 Site Development	0.98	9,259 m2	58.84 /m2	544,812	58 /m2	3.3%
D12 Mechanical Site Services	0.98	9,259 m2	1,134 /m2	10,497,238	1,115 /m2	63.6%
D13 Electrical Site Services	0.98	9,259 m2	34.50 /m2	319,400	34 /m2	1.9%
NET BUILDING COST (Including Site)				11,361,450	1,207 /m2	68.8%
Net Construction Estimate				$11,361,450	1,207 /m2	68.8%
Z1 General Requirements & Fee				2,054,968	218 /m2	12.5%
Z11 General Requirements and Fee		8.0 %		908,916	97 m2	5.5%
Z12 Freight and Accommodations		9.3 %		1,146,052	122 m2	6.9%
Total Construction Estimate (Excluding Contingencies)				$13,416,418	1,425 /m2	81.3%
Z2 Contingencies				3,085,776	328 /m2	18.7%
Z21 Design and Pricing Contingency		15.0 %		2,012,463	214 m2	12.2%
Z22 Escalation Contingency		8.0 %		1,073,313	114 m2	6.5%
Z23 Construction Contingency				EXCLUDED		
TOTAL CONSTRUCTION COST				$16,502,194	1,753 /m2	100%

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D11 Site Development			
	Preparation - Site 3			
Site.D11.1	Clearing and grubbing	9,258 m2	3.50	32,404
Site.D11.2	Rough grading	9,258 m2	6.00	55,550
Site.D11.3	Pumphouse - Allowance Assume 5m x 5m	1 sum	50,000.00	50,000
Site.D11.4	Truck fill area Allows for excavation and backfill	1,200 m2	66.38	79,650
	Allowance for cut/ fill c/w compaction	420 m3	50.00	21,000
	Granular 150mm	390 m3	95.00	37,050
	Non woven geotextile	1,200 m2	18.00	21,600
	Preparation - Tanks			
Site.D11.5	Clearing and grubbing	158 m2	3.50	552
Site.D11.6	Rough grading	158 m2	6.00	946
Site.D11.7	Excavation, backfill and insulation to thermosyphon system See provisional pricing	1 note	0.00	Excluded
Site.D11.8	Allowance for thermosyphon system See provisional pricing	1 note	0.00	Excluded
	Paving and Surfacing Including Base - Site			
Site.D11.9	Granular 250mm thick Placed around the building	2,054 m3	95.00	195,130
	Fences, Gates, Rails, & Barriers			
Site.D11.10	Chain link fences and gates Allow for perimeter of site	400 m	250.00	100,080
Site.D11.11	Double swing gate	1 no	7,500.00	7,500
Site.D11.12	Bollards	4 no.	2,000.00	8,000

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D11 Site Development			
	Signage			
Site.D11.13	Exterior signage allowance	1 sum	15,000.00	15,000
	TOTAL FOR D11 SITE DEVELOPMENT	9,259 m2	58.84 /m2	$544,812
	D12 Mechanical Site Services			
Site.D12.1	Plumbing & Drainage - Pumphouse	25 m2	27,957.68	698,942
	Equipment	1 sum	546,000.00	546,000
	Piping-Above Grade	1 sum	146,322.05	146,322
	Plumbing Fixtures	1 sum	6,620.00	6,620
Site.D12.2	Fire Protection - Pumphouse	25 m2	70.00	1,750
	Building	1 sum	1,750.00	1,750
Site.D12.3	HVAC - Pumphouse	25 m2	8,811.20	220,280
	Unit heaters - hydronic	1 sum	77,000.00	77,000
	Entrance force flow heater - hydronic	1 sum	48,000.00	48,000
	Wall fin radiation - enclosed by others	1 sum	33,750.00	33,750
	RHC-1	1 sum	15,750.00	15,750
	BB Coils	1 sum	45,780.00	45,780
Site.D12.4	Controls -Pumphouse	25 m2	7,380.00	184,500
	Controls	1 sum	184,500.00	184,500
Site.D12.5	Piping-Above Grade - Trammission and Recirculation lines	1 sum	9,391,766.35	9,391,766
	150mm Transmission Line	6,550 m	612.50	4,011,802
	75mm recirculation line	6,550 m	306.25	2,005,901
	Allowance for Line Isolation Valves (Isolation, Check, Etc)	1 sum	50,000.00	50,000
	Pipe insulation	13,100 m	253.75	3,324,064
	TOTAL FOR D12 MECHANICAL SITE SERVICES	9,259 m2	1,134 /m2	$10,497,238
	D13 Electrical Site Services			
Site.D13.1	Incoming Power	3,993 m2	48.25	192,678
	Allowance for utility provider for Site 2 WTP- Assumes an additional pole will be required and overhead feeder to building	1 sum	41,164.20	41,164
	Secondary feeder from utility providers pole - assumed over head and ran to service mast provided by structure provider	1 sum	22,453.20	22,453
	Feeder from generator to Building	1 sum	7,488.00	7,488
	Feeders from building to tanks - Assumed not in modular providers scope	1 sum	45,900.00	45,900
	Allowance for utility provider for Site Pump House- Assumes an additional pole will be required and overhead feeder to building	1 sum	41,164.20	41,164
	Secondary feeder from utility providers pole for pump house - assumed over head and ran to service mast provided by structure provider	1 sum	14,720.40	14,720
	Pump house distribution Panel/meter socket	1 sum	8,420.00	8,420
	Pump house, fitou, lighting, power, receptacles, equipment/pump connections	1 sum	11,368.35	11,368

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D13 Electrical Site Services			
Site.D13.2	Incoming Communications	3,993 m2	7.52	30,033
	Allowance for communication lines ran from Main overhead utility pole to structure	1 sum	12,537.00	12,537
	Communications - Interconnect from existing facility - To remain during construction	60 m	291.60	17,496
Site.D13.3	Site Lighting & Devices	3,993 m2	24.21	96,688
	Allowance for site lighting poles and branch not included by modular structure provider scope	2 no	15,577.20	31,154
	Heat trace for Intakes - Dual with two runs each intake	512 lm	128.00	65,534
	TOTAL FOR D13 ELECTRICAL SITE SERVICES	9,259 m2	34.50 /m2	$319,400
	NET BUILDING COST (Including Site)	9,416 m2	1,207 /m2	$11,361,450
	General Requirements and Fee	8.00 %		908,916
	Freight and Accommodations	9.34 %		1,146,052
	TOTAL CONSTRUCTION ESTIMATE (Excluding contingencies)	9,416 m2	1,425 /m2	$13,416,418
	Design and Pricing Contingency	15.00 %		2,012,463
	Escalation Contingency	8.00 %		1,073,313
	Construction Contingency			EXCLUDED
	TOTAL CONSTRUCTION ESTIMATE (Including contingencies)	9,416 m2	1,753 /m2	$16,502,194
	TOTAL CONSTRUCTION ESTIMATE (Excluding Taxes)	9,416 m2	1,753 /m2	$16,502,194

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Elemental Summary & Details - Site Option 4

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ELEMENTAL SUMMARY
SITE DEVELOPMENT - SITE OPTION 4

$19,208,000
SITE DEVELOPMENT - SITE OPTION 4 TOTAL

$2,038/m²
TOTAL /m²

$189/sf
TOTAL /sf

9,424 m²

101,437 sf
COMP. SCA

Element	SCA Ratio	Element Quantity	Element Unit Rate	Cost Total	$ Total /m2 SCA	%
D SITE & ANCILLARY WORK				13,224,561	1,403 /m2	68.8%
D1 Site Work				13,224,561	1,403 /m2	68.8%
D11 Site Development	0.98	9,267 m2	58.80 /m2	544,926	58 /m2	2.8%
D12 Mechanical Site Services	0.98	9,267 m2	1,334 /m2	12,360,235	1,312 /m2	64.3%
D13 Electrical Site Services	0.98	9,267 m2	34.47 /m2	319,400	34 /m2	1.7%
NET BUILDING COST (Including Site)				13,224,561	1,403 /m2	68.8%
Net Construction Estimate				$13,224,561	1,403 /m2	68.8%
Z1 General Requirements & Fee				2,391,953	254 /m2	12.5%
Z11 General Requirements and Fee		8.0 %		1,057,965	112 m2	5.5%
Z12 Freight and Accommodations		9.3 %		1,333,988	142 m2	6.9%
Total Construction Estimate (Excluding Contingencies)				$15,616,513	1,657 /m2	81.3%
Z2 Contingencies				3,591,798	381 /m2	18.7%
Z21 Design and Pricing Contingency		15.0 %		2,342,477	249 m2	12.2%
Z22 Escalation Contingency		8.0 %		1,249,321	133 m2	6.5%
Z23 Construction Contingency				EXCLUDED		
TOTAL CONSTRUCTION COST				$19,208,311	2,038 /m2	100%

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D11 Site Development			
	Preparation - Site 4			
Site.D11.1	Clearing and grubbing	9,266 m2	3.50	32,432
Site.D11.2	Rough grading	9,266 m2	6.00	55,597
Site.D11.3	Pumphouse - Allowance Assume 5m x 5m	1 sum	50,000.00	50,000
Site.D11.4	Truck fill area Allows for excavation and backfill	1,200 m2	66.38	79,650
	Allowance for cut/ fill c/w compaction	420 m3	50.00	21,000
	Granular 150mm	390 m3	95.00	37,050
	Non woven geotextile	1,200 m2	18.00	21,600
	Preparation - Tanks			
Site.D11.5	Clearing and grubbing	158 m2	3.50	552
Site.D11.6	Rough grading	158 m2	6.00	946
Site.D11.7	Excavation, backfill and insulation to thermosyphon system See provisional pricing	1 note	0.00	Excluded
Site.D11.8	Allowance for thermosyphon system See provisional pricing	1 note	0.00	Excluded
	Paving and Surfacing Including Base - Site			
Site.D11.9	Granular 250mm thick Placed around the building	2,054 m3	95.00	195,130
	Fences, Gates, Rails, & Barriers			
Site.D11.10	Chain link fences and gates Allow for perimeter of site	400 m	250.00	100,120
Site.D11.11	Double swing gate	1 no	7,500.00	7,500
Site.D11.12	Bollards	4 no.	2,000.00	8,000

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		Quantity	Unit Rate ($)	Total ($)
	D1 Site Work			
	D11 Site Development			
	Signage			
Site.D11.13	Exterior signage allowance	1 sum	15,000.00	15,000
	TOTAL FOR D11 SITE DEVELOPMENT	9,267 m2	58.80 /m2	$544,926
	D12 Mechanical Site Services			
Site.D12.1	Plumbing & Drainage - Pumphouse	25 m2	27,957.68	698,942
	Equipment	1 sum	546,000.00	546,000
	Piping-Above Grade	1 sum	146,322.05	146,322
	Plumbing Fixtures	1 sum	6,620.00	6,620
Site.D12.2	Fire Protection - Pumphouse	25 m2	70.00	1,750
	Building	1 sum	1,750.00	1,750
Site.D12.3	HVAC - Pumphouse	25 m2	8,811.20	220,280
	Unit heaters - hydronic	1 sum	77,000.00	77,000
	Entrance force flow heater - hydronic	1 sum	48,000.00	48,000
	Wall fin radiation - enclosed by others	1 sum	33,750.00	33,750
	RHC-1	1 sum	15,750.00	15,750
	BB Coils	1 sum	45,780.00	45,780
Site.D12.4	Controls - Pumphouse	25 m2	7,380.00	184,500
	Controls	1 sum	184,500.00	184,500
Site.D12.5	Piping-Above Grade - Trammission and Recirculation lines	1 sum	11,254,762.63	11,254,763
	150mm Transmission Line	7,856 m	612.50	4,811,861
	75mm recirculation line	7,856 m	306.25	2,405,931
	Allowance for Line Isolation Valves (Isolation, Check, Etc)	1 sum	50,000.00	50,000
	Pipe insulation	15,712 m	253.75	3,986,971
	TOTAL FOR D12 MECHANICAL SITE SERVICES	9,267 m2	1,334 /m2	$12,360,235
	D13 Electrical Site Services			
Site.D13.1	Electrical Site Services	3,993 m2	79.99	319,400
	Incoming Power	3,993 m2	48.25	192,678
	Incoming Communications	3,993 m2	7.52	30,033
	Site Lighting & Devices	3,993 m2	24.21	96,688
	TOTAL FOR D13 ELECTRICAL SITE SERVICES	9,267 m2	34.47 /m2	$319,400
	NET BUILDING COST (Including Site)	9,424 m2	1,403 /m2	$13,224,561
	General Requirements and Fee	8.00 %		1,057,965
	Freight and Accommodations	9.34 %		1,333,988

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	Quantity	Unit Rate ($)	Total ($)
TOTAL CONSTRUCTION ESTIMATE (Excluding contingencies)	9,424 m2	1,657 /m2	$15,616,513
Design and Pricing Contingency	15.00 %		2,342,477
Escalation Contingency	8.00 %		1,249,321
Construction Contingency			EXCLUDED
TOTAL CONSTRUCTION ESTIMATE (Including contingencies)	9,424 m2	2,038 /m2	$19,208,311
TOTAL CONSTRUCTION ESTIMATE (Excluding Taxes)	9,424 m2	2,038 /m2	$19,208,311

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Provisional Pricing

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The below costs are excluded from the construction total and are inclusive of all contingencies.
(Design & Pricing, and Construction Contingency)

Item	Quantity	Unit Rate	Total
Provisional Item 1 - Thermosyphons to storage tanks	158 m2	$2,145 /m2	$338,100

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Annual Maintenance and 30 Year LifeCycle Estimate

Arctic Bay Water Treatment Plant, Nunavut

Job Number: 13130.101307.000

Issued: May 12, 2022

Prepared for: EXP Services

Prepared by: Altus Group Limited

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May 12, 2022

Job Number: 13130.101307.000

EXP Services
Suite 100 – 2650 Queensview Drive
Ottawa
ON, K2B 8H6

Re: **Annual Maintenance and 30 Year LifeCycle Estimate** for **Arctic Bay Water Treatment Plant, Nunavut**

We are pleased to submit our revised Annual Maintenance and 30 Year LifeCycle Estimate for the above-noted Project.

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We trust the Report meets your requirements. Should you have any questions related to the document or require additional information, please contact the undersigned.

Yours truly,

Altus Group

Per:	Mark Orge	Per:	Ashley Richardson
	MBA CFM PMP		MA MRICS MIWFM AIAM
	Director, Facilities		Managing Consultant
	Cost & Project Management		Cost & Project Management

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1. Estimate

We present out rough-order-of-magnitude (ROM) estimate for the Arctic Bay Water Treatment Plant based on the information provided through out cost team that includes a footprint schematic plan, schematic design report draft, and capital cost estimates.

1.1 Information used:

To provide the information needed for the estimate, we used the:

- Arctic Bay Conceptual Footprint Schematic #1 Plan (EXP Services dated February 2022)
- Technology Assessment and Service Condition Report draft (Exp. Services December 20th, 2021), and
- Arctic Bay Class D Cost estimate dated March 15th, 2022 (provided by the Altus Cost & Project Management team to support the development of the maintenance and lifecycle needs for the project.

1.2 Location and operating factors:

Arctic Bay is a very small community in the province of Nunavut with a reported population of 956 for 2023 (forecasted to rise to 1,106 for 2035 - Nunavut Bureau of Statistics). The availability of trained technicians and specialists is likely very limited, and so specialist maintenance technicians may need to be brought in for anything other than day to day unskilled maintenance. The training and development of the operators for the facility should therefore be considered carefully, perhaps by early recruitment and training on other/like facilities. They should be recruited with regard to their adaptability to be trained in other maintenance tasks so they can carry out the routine facilities maintenance, routine process equipment maintenance, as well as their operator duties.

Another influence on the development of the models is how the facility will be run and how the day-to-day activities and ongoing maintenance will be carried out. As the design matures and is finalized, it is recommended that equipment and element selection is carried out with regard to ease of routine maintenance wherever possible to reduce specialist maintenance visits from outside of the local community.

1.3 General Assumptions:

We have made a number of assumptions in the development of this ROM cost estimate for the maintenance of the water treatment plant located in the community of Arctic Bay, NU. While we have examined the limited maintenance and lifecycle information for the facility, we have also made some general assumptions in the development of the estimates as follows:

General:

- Maintenance and Lifecycle costs are based on the Capital Cost estimate (Class D R1) provided by Altus Group under the same assignment dated March 15, 2022.
- There are 3 options in consideration
  - Site 1 WTP and Truckfill
  - Site 3 WTP and Truckfill with 6.6km transmission / recirc. Line
  - Site 4 WTP and Truckfill with 7.9km transmission / recirc. line
- Design considerations for all WTP and truckfill options are almost identical.
- Ballpark estimates have been provided for annual other operating costs (based on EXP document provided by Altus Group under the same assignment)
- Insurance costs are excluded from the estimate
- Rough order of magnitude (ROM) estimates have been provided for annual maintenance costs and can be refined as the design develops.
- All costs are in 2022 $$. For future maintenance and lifecycle analysis, costs should be inflated.
- A 50% allowance for repairs due to low/no availability of skilled trades within the local community
- Maintenance impacted by operational model, hours and expected usage for the facility are unknown.
- Estimate does not include internet or other IMIT ongoing operating costs and that IMIT support provided by Municipality

Technical:

- UV lamp replacement has been included in Lifecycle
- Membrane replacement included in Lifecycle
- Truck replacement x four (4) included in lifecycle
- Estimate does not include removal of fluid waste from site
- Assumed snow and ice clearance undertaken by Staff
- Heat loss electrical costs for transmission piping included in summary costs for sites 3 & 4
- Additional electrical running costs included for Sites 3 and 4 recirculating pumps
- General average estimates have been provided for annual other operating costs including general electrical consumption and can be refined as the design develops and site option selected.

Contract Maintenance assumptions

- Assumed most basic SubContractors (e.g. electrical/mechanical) are available regionally
- All non-routine day to day maintenance undertaken by subcontractor within daily travel distance
- Initial first year operations include assumed 6-month support for training staff and running plant totaling $300,000

- No allowance included for subcontractor overnight / travel expenses; and
- Estimate contingency of 10% is included.

Staffing

Site Labour:

- See Data Assumptions sheet for labour burden.
- Assumed operating hours are 12hrs/day, 5 days/week (per EXP document).
- Assumed there will be five (5) full time site staff plus one (1) part time (8hr x 2 days/week) Supervisor (per EXP direction).
- Assumed there are four (4) 12,000 litre capacity water trucks in operation.
- Assume no coverage needed for vacation / sick etc., however $10,000 annual allowance included for additional staff back fill.
- Outside normal operating hours, assumed one member of staff will be on call with an additional $2.00 per/ hour supplement.

Vacation and other time off:

- Assumed non-productive time included in table at Appendix A.
- If more than one person is away at any one time (e.g. one person going sick when another is on a planned vacation) there is contingency included in the cost build up as stated above.

On call, shift and overtime assumptions

- Whenever the site is not operating, then one of the three full time staff will be “on-call” for emergency access to the site.

1.4 Maintenance

We estimate the annual maintenance and repair budget for the facility to be approximately: -

- $1,899,304 for Site Option #1
- $2,031,984 for site option #3, and
- $2,043,809 for site option #4.

1.5 Lifecycle

We estimate the total thirty-year cost for major repair and rehabilitation works as follows: -

- $6,236,701 for site option #1 (annual average of $207,890)
- $7,877,107 for site option #3, (annual average of $262,570) and

- $8,282,518 for site option #4, (annual average of $276,084).

Assumptions and allowances made in the development of the lifecycle portion of this estimate include: -

- Design and pricing contingency of 10% is included;
- Oncosts of 20% included to account for individual isolated lifecycle projects;
- Project Management fee of 15% included as an allowance
- Costing includes 'freeze up' repair allowance of just over $50,000 every 3 years for Sites 3 & 4 transmission pipeline

1.6 Altus Methodology

Estimates are based on a combination of RSMeans data, BOMA recommendations, and past project experience, and are subject to refinement as more detail becomes available.

2. Reporting Qualifications and Limitations

The qualifications described below shall apply to this report:

- We have endeavored to examine all the relevant information provided.
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- This assessment does not wholly eliminate uncertainty regarding the potential for existing or future costs, hazards or losses in connection with any property.
- The opinions expressed in this report are statements of judgment and fact as of the date of publication and are subject to change without further notice.
- Altus accepts no responsibility for any decisions made or actions taken as a result of this report unless specifically advised of and participate in such action, in which case our responsibility will be as agreed to at that time.
- Any use of this report specifically denies any right to claims against Altus, its officers, agents and employees in excess of the fee paid for professional service.
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APPENDIX A LIFE CYCLE ROM ESTIMATE DETAIL

Summary Costs Total

Operations and Maintenance (O&M)		Option Site 1	Option Site 3	Option Site 4
Operations Costs				
Total labour costs	$739,675			
Total Annual Operating Costs	$902,600			
	$1,642,275			
Total Annual Operations Costs		$1,642,275	$1,642,275	$1,642,275
Maintenance Costs				
Modular Building	$51,175			
Processing Equipment and Tanks	$24,250			
	$75,425	$75,425	$75,425	$75,425
Site Maintenance Costs (including additional pump house building and transmission line for Options 3&4)		$8,940	$28,558	$29,308
Additional annual electricty - transmission pipeline		-	$85,000	$95,000
Additional annual electricty - recirc pumps		-	$16,000	$16,000
Total Annual O&M Costs		$84,365	$204,983	$215,733
Sub-Total Operating and Maintenance Costs		$1,726,640	$1,847,258	$1,858,008
Contingency 10%		$172,664	$184,726	$185,801
Total Annual O&M Costs		**$ 1,899,304**	**$ 2,031,984**	**$ 2,043,809**
Total 30 Yr O&M Costs		**$ 56,979,112**	**$ 60,959,506**	**$ 61,314,256**
LIFECYCLE				
Trucks	$920,400			
Modular Building	$2,187,142			
Processing Equipment and Tanks	$2,852,568			
	Sub total	$5,960,110	$5,960,110	$5,960,110
	Site Options	$276,591	$1,916,997	$2,322,408
Total Lifecycle 30 Years		**$ 6,236,701**	**$ 7,877,107**	**$ 8,282,518**
	Annual Average	$207,890	$262,570	$276,084
O&M and LIFECYCLE				
Total 30 Yr O&M and Lifecycle Cost		**$ 63,215,814**	**$ 68,836,613**	**$ 69,596,774**
	Annual Average	2,107,194	2,294,554	2,319,892
Aditional Investment over 30 years compared to Site 1		n/a	5,620,800	6,380,960

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Labour Burden and Common Data Assumptions

Labour Burden

Benefits / burden

EI	**1.58%**	Employment Insurance
CPP	**5.25%**	Canada Pension Plan
WCB	**3.75%**	Workers Comp
EHT	**4.00%**	Employer Health Tax
Vacation		
Other	**6.00%**	Health / Dental benefits
Overtime	**5.00%**	Allowance for overtime for hourly staff
Paid Hours	52.14	weeks/year
	5	days/week
	8	hours/day
	2085.7	hours /year

Operating hours

12hrs/day, 5 days /week

Proportional costs

Nil	**0.00%**

Productive Hours Calculations

Total productive hours

	1,779.71	
Paid Hours	2085.71	
Vacation	120.00	hours
Sick	40.00	hours
Stat Hols	96.00	hours
Other	50.00	Union personal etc.
Total	306.00	
Non-working hours	1,138.86	
Stat Hols:	1	New Year's Day
12	1	Good Friday
	1	Easter Monday
	1	Victoria Day
	1	Canada Day
	1	Nunavut Day
	1	Civic holiday
	1	Labour Day
	1	Thanksgiving Day
	1	Remembrance Day
	1	Christmas Day
	1	Boxing Day

12/5 shift requirements

Operating hours	3,129
Shift Hours	4,027
Staff reqt for 12/5	1.8

Annual Other Costs

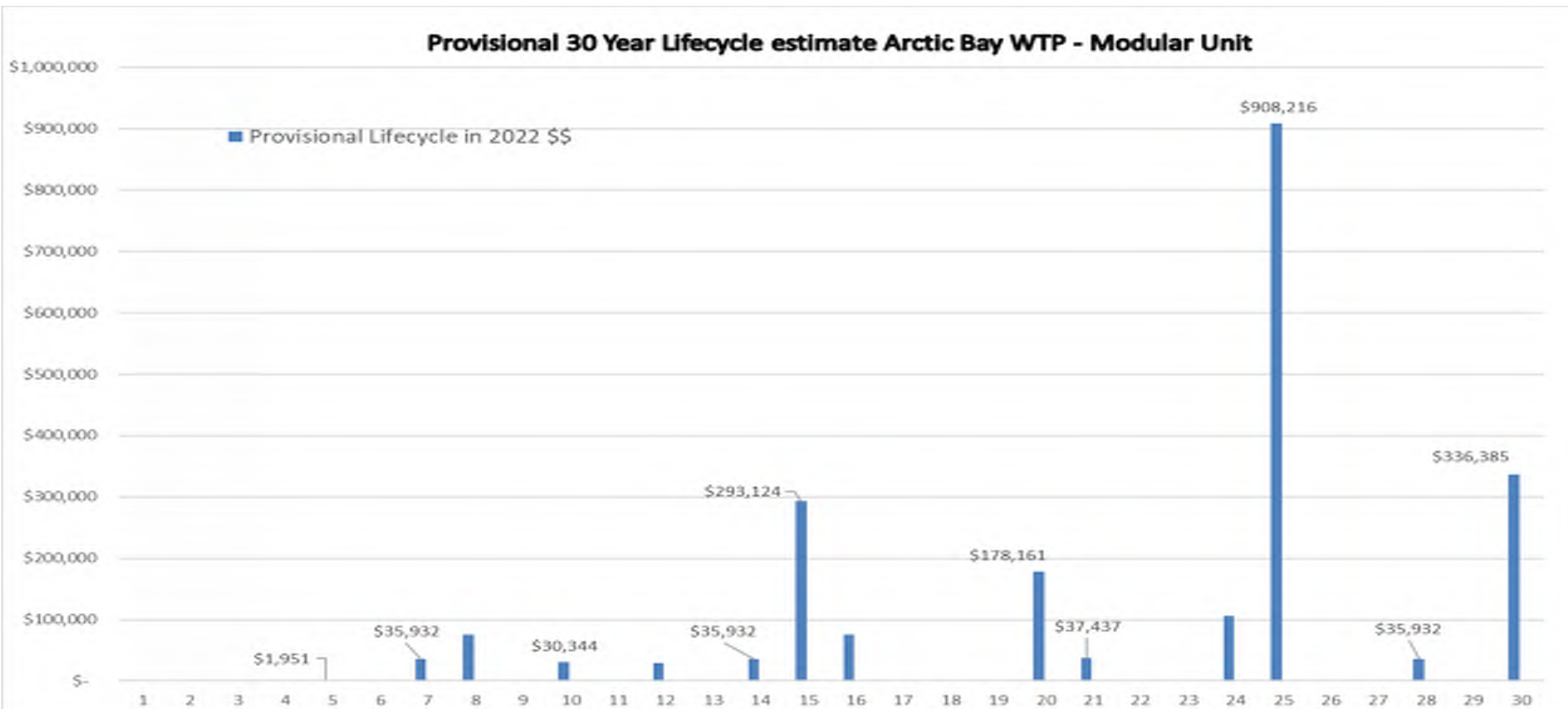
Annual Operating Costs	Cost/occurance	Frequency	Total Cost/Year
Utilities			
Electricity Consumption	$292,000.00	1	$292,000.00
Fuel			
Truck Fuel @ 200 litre/day x $2/litre	$104,000.00	4	$416,000.00
Equipment Diesel Fuel (Genset, Pumps etc)	$10,000.00	1	$10,000.00
Heating Fuel - Oil	$40,000.00	1	$40,000.00
Water Production Costs			
Chemicals	$40,000.00	1	$40,000.00
Water Sampling	$84,000.00	1	$84,000.00
Other Operating Costs			
Radio License	$50.00	12	$600.00
Truck annual maintenance allowance	$2,500.00	4	$10,000.00
General Staff training	$10,000.00	1	$10,000.00
		Annual Total	**$902,600.00**
Initial Support start up Costs			
Certified operator running facility and providing initial operator training for first 6 months.	$50,000.00	6	$300,000.00
		1st Year Total	**$1,202,600.00**
Operating Costs assumed by Municipality			
IT Network, WiFi & Communications, insurances			

Lifecycle – Arctic Bay WTP Modular Building

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Provisional Lifecycle in 2022 $$	$ -	$ -	$1,505	$ -	$ 1,951	$ 1,505	$ 35,932	$ 75,402	$ 1,505	$ 30,344	$ -	$30,000	$ -	$35,932	$293,124	$ 75,402	$ -	$1,505	$ -	$178,161	$ 37,437	$ -	$ -	$105,402	$908,216	$ -	$1,504.50	$35,932	$ -	$336,385	$2,187,142

Project: Arctic Bay WTP - Modular Building
Location: Nunavut

	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
A1 Substructure																															
A2 Structure															62,789					27,512										62,789	$153,090
A3 Exterior Envelope															37,301					24,308					265,736					37,301	$364,646
B1 Partitions and doors																														14,868	$14,868
B2 Finishes							22,734			12,464				22,734						12,464	22,734							22,734		12,464	$128,327
B3 Fitting & Equipment																				61,008											$61,008
C1 Mechanical			1,505		1,951	1,505		41,267	1,505	17,881		1,505			82,043	41,267		1,505		52,869	1,505			42,771	307,910		1,505			97,973	$696,462
C2 Electrical							13,198	34,135				28,496		13,198	110,991	34,135					13,198			62,631	334,570			13,198		110,991	$768,740
D Ancillary																															
Total			**1,505**		**1,951**	**1,505**	**35,932**	**75,402**	**1,505**	**30,344**		**30,000**		**35,932**	**293,124**	**75,402**		**1,505**		**178,161**	**37,437**			**105,402**	**908,216**		**1,505**	**35,932**		**336,385**	$2,187,142

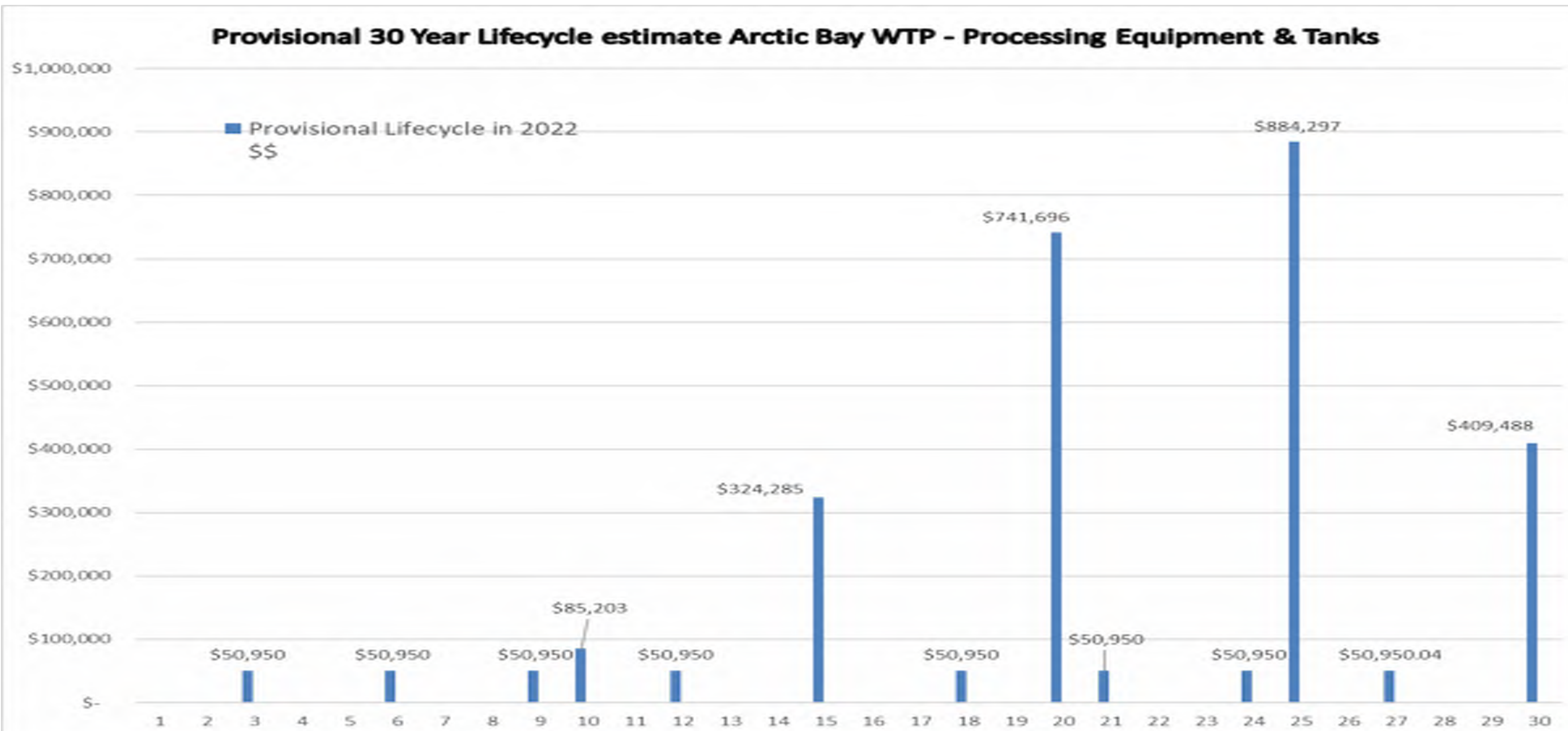


Lifecycle – Arctic Bay Processing Equipment & Tanks

Provisional Lifecycle in 2022 $$	$ -	$ -	$50,950	$ -	$ -	$ 50,950	$ -	$ -	$ 50,950	$ 85,203	$ -	$50,950	$ -	$ -	$324,285	$ -	$ -	$50,950	$ -	$741,696	$ 50,950			$ 50,950	$884,297	$ -	$50,950.04	$ -	$ -	$409,488	$2,852,568

Project: Arctic Bay WTP - Processing Equipment & Tanks
Location: Nunavut

	Year																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
B3 Fitting & Equipment			37,760			37,760			37,760	85,203		37,760			286,787			37,760		741,696	37,760			37,760	86,994		37,760			371,990	$1,874,749
D 1 Site Work			13,190			13,190			13,190			13,190			37,498			13,190			13,190			13,190	797,302		13,190			37,498	$977,819
Total			**50,950**			**50,950**			**50,950**	**85,203**		**50,950**			**324,285**			**50,950**		**741,696**	**50,950**			**50,950**	**884,297**		**50,950**			**409,488**	$2,852,568

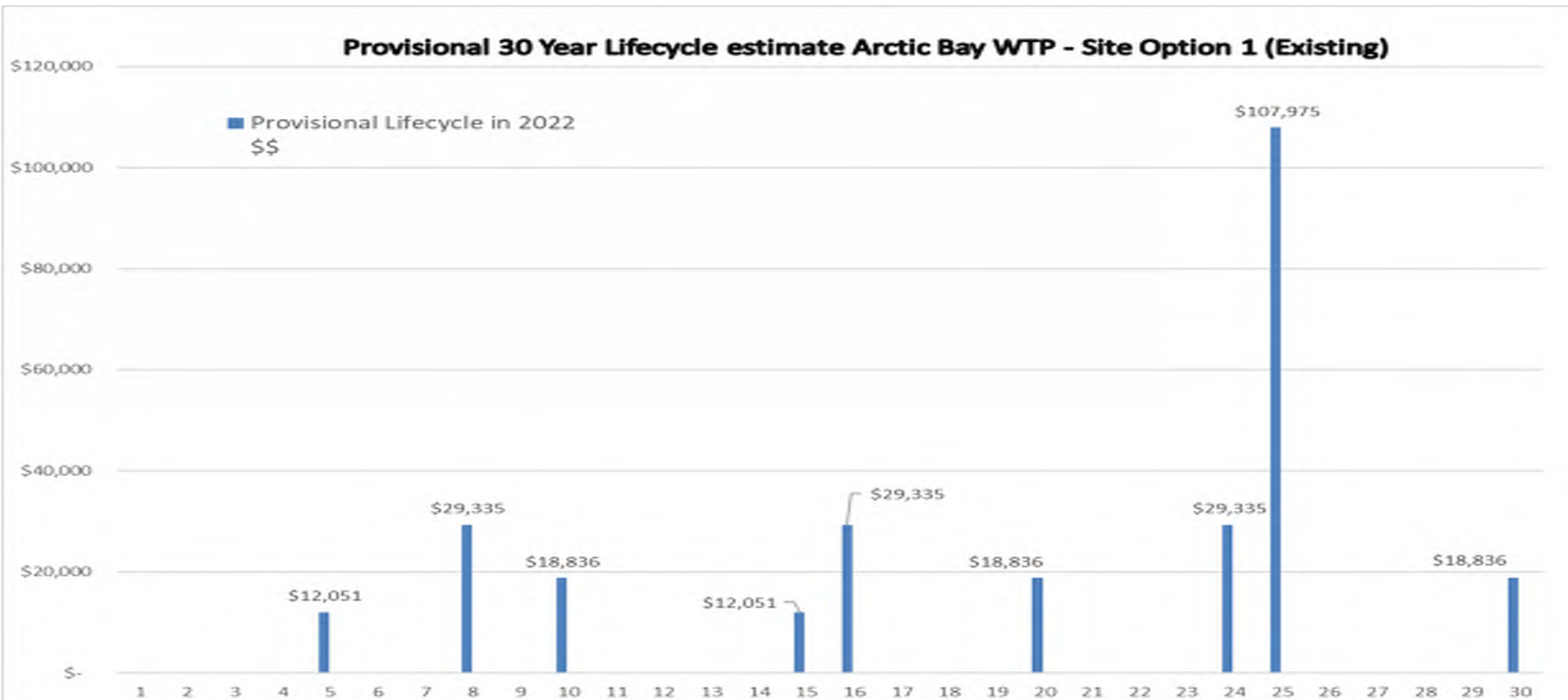


Lifecycle – Arctic Bay Site Option 1 (Existing)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Provisional Lifecycle in	$ -	$ -	$ -	$ -	$ 12,051	$ -	$ -	$ 29,335	$ -	$ 18,836	$ -	$ -	$ -	$ -	$ 12,051	$ 29,335	$ -	$ -	$ -	$ 18,836	$ -	$ -	$ -	$ 29,335	$107,975	$ -	$ -	$ -	$ -	$ 18,836	$276,591

Project: Arctic Bay WTP - Site Option 1 (Existing)
Location: Nunavut

	Year																														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**Total**
D11 Site Development					12,051					18,836					12,051					18,836					12,051					18,836	$92,663
D12 Mechanical Site Services								29,335								29,335								29,335							$88,005
D13 Electrical Site Services																									95,924						$95,924
Total					**12,051**			**29,335**		**18,836**					**12,051**	**29,335**				**18,836**				**29,335**	**107,975**					**18,836**	$276,591



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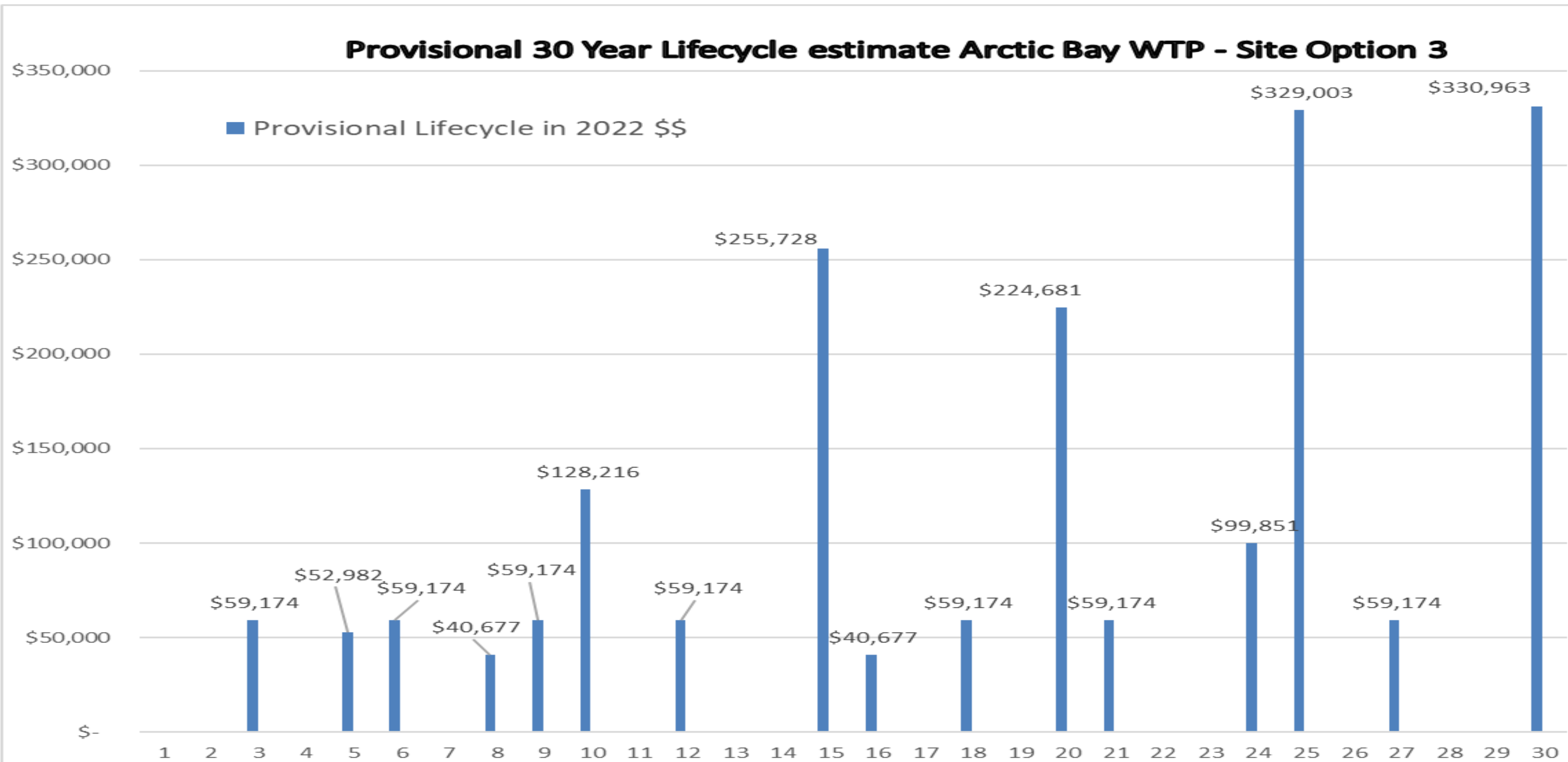
Lifecycle – Arctic Bay Site Option 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
Provisional Lifecycle in 2022 $$	$ -	$ -	$ 59,174	$ -	$ 52,982	$ 59,174	$ -	$ 40,677	$ 59,174	$128,216	$ -	$ 59,174	$ -	$ -	$255,728	$ 40,677	$ -	$ 59,174	$ -	$224,681	$ 59,174	$ -	$ -	$ 99,851	$329,003	$ -	$ 59,174	$ -	$ -	$330,963	$1,916,997

Project: Arctic Bay WTP - Site Option 3
Location: Nunavut

	Year																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
D11 Site Development					13,758					34,565					13,758					34,565					13,758					34,565	$144,967
D12 Mechanical Site Services			59,174		39,224	59,174			59,174	93,651		59,174			241,970			59,174		190,116	59,174			59,174	202,689		59,174			296,398	$1,537,442
D13 Electrical Site Services								40,677								40,677								40,677	112,556						$234,588
Total			59,174		52,982	59,174		40,677	59,174	128,216		59,174			255,728	40,677		59,174		224,681	59,174			99,851	329,003		59,174			330,963	$1,916,997



Lifecycle – Arctic Bay Site Option 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Provisional Lifecycle in 2022 $$	$ -	$ -	$ 59,619	$ -	$ 60,745	$ 59,619	$ -	$ 40,677	$ 59,619	$135,984	$ -	$ 59,619	$ -	$ -	$441,120

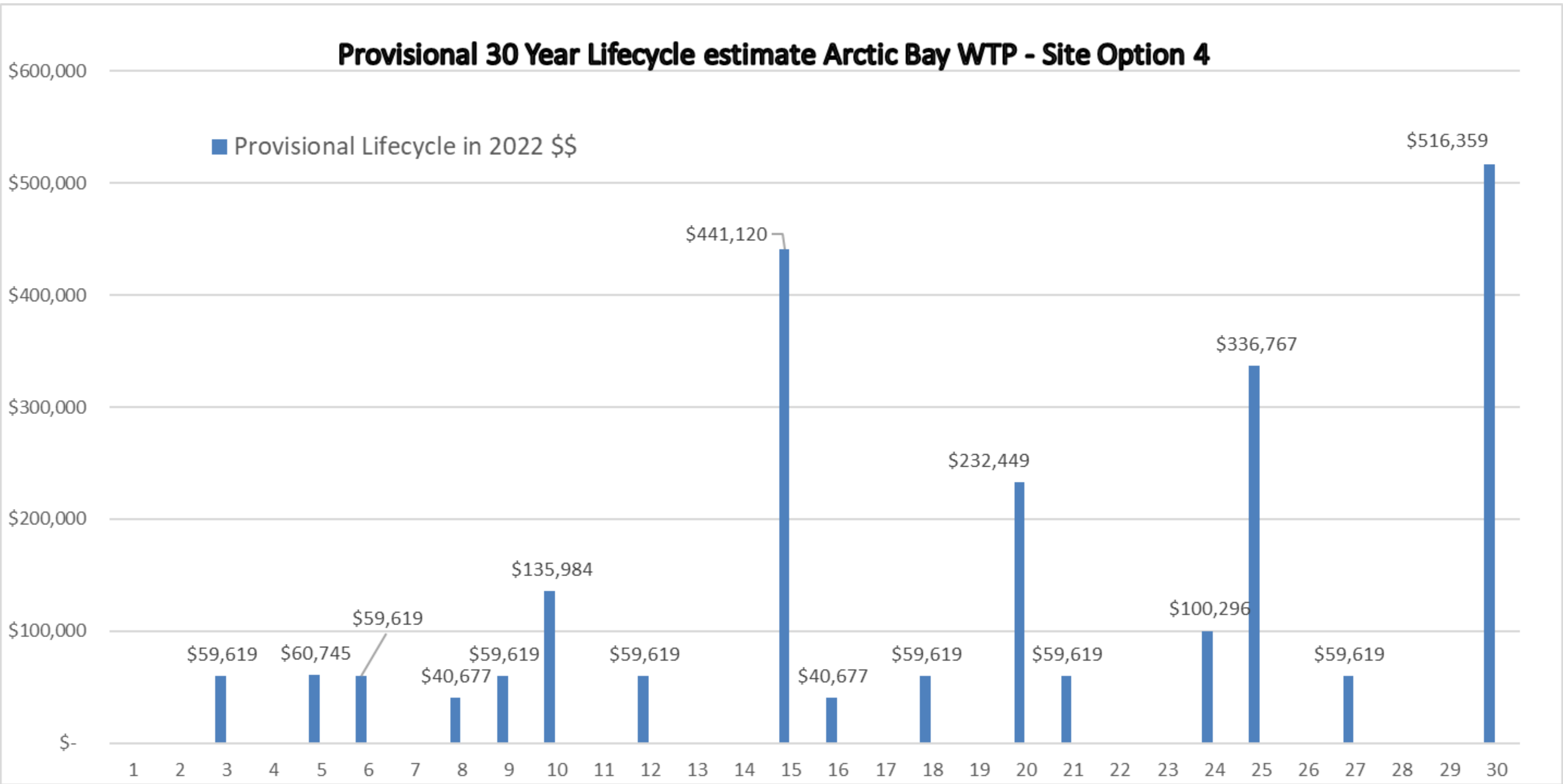
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Provisional Lifecycle in 2022 $$	$ 40,677	$ -	$ 59,619	$ -	$232,449	$ 59,619	$ -	$ -	#######	$336,767	$ -	$ 59,619	$ -	$ -	$516,359	$2,322,408

Project: Arctic Bay WTP - Site Option 4
Location: Nunavut

Year

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
D11 Site Development					13,699					34,510					13,699
D12 Mechanical Site Services			59,619		47,046	59,619			59,619	101,474		59,619			427,422
D13 Electrical Site Services								40,677							
Total			**59,619**		**60,745**	**59,619**		**40,677**	**59,619**	**135,984**		**59,619**			**441,120**

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
D11 Site Development					34,510					13,699					34,510	$144,627
D12 Mechanical Site Services			59,619		197,939	59,619			59,619	210,512		59,619			481,849	$1,943,193
D13 Electrical Site Services	40,677								40,677	112,556						$234,588
Total	**40,677**		**59,619**		**232,449**	**59,619**			**100,296**	**336,767**		**59,619**			**516,359**	$2,322,408



Appendix D – Geotechnical Investigation Feasibility Study

1. **Geotechnical Investigation Feasibility Study Report (EXP) – Arctic Bay (March 22, 2022)**

Feasibility Study Geotechnical Investigation, Water Treatment Plant, Arctic Bay, Nunavut

Client:
Department of Community and Government Services
Government of Nunavut

Type of Document:
Final Report

Project Name:
Water Treatment Plant Feasibility Study, Arctic Bay, Nunavut

Project Number:
FRN-21016638-A0

Prepared By:
Surinder K. Aggarwal, M.Sc., P.Eng.

Reviewed By:
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Date Submitted:
2022-03-22

Legal Notification

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Summary

A geotechnical investigation was undertaken at three sites in the Hamlet of Arctic Bay, Nunavut to assess the most suitable site for construction of the new Water Treatment Plant (WTP) for the community. This work was authorized by Department of Community and Government Services, Government of Nunavut and is part of the High Arctic Water Treatment Plant Business Case Study.

The proposed facility would comprise of a 30 m by 20 m Water Treatment Plant building which will be maintained at ~22^{o}C and an 8 m diameter by 8 m high treated water and an 8 m diameter by 6 m high wastewater storage tanks. The water in the storage tank will be maintained at 5^{o}C to 10^{o}C. The Raw water source will be Merci Lake reservoir located approximately 8 km from the community. The existing WTP is located at Merci Lake. Water is trucked from the plant to the community.

The three sites investigated are located approximately 8 km from the community (Site 1), 1.3 km from the community (Site 3), and adjacent to the community (Site 4). The investigation revealed that Site 1 is mostly flat with a gentle gradient (39.7H:1V). Sites 3 and 4 are located on steep slopes with a gradient of 7.7H:1V and 5.9H:1V respectively. In addition, Site 4 contains surficially disturbed material which extends to a depth of 1 m to 4 m. This material is not suitable for construction and would have to be excavated and disposed of. The surficial soils at Site 1 are well drained sand and gravel to sandy gravel and contains few ice crystals or lenses. The soils on Site 4 are similar to Site 3 except for the surficially disturbed material or fill which was encountered to 1 m to 4 m depth. The soils contain more ice crystals and lenses compared to site 3.

Based on the structural requirements (heated structures with slab-on-grade construction) and the geotechnical conditions encountered, it is considered that the most suitable foundation option for all three sites is likely to be spread and strip footings for the WTP and slabs for the tanks set on an inground engineered fill pad incorporating insulation and thermosyphons under the building and likely insulation only under the tanks.

The design is based on the premise that degradation of the permafrost under the structures will be prevented or minimized to prevent settlement and cracking of the structures. Geothermal analyses were undertaken to determine the thickness of the granular bed and insulation and the extent of thermosyphons required to maintain the ground below the founding level of the structures in a permanently frozen state.

The geothermal analyses have revealed that the required thickness of granular bed and insulation is 1.2 m and 100 mm respectively for both the Water Treatment Plant building and the storage tanks. Thermosyphons would be required for the Water Treatment Plant building modelled on the smallest available radiator area (typically about 9.75 m^2) with thermosyphon horizontal evaporator loops 25 mm in diameter and 60 m long with consistent spacing of 1 m would prevent or minimize degradation of the permafrost under the foundations. Thermosyphons will not be required under the storage tanks.

It is anticipated that Serviceability Limit State (SLS) bearing pressure of 150 kPa and factored geotechnical resistance at Ultimate Limit State of 225 kPa would likely be available provided that the engineered fill pad is constructed as detailed in Section 5.6.5 of the report.

It is noted that whilst construction of the WTP on Site 3 and Site 4 is also feasible, extensive site grading would be required at both the sites. In addition, in the case of Site 4, the surficially disturbed material would have to be excavated from the building areas and disposed of elsewhere. For these reasons, from a geotechnical perspective, Site 1 is to be preferred provided the new Water Treatment Plant is located south of the existing Water Treatment Plant and the Environment Canada weather station.

The above and other considerations are discussed in greater details in the accompanying report.

1.0 Introduction

A geotechnical investigation was undertaken at three sites in the Hamlet of Arctic Bay, Nunavut to assess the most suitable site for construction of the new Water Treatment Plant (WTP) for the community. This work was authorized by Department of Community and Government Services, Government of Nunavut and is part o the High Arctic Water Treatment Plant Business Case Study.

The location of the Hamlet of Arctic Bay is shown on Figure 1. The locations of the sites (Sites 1, 3, and 4) under consideration are shown on Figure 2. The proposed facilities would comprise of a WTP building with a footprint of 30 m by 20 m, an 8 m diameter by 8 m high treated water storage tank, and an 8 m diameter by 6 m high wastewater storage tank. The building will be maintained at a temperature of 22^{o}C approximately and the water in the treated water storage and the wastewater storage tanks will be heated to 5^{o}C to 10^{o}C. The raw water source will be the Merci Lake watershed and raw water seasonal storage will be Merci Lake reservoir.

The geotechnical investigation was undertaken at each site to:

- Establish geotechnical, groundwater and permafrost conditions at the site;
- Carry out associated laboratory tests to classify the soils;
- Determine the active layer thickness;
- Establish ground temperature profile;
- Discuss various foundation options and make recommendations regarding the most suitable type of foundation, founding depth, Serviceability Limit State (SLS) bearing pressure of the founding stratum, and factored geotechnical resistance at Ultimate Limit State (ULS);
- Undertake geotechnical analysis to assess the impact of the proposed structure and climate change on permafrost degradation and recommend mitigating measures;
- Provide seismic design parameters; and,
- Discuss subsurface concrete requirements.

The comments and recommendations given in this report are preliminary for guidance of design engineers and should not be used for construction.

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2.0 Background Information

Arctic Bay is the third most northerly community in Canada after Grise Fiord and Resolute Bay. It is located in the northwest corner of Baffin Island and is connected to the nearby mine of Nanisivik by a 32 km long gravel road. Arctic Bay is situated on the north shore of Adams Sound and is home to about 850 people. It is situated on a low gravel beach and is surrounded on three sides by high hills. Nanisivik was developed in the 1970s to support Breakwater Resources' lead, zinc and silver mine which is now in the last stages of closing.

Arctic Bay experiences a tundra climate like most northern Canadian Territories at low elevations with long very cold winters and short cool to cold summers. Its climate does not differ from more severe subarctic climate except for practically non-existence of summer. It has an arid climate with less than 250 mm (9.8 inches) precipitation per year. With thawing of the permafrost, Arctic Bay may be affected by flooding due to the melting of sea ice and due to erosion. The average high and low yearly temperatures are -12.5^{o}C and -17.8^{o}C. Its elevation is 31 m.

Currently water for the community is drawn from Merci Lake which is located 8 km from the community. Truck fill station is located on the lake. The water is trucked from the plant to the community. Chlorination is the only treatment to water. Treated water does not meet the Guidelines for Canada Drinking Water Quality. It is understood that in order to meet the federal and territorial standards for drinking water, a well-designed water treatment plant will have to be constructed. For this purpose, EXP is required to review three potential sites, one adjacent to the existing Water Treatment Plant and at least one closer to the community.

3.0 Surficial Geology of Arctic Bay

The surficial geology of Arctic Bay is shown on Figure 3. It indicates that the surficial soils in the area are predominantly till veneer which is thin and discontinuous and may include extensive areas of rock outcrop.

4.0 Bedrock Geology of Arctic Bay

The bedrock geology of Arctic Bay is shown on Figure 4. A review of this figure indicates that the bedrock at the site consists of Cambrian Silurian carbonate and siliciclastic rocks, i.e., limestone, dolomite, conglomerates, sandstone, and shales.

5.0 Site 1 Considerations

5.1 Site Description

The site is located adjacent to the existing WTP and the existing lake reservoir (Lake Merci) (Figure 5a). It is understood that the intake structure is old and the pump is not performing well. The site has an Environment Canada weather station located west of the existing pumphouse. The weather station shares power from the pumphouse. It is reported that the east side of the pumphouse is considerably lower and it is suspected that it may flood in the spring. It is also reported that a lot of fill would be required to raise the grade of the pumphouse on the east side.

A review of Site Plan, Figure 5a indicates that the site is fairly flat lying with the ground surface elevations varying from Elevation 6.0 m to Elevation 8.0 m approximately except for the northeast corner where the ground surface rises to Elevation 11 m. The site is located approximately 30 m east of the lakeshore. The extent of talik under the lake or in its vicinity is currently not known.

5.2 Geotechnical Investigation Procedure

The fieldwork for the geotechnical investigation was undertaken with an air track drill between September 29 and 30, 2021. It was supervised on a full-time basis by a senior geotechnician experienced in permafrost soils and northern construction.

The fieldwork consisted of drilling seven boreholes, each to 10 m depth except for Borehole 1 which was terminated at 6 m depth due to extensive cave-in of the borehole and excavating two test pits with a rubber tired backhoe to refusal at 1.2 m depth. The locations of the boreholes and test pits are shown on Figure 5a. Bulk soil samples were obtained from the boreholes at 1 m depth intervals.

On completion of drilling, multi-bead thermistor string was installed in Borehole No. 2. A 19 mm diameter PVC standpipe was installed to the bottom of the borehole and the thermistor string was placed in the standpipe. Initial readings were taken 24 hours after installation. All other boreholes were backfilled to the surface with drill cuttings on completion.

The soil samples were visually examined for textural classification and logged in accordance with the Standard Practice of Description and Classification of Soils Visual Manual Procedure (ASTM 2488) and Standard Practice for Description of Frozen Soils, Visual Manual Procedure (ASTM D4083). Part of each soil sample was placed in a plastic bag, sealed and weighed on-site for moisture content determination. The remainder of the soil sample was placed in another plastic bag, sealed and identified for visual examination by a senior geotechnical engineer and additional laboratory testing.

Representative soil samples were also obtained from the test pits and the test pits logged. The samples were examined for visual classification, logged, preserved in plastic bags and identified. The test pits were backfilled on completion.

The locations of the boreholes and test pits were established using a commercial grade handheld GPS device and are approximate. The coordinates of the boreholes and test pits have been listed on Table 1. The elevations of the boreholes were established in the office based on GPS locations and topographic surveys of the site. The elevations refer to the Geodetic Datum and are approximate.

On completion of the fieldwork, all soil samples were transported to the EXP laboratory in the city of Ottawa, Ontario where they were examined by a senior geotechnical engineer and borehole logs prepared. The engineer also assigned laboratory testing which consisted of performing natural moisture content tests on all the samples and grain size analyses, Atterberg Limit tests, pH, sulphate, chloride and electrical resistivity tests on selected soil samples.

Table 1: Coordinates of Boreholes and Test Pits, Arctic Bay, Site 1

Borehole or Test Pit #	Eastings	Northings	Elevation (m)
BH1	564879	8100592	5.7
BH 2	564918	8100650	7.3
BH3	564552	8100831	9.0
BH4	564547	8100579	7.5
BH5	564882	8100706	6.3
BH6	564955	8100731	7.7
BH7	564887	8100785	6.6
TP 1	564892	8100700	6.9
TP 2	564906	8100653	6.7

5.3 Soil Description

A detailed description of the subsurface soil and groundwater conditions determined from the boreholes and test pits are given on the attached Borehole Logs, Figures 6 to 14 inclusive. The borehole and test pit logs and related information depict subsurface conditions only at the specific locations and times indicated. Subsurface conditions and water levels at other locations may differ from conditions at the locations where sampling was conducted. The passage of time also may result in changes in the conditions interpreted to exist at the locations where sampling was conducted. Boreholes were drilled and test pits excavated to provide representation of subsurface conditions as part of a geotechnical exploration program and are not intended to provide evidence of potential environmental conditions.

It should be noted that the soil boundaries indicated on the borehole logs are inferred from non-continuous sampling and observations during drilling. These boundaries are intended to reflect approximate transition zones for the purpose of geotechnical design and should not be interpreted as exact planes of geological change. The “Notes on Sample Descriptions” preceding the borehole logs form an integral part of this report and should be read in conjunction with this report. The soil stratigraphy encountered at the site is discussed below in descending order from the existing ground surface. Grain size analyses and soil classification is given on Table 2.

5.3.1 Topsoil / Tundra

The site is covered with approximately 50 mm of topsoil / tundra.

5.3.2 Fill

Beneath the topsoil, granular fill was encountered in Borehole 7 which extended to 2 m depth (Elevation 4.6 m). The fill consists of crusher run 19 mm limestone sand and gravel. It is well compacted and grey in colour. Its moisture content varied from 1.7 percent to 2.2 percent.

Table 2: Results of Laboratory Tests, Arctic Bay, Site 1

Borehole #	Depth (m)	Grain Size Analyses (%)			Atterberg Limits (%)			USCS Classification
		Clay & Silt	Sand	Gravel	Liquid Limit	Plastic Limit	Plasticity Index	
TP1	0 – 1.2	2	33	64				GW
BH1	1 – 2	5	48	47				GP
BH1	4 – 5	5	49	46				GP
BH2	5 – 6	9	56	35				SP
BH2	9 – 10	23	64	13			Non-plastic	SM
BH3	2 - 3	26	68	6			Non-plastic	SM
BH3	4-5	22	70	8			Non-plastic	SM
BH4	3 – 4	7	42	51				GP
BH4	7 - 8	11	57	32			Non-plastic	SP
BH5	1 – 2	4	37	59				GP
BH5	6 – 7	9	57	34				SW
BH6	1 – 2	4	44	52				GW
BH6	8 – 9	23	67	10			Non-plastic	SM
BH7	2 – 3	6	55	39				SP
BH7	4 – 5	22	58	20			Non-plastic	SM
BH7	8 - 9	12	81	7			Non-plastic	SW

5.3.3 Sandy Gravel to Sand and Gravel

Beneath the tundra / topsoil in Boreholes 1 and 3 to 6 and Test Pits 1 and 2, sandy gravel to sand and gravel extends to the entire depth investigated in Test Pits 1 and 2 (i.e., 1.2 m depth, Elevation 5.2 m and 5.5 m respectively) and to a depth of 1.0 m to 5.0 m in Boreholes 3 to 6 (Elevation 1.3 m to 8.0 m). Borehole 1 was terminated in this stratum at 6 m depth due to extensive cave-in. This stratum was also encountered in Borehole 3 between 5 m and 10 m depth (Elevation 3.0 m to Elevation -1.0 m) and in Borehole 7 between 5 m and 8 m depth (Elevation 1.6 m to -1.4 m). The sandy gravel and sand and gravel is poorly to well graded. It comprises of 3 to 7 percent clay and silt, 33 to 49 percent sand, and 46 to 64 percent gravel (Figures 15 to 20). Its moisture content varies from 1.7 to 32.3 percent.

5.3.4 Gravelly Sand to Sand

The topsoil in Borehole 2 and the sand and gravel stratum in Boreholes 4 and 5 and the fill in Borehole 7 are underlain by gravelly sand which extends to a depth of 8.8 m in Borehole 2 (Elevation -1.5 m), 3.0 m in Borehole 7 (Elevation 3.6 m), and to the entire depth investigated in Boreholes 4 and 5, i.e., 10 m depth (Elevation -2.5 m and-3.7 m respectively). This stratum comprises of 6 to 11 percent clay and silt, 53 to 57 percent sand, and 32 to 39 percent gravel (Figures 21 to 24). Its moisture content varies from 3.0 to 24.5 percent.

5.3.5 Silty Sand

In Boreholes 2, 3, 6 and 7, the sandy gravel to gravelly sand is underlain by silty sand which extends to the entire depth investigated (10 m) in Boreholes 2 and 6 (Elevation -2.7 m and -2.3 m) and to 5.0 m depth in Boreholes 3 and 7 (elevation 4.0 m and 1.6 m respectively). It consists of 22 to 26 percent clay and silt, 58 to 70 percent sand, and 6 to 20 percent gravel (Figures 26 to 30). It has a moisture content of 13.4 to 24.5 percent.

5.3.6 Sand

In Borehole 7, the sand and gravel is underlain by a sand layer which extends to the maximum depth investigated, i.e., 10 m (Elevation -3.4 m). It comprises of 12 percent silt and clay, 81 percent sand, and 7 percent gravel (Figure 25). Its moisture content was determined as 18.3 to 18.4 percent.

5.3.7 Groundwater

Water level observations were made in the boreholes on completion of drilling of each borehole. These observations have been summarized on Table 3.

Table 3: Groundwater Observations in Boreholes, Arctic Bay, Site 1

Borehole #	Observation Date	Depth to WL below Ground Surface	Borehole Open to (m)	WL Elevation (m)
BH1	September 29, 2021	4.0	5.0	1.7
BH2	September 30, 2021	N/A	10.0	
BH3	September 30, 2021	N/A	10.0	
BH4	September 29, 2021	N/A	10.0	
BH5	September 30, 2021	4.6	10.0	1.7
BH6	September 30, 2021	4.6	10.0	3.1
BH7	September 30, 2021	3.7	10.0	2.9

The above observations indicate that groundwater level in the west and central parts of the site ranged between 3.7 m and 4.5 m depth below the existing ground surface, i.e., Elevation 1.7 m to 3.1 m. The groundwater table at the site is subject to seasonal fluctuations and is expected to be at a higher level during spring freshet.

5.4 Ground Temperatures and Active Layer Thickness

Multiple thermistor beads were installed in Borehole 2 on completion of drilling to monitor the ground temperatures. Thermistor beads were installed at 0.5 m, 1.0 m, 2.0 m, 3.0 m, 4.0 m, 6.0 m, 8,0 m, and 10.0 m depth below the existing ground surface. Readings were taken on October 1, 2021, and the observations made have been tabulated on Table 4.

A review of this table indicates that the ground temperature in the upper 3 m depth was 1.0^{o}C. The ground was frozen below 4.0 m depth.

5.4.1 Active Layer Thickness

The initial set of readings taken at the site indicate that the ground was frozen below 4 m depth. However, these readings had not stabilized and therefore cannot be relied upon. It is recommended that ground temperature should be monitored during early spring to fall of 2022 in order to estimate the active layer thickness. It is noted that Ednie and Smith[1] have recorded a measured deep thaw depth of 1.3 m for Arctic Bay.

Table 4: Temperature Records in Multi-Bead Thermistors, Arctic Bay, Site 1

Borehole #	Borehole 25											
Observations Date	October 7, 2021											
	Bulb	Depth (m)	Meter RDG (K ohms)	Temp (°C)	Bulb	Depth (m)	Meter RDG (K ohms)	Temp (°C)	Bulb	Depth (m)	Meter RDG (K ohms)	Temp (°C)
	1	0.5	16.3	1.0								
	2	1.0	16.3	1.0								
	3	1.5	16.3	1.0								
	4	2.0	16.8	-0.6								
	5	3.0	17.7	-1.6								
	6	4.0	18.4	-2.3								
	7	6.0	20.1	-4.0								
	8	8.0	22.1	-5.8								
	9	10.0	24.3	-7.6								

[1] Ednie, M. and Smith, S.L., 2015, Permafrost temperature data 2008-2014 from community based monitoring sties in Nunavut; Geological Survey of Canada, Open File 7784.

5.5 Foundation Options

The following foundation options were considered for WTP and the storage tanks:

1) Spread and strip footings on permafrost;
2) Adfreeze piles;
3) End bearing piles; and,
4) Spread and strip footings on engineered fill pad with insulation and thermosyphons.

5.5.1 Spread and Strip Footings on Permafrost

A heated building with a slab-on-grade floor has the potential of degrading the permafrost which may result in settlement of the building. Experience indicates the provision of insulation alone under the floor slab of the building will not prevent the permafrost from degradation. Therefore, this is not considered to be a viable option.

5.5.2 Ad-Freeze Piles

Ad-freeze piles normally require that the floor slab is elevated above the ground surface to prevent degradation of the permafrost. In addition, the climate warming is expected to result in degradation of the permafrost and increase in thickness of the active layer. Since the ad-freeze piles support the load in adhesion between the frozen soil and the pile, this pile type cannot be relied upon to perform satisfactorily during the life of the structure. Therefore, ad-freeze piles are not considered an option for the proposed structure.

5.5.3 End Bearing Piles

From a geotechnical perspective, end bearing piles socketed into the bedrock would be feasible. However, bedrock was not encountered in the boreholes to the depth investigated. Construction of this type of pile has practical limitations due to lack of availability of suitable equipment in the Hamlet. Also, an additional geotechnical investigation would be required if this type of pile is to be considered to establish the depth to bedrock and its properties. Installation of end bearing piles is also expected to be more costly compared to the option provided below.

5.5.4 Spread and Strip Footings or Slabs on Engineered Fill Pad with Insulation and Thermosyphons

Based on the geotechnical conditions encountered and structural requirements, it is considered that the most suitable foundation option for the proposed WTP is to set it on below ground engineered fill pad with insulation and thermosyphons installed under the footings. The most suitable type of foundations for the wastewater and treated water storage tanks is to set the tanks on slabs on the extension of the engineered fill pad constructed for the Water Treatment Plant with insulation under the tanks (and thermosyphons if required). These options have been discussed in greater detail in Section 5.6.

The investigation has revealed that the geotechnical conditions at the site consist of sandy gravel to sand and gravel which is underlain by gravelly sand to sand and silty sand. Bedrock was not encountered in any of the boreholes.

The proposed structure is to incorporate a slab-on-grade floor. It will be heated to ~22°C. The water in the wastewater and treated water storage tanks will be maintained at a temperature of 5°C to 10°C. The tanks will be located outside within 10 m of the building. Because the proposed structures will be heated, the potential for degradation of the permafrost below the structures exists due to heat loss from the structures. The type of foundations selected should ensure that degradation of permafrost under the structures is prevented or minimized.

5.6 Water Treatment Plant and Wastewater and Treated Water Storage Tanks Foundations

In order to determine the thickness of engineered fill pad, insulation and the extent of thermosyphons required to maintain the permafrost below the structures, geothermal analyses were undertaken. The geothermal analyses assumptions, procedures, results and recommendations have been detailed in Appendix A of this report and have been summarized below.

5.6.1 Geothermal Analyses Assumptions

The following assumptions were made in preparing the geothermal models.

1) Based on the Environment Canada long-term climate norm data for Pond Inlet, the mean annual air temperature for Pond Inlet was estimated to be -14.8°C. The climate norm for Arctic Bay is expected to be similar to that of Pond Inlet.
2) It was assumed that the proposed structure and the wastewater and treated water tanks will be founded on a below-ground engineered fill pad approximately 1.2 m thick and the structures would be underlain by insulation and thermosyphons. The engineered fill pad will be constructed on natural undisturbed soil.
3) The annual air warming rate was assumed as 0.08°C/year based on climate warming data.
4) The soil stratigraphy used in the analyses was based on the results of Boreholes 1 to 7, TP1, and TP2 of the geotechnical investigation as described previously.
5) The geothermal design was based on a mean annual ground temperature (MAGT) of -10.2°C. The design isotherm assumed to represent ice melting temperature was taken as -2°C.
6) Geotechnical modelling (see Figure 2, Appendix A) considered WTP structure as an at-grade building that would be constructed by excavating all the fill from the building area and excavating the natural soil within the building footprint to approximately 1.2 m depth and backfilling the excavation with thaw-stable and non-frost susceptible engineered fill. Rigid insulation and thermosyphons will be embedded within the engineered fill (Figure 2, Appendix A).

5.6.2 Geothermal Modelling Assessments

The geothermal modelling addressed the following.

1) Assess the late summer thaw progression under the WTP floor slab and adjacent potable water and wastewater storage tanks.
2) Assess annual and long-term temperature conditions under the structures where a 100 mm thick layer of rigid extruded polystyrene insulation is installed under the WTP building and the water storage tanks.
3) Assess thermosyphon operation, considering a specific radiator area and evaporator spacing. The thermosyphons were modelled on a smallest available radiator area (9.75 m^2). The thermosyphon horizontal evaporator loops considered in the thermal model were 25 mm in diameter and 60 m long with a constant spacing of 1 m.
4) Assess a thermosyphon loop failure scenario by considering the loss of one thermosyphon loop during operations. It was assumed that the thermosyphon system would be able to maintain thermal stable conditions under the WTP for up to two years, even in the event of a malfunction of one evaporator loop. The two year period was used, assuming that the remedial repairs of the inoperative thermosyphon would be applied within this timeframe.

5.6.3 Geothermal Modelling Results

5.6.3.1 Water Treatment Plant

Figure 5 (Appendix B) presents a view of two-dimension model domain for the WTP. The subsurface was divided into several layers representing the geotechnical conditions.

Figure 6 (Appendix B) shows and expanded view of the WTP building and engineered fill pad with floor slab, rigid insulation and thermosyphons in place.

It was assumed that the WTP building is underlain by 100 mm of rigid insulation and thermosyphons as indicated in Section 5.6.2 (3). The results of these analyses are given on Figure 7 of Appendix A. The results indicate that with 100 mm of insulation under the building with no climate warming, the -2°C isotherm (which represents melting point of ice) remains within the fill pad. When the effect of global warming is taken into consideration, after 40 years, the ground temperatures are a few degrees warmer than with no climate warming. Also, the -2°C isotherm remains within the frost-stable engineered fill pad (Figure 8, Appendix A). The effect of a single thermosyphon loop under the centre of the structure becoming inoperable for more than two years and is not repaired or otherwise mitigated is negligible and the -2°C isotherm remains within the engineered fill pad. In the long term, if an inoperative thermosyphon loop is not repaired or otherwise mitigated, a thaw bulb will likely form in the area of the inoperative thermosyphon.

The geothermal analysis has shown that a foundation system for WTP comprising an engineered fill pad with 100 mm of rigid insulation and a horizontal thermosyphon system will maintain frozen conditions within the engineered fill pad for a 40 year design life with climate warming.

5.6.3.2 Potable Water and Wastewater Storage Tanks

A model domain similar to WTP was used to assess the ground temperatures under the exterior potable water and wastewater tanks. The model domain was similar to Figure 5 (Appendix A), except the left vertical boundary of the domain is an axis of radial symmetry with storage tank 4 m in radius. Figure 10, Appendix A shows the model domain for the storage tanks. The thermosyphons were not considered for this case. A rigid insulation thickness of 100 mm was applied by the model. The base of the tanks was held at +10°C year-round.

The analysis revealed that with 100 mm of rigid insulation within the engineered fill pad with no climate warming, the engineered fill pad does not warm above -6°C under the tanks even in late summer (Figure 11, Appendix A). When the effect of climate warming is taken into consideration, ground temperatures within the subgrade below the tank remain colder than -2°C, even in the presence of long-term climate warming.

5.6.4 Conclusion

The geothermal analysis has shown that a foundation system for the Water Treatment Plant consisting of an inground engineered fill pad with 100 mm of rigid insulation and a horizontal thermosyphon system represents a viable design. The -2°C isotherm does not progress below the base of the thaw stable engineered fill pad. For the 8 m diameter water storage tanks, minimal thaw progresses below the 100 mm rigid insulation for the applied climate warming case and represents a viable design.

5.6.5 Engineered Fill Pad

Excavation for construction of the engineered fill pad would extend at least 1.2 m below the underside of the floor slab to the underlying natural undisturbed soil. It would extend at least 2 m beyond the perimeter of the structures and would thereafter be sloped at an inclination of 1H:1V or flatter depending on the site conditions at the time of construction. The subgrade would be examined and approved by an experienced geotechnician. The exposed subgrade would then be proof-rolled with a highway type roller in the presence of geotechnical personnel if construction is undertaken during summer months. Any soft pockets identified would be sub-excavated and the excavations backfilled with engineered fill (conforming to gradation requirements of Table 5) compacted to 100 percent standard Proctor Maximum Dry Density (SPMDD). Construction of the granular pad may then proceed.

From a geotechnical perspective, the fill used to construct the engineered fill should consist of frost stable sand and gravel, preferably conforming to the gradation given on Table 4. The engineered fill should be placed in lifts compatible with the compaction equipment and each lift compacted to 100 percent SPMDD. In-place density tests should be performed on each lift to ensure that the specified degree of compaction has been achieved. Consideration should be given to placement of a thick (50 mm thick) sand bedding layer below the rigid EPS insulation. This will reduce the possibility of coarse-grained particles from puncturing the EPS.

It should be noted that the thermosyphon system is a proprietary design and build activity. Therefore, construction of the pad and material specification would also have to comply to the requirement of the design-build engineer.

The presence of subsurface waterflow under the structure may render the insulated slab design ineffective. If there is access to groundwater, frost heaving may occur. Steps would need to be taken to limit or completely prevent subsurface waterflow under the structure by using drainage ditches and/or construction of a cut-off, e.g., ditches filled with compacted clay.

Table 5: Engineered Fill Gradation Requirements

Sieve Size	Percentage Passing
25.0 mm	100
19.0 mm	75 – 100
9.5 mm	50 – 85
4.75 mm	35 – 65
2.0 mm	25 – 50
0.42 mm	15 – 30
0.75 mm	5 – 10

5.7 Site Classification and Seismic Site Response

The investigation has revealed that the on-site soils are granular. They mostly comprise of sandy gravel to sand and gravel in the upper levels and are underlain by gravelly sand and silty sand. The active layer thickness could not be established due to time constraints. However, the proposed WTP building would be founded on a below ground engineered fill pad underlain by insulation and thermosyphons to maintain the soil below the founding level in a permanently frozen state. The frozen soil will be dense to very dense. Therefore, the site has been classified as Class D for Seismic Site Response in accordance with the requirements of Section 4.1.8.4 of the National Building Code of Canada, 2015.

The on-site frozen soils will not be subject to liquefaction during a seismic event.

5.8 Site Grading and Drainage

The majority of the site is flat lying. Therefore, it is anticipated that nominal site grading would be required for construction of the proposed foundations on level ground. This can likely be undertaken by excavating from higher ground and backfilling any low areas. If the on-site materials are to be used for construction of the engineered fill pad, an assessment of the on-site materials would be required to assess their free-draining and frost susceptibility characteristics.

Satisfactory performance of the foundation system would be contingent on eliminating or minimizing subsurface water flow under structures to prevent degradation of the permafrost. This may be achieved by construction of drainage ditches or cut offs (trenches filled with clay) as necessary. The drainage ditches or cut off would have to be deep enough to intercept the subsurface water during spring freshet. The downspouts from the structures should be directed to preferably discharge to the drainage ditches or should discharge at least 2 m beyond the perimeter of the structures.

The finished grade around the structures should be sloped away from the structures at an inclination of at least 2 percent to prevent ponding of the surface water around the foundations of the structures.

5.9 Subsurface Concrete Requirements

Chemical tests limited to determination of pH, sulphates, chlorides, and electrical resistivity of the on-site soils were performed. The results of the tests are given on Table 6.

A review of Table 6 indicates that the on-site soils contain 0.0006 percent to 0.0642 percent of water-soluble sulphates in the soil. This concentration of sulphates is considered to have a negligible potential of sulphate attack on sub-surface concrete. Therefore, General Use (GU) Portland cement may be used in the subsurface concrete at the site. The concentration of chlorides exceeds the threshold value. Therefore, special measures to protect the concrete from chloride attack may be required. The concrete mix design should conform to all the requirements of CSA 123.1-14 including with regard to mitigating detrimental effect of chlorides in the subsoils on the concrete.

The electrical resistivity tests indicated that the soils at the site are non-corrosive to very corrosive to steel. It is therefore recommended that a corrosion specialist should be consulted to provide recommendations to mitigate corrosion potential of the soil if steel is to be buried at the site.

Table 6: Results of Chemical Tests, Arctic Bay Site 1

Borehole #	Depth (m)	pH	Sulphates (%)	Chlorides (%)	Electric Resistivity (ohm-cm)	Remarks
1	1 – 2	7.54	0.0006	0.0006	26300	Non-corrosive
2	5 – 6	7.58	0.0007	0.0012	19200	Non-corrosive
3	2 – 3	7.19	0.0642	0.0554	606	Very corrosive
4	7 – 8	7.71	0.0063	0.0007	8700	Mildly corrosive
5	1 – 2	1.23	0.0006	0.0002	40000	Non- corrosive
6	1 – 2	7.05	0.0015	0.0193	2910	Moderately corrosive
7	2 - 3	7.09	0.0014	0.0145	3790	Moderately corrosive
Threshold Values		<5	>0.1	>0.04	<750	Very corrosive

6.0 Site 3 Considerations

6.1 Site Description

This site is located next to the new Power Plant which is currently under construction. It is located approximately 6.7 km north of Merci Lake reservoir and approximately 1.3 km south of the community. The ground surface elevations at the site vary from Elevation 12.5 m at the southwest corner to Elevation 27.5 m at the northeast corner. The site slopes down to the southwest at a slope of 8 degrees approximately, i.e., ~7.4H:1V. As the slope is relatively steep, the earthworks at the site are expected to be more extensive as is reported to be the case at the Power Plant site. A long hill is located behind the site and would necessitate integrating drainage plans directly into the design.

6.2 Geotechnical Investigation Procedure

The geotechnical investigation was undertaken with an air track drill and a backhoe on October 1 and 2, 2021. It was supervised on a full-time basis by a senior geotechnician experienced in permafrost soils and arctic construction.

The fieldwork consisted of drilling five boreholes, each to 10 m depth and excavating two test pits with a backhoe to refusal at 1.4 m and 1.7 m depth. The locations of the boreholes and test pits are shown on Figure 5b.

Bulk soil samples were obtained from the boreholes at 1 m depth interval. On completion of drilling, multi-bead thermistor string was installed in Borehole 5. A 19 mm diameter PVC standpipe was placed to the bottom of the borehole, the thermistor string was placed in the standpipe, and initial readings were taken 24 hours after installation. All boreholes were backfilled to the surface with drill cuttings on completion.

The soil samples were visually examined for textural classification and logged in accordance with the Standard Practice of Description and Classification of Soils Visual Manual Procedure (ASTM 2488) and Standard Practice for Description of Frozen Soils, Visual Manual Procedure (ASTM D4083). Part of each soil sample was placed in a plastic bag, sealed, identified, and weighed on-site for moisture content determination. The remainder of the soil sample was placed in another plastic bag, sealed and identified for visual examination by a senior geotechnical engineer and additional laboratory testing.

Representative soil samples were also obtained from the test pits and the test pits logged. The samples were examined for visual classification, logged, preserved in plastic bags and identified. The test pits were backfilled on completion.

The locations of the boreholes and test pits were established using a commercial grade handheld GPS device and are approximate. The coordinates of the boreholes and test pits have been listed on Table 7. The elevations of the boreholes were established in the office based on GPS locations and topographic surveys of the site. The elevations refer to the Geodetic Datum.

On completion of the fieldwork, all soil samples were transported to the EXP laboratory in the city of Ottawa, Ontario where they were examined by a senior geotechnical engineer and borehole logs prepared. The engineer also assigned laboratory testing which consisted of performing natural moisture content tests on all the samples and grain size analyses, Atterberg Limit tests, pH, sulphate, chloride and electrical resistivity tests on selected soil samples.

Table 7: Coordinates of Boreholes and Test Pits, Arctic Bay, Site 3

Borehole or Test Pit #	Eastings	Northings	Elevation (m)
TP1	561866	8105138	27.2
TP2	561851	8105079	19.3
BH1	561772	8105052	14.1
BH2	561873	8105060	16.4
BH3	561867	8105137	27.0
BH4	561779	8105133	26.1
BH5	561829	8105077	18.8

6.3 Soil Description

A detailed description of the subsurface soil and groundwater conditions determined from the boreholes and test pits are given on the attached Borehole Logs, Figures 31 to 37 inclusive. The borehole logs and related information depict subsurface conditions only at the specific locations and times indicated. Subsurface conditions and water levels at other locations may differ from conditions at the locations where sampling was conducted. The passage of time also may result in changes in the conditions interpreted to exist at the locations where sampling was conducted. Boreholes were drilled and test pits excavated to provide representation of subsurface conditions as part of a geotechnical exploration program and are not intended to provide evidence of potential environmental conditions.

It should be noted that the soil boundaries indicated on the borehole logs are inferred from non-continuous sampling and observations during drilling. These boundaries are intended to reflect approximate transition zones for the purpose of geotechnical design and should not be interpreted as exact planes of geological change. The “Note on Sample Descriptions” preceding the borehole logs form an integral part of this report and should be read in conjunction with this report. The soil stratigraphy encountered at the site is discussed below in descending order form the existing ground surface. Grain size analyses and soil classification is given on Table 8.

6.3.1 Tundra / Topsoil

The site is covered with up to 50 mm of tundra / topsoil.

6.3.2 Silty Sandy Gravel to Sand and Gravel

The topsoil in the boreholes and test pits is underlain by sand and gravel which extends to the entire depth investigated in test pits 1 and 2, i.e., 1.7 m depth (Elevation 25.0 m) and 1.4 m depth (Elevation 17.9 m) respectively and to a depth of 1.0 m to 4.0 m in the boreholes (Elevation 13.1 m to 25.5 m). A grain size analysis performed on this stratum indicates a composition of 24 percent silt and clay, 26 percent sand, and 50 percent gravel (Figure 38). This stratum has a moisture content of 7.0 to 14.8 percent.

6.3.3 Silty Sand (SM)

The sand and gravel in Boreholes 1, 2, and 3 is underlain by silty sand which extends to 2 m to 4.5 m depth (Elevation 11.9 to 23.0). This stratum was also encountered in Borehole 2 between 8 m and 10 m depth (Elevation 8.4 m to 6.4 m), in Borehole 3 between 5 m and 8 m depth (Elevation 22.0 m to 19.0 m), in Borehole 4 between 8 m and 9 m depth (Elevation

18.1 m to 17.1 m), and in Borehole 5 between 6 m and 8 m depth (Elevation 12.8 m to Elevation 10.8 m). It comprises of 21 to 37 percent clay and silt, 51 to 64 percent sand, and 12 to 23 percent gravel (Figures 39 to 45). Its moisture content varies from 5.9 percent to 18.1 percent.

6.3.4 Clayey Silty Sand

Beneath the silty sand stratum in Boreholes 1 and 3 and the sand and gravel stratum in Boreholes 4 and 5, clayey silty sand extends to a depth of 4.0 m to 7.0 m (Elevation 8.1 m to 22.0 m). This stratum comprises of 39 to 51 percent clay and silt, 36 to 46 percent sand, 9 to 15 percent gravel (Figures 46 to 50). Its liquid limit varies from 22.9 to 28.8 percent and its plastic limit varies from 12.9 to 13.6 percent. It has a moisture content of 9.0 to 24.9 percent.

6.3.5 Sand and Gravel

The clayey silty sand in Boreholes 1, 4 and 5, and the silty sand in Boreholes 2 and 3 are underlain by sand and gravel which extends to 8.0 m depth in Borehole 2, to 4 m to 6 m depth in Borehole 5 (Elevation 14.8 to 12.8 m), and to 10 m in depth in Boreholes 1, 3 and 4 (Elevation 4.1 m to 19.1 m). This stratum has a moisture content of 4.8 to 9.8 percent.

6.3.6 Gravelly Sand

In Borehole 5, the silty sand is underlain by gravelly sand which extends to 10 m depth (Elevation 8.8 m). It has a moisture content of 7.3 to 12.2 percent.

Table 8: Results of Laboratory Tests, Arctic Bay Site 3

Borehole #	Depth (m)	Grain Size Analyses (%)			Atterberg Limits (%)			USCS Classification
		Clay & Silt	Sand	Gravel	Liquid Limit	Plastic Limit	Plasticity Index	
BH1	1 – 2	37	51	12	18.4	Non-plastic		SM
BH1	3 – 4	46	45	9	23.6	12.9	10.7	SM-SC
BH1	5 – 6	39	46	15	22.9	13.2	9.7	SM-SC
BH2	2 – 3	21	59	20		Non-plastic		SM
BH2	8 – 9	28	61	11		Non-plastic		SM
BH3	2 – 3	25	52	23		Non-plastic		SM
BH3	4 – 5	44	47	9	27.7	13.2	14.6	SM-SC
BH3	7 – 8	27	59	14		Non-plastic		SM
BH4	4 – 5	51	38	13	28.8	12.9	15.8	SM-SC
BH4	8 – 9	16	74	10				SM
BH5	1 – 2	41	44	15	28.1	13.6	14.5	SM-SC
BH5	6 – 7	22	64	14		Non-plastic		SM
TP 2	0 – 1.4	24	26	50				GM

6.3.7 Groundwater

Groundwater observations were made in the boreholes on completion of drilling. Groundwater observations have been tabulated on Table 8. This table indicates that the water levels at the site vary from 1.5 m depth in Borehole 5 to 4.6 m depth in Borehole 1. Borehole 2 was dry.

Table 9: Groundwater Observations in Boreholes, Arctic Bay Site 3

Borehole #	Date of Observation	Depth to Water (m)	Hole Open to (m)	Elevation (m)
1	October 1, 2021	4.6	10.0	9.5
2	October 1, 2021	N/A	10.0	-
3	October 1, 2021	3.0	10.0	24.0
4	October 1, 2021	4.0	10.0	22.1
5	October 1, 2021	1.5	10.0	17.3

The groundwater table had not stabilized during the short time interval over which the observations were made. The groundwater is also subject to seasonal variations.

6.4 Ground Temperatures and Active Layer Thickness

Thermistor beads were installed in Borehole 5 at 0.5 m, 1.0 m, 2.0 m, 3.0 m, 4.0 m, 6.0 m, 8,0 m, and 10.0 m depth on completion of drilling of the boreholes. The ground temperature was monitored one day after installation of the thermistors. Observations made have been tabulated on Table 10. The ground temperature was recorded as -0.1^{o}C at 0.5 m depth, decreasing to -8.6^{o}C at 10.0 m depth. These observations indicate that the freeze back had commenced prior to drilling the borehole.

6.4.1 Active Layer Thickness

The thickness of the active layer could not be established since the freeze back had commenced prior to drilling the boreholes. It is recommended that the ground temperatures should be monitored during 2022 to estimate the active layer thickness at the site. As indicated previously, Ednie, M. and Smith, S.L. have reported a measured deep thaw depth of 1.3 m for Arctic Bay.

Table 10: Temperature Records in Multi-Bead Thermistors, Arctic Bay Site 3

Borehole #	5				5				5			
Observations Date	October 2, 2021											
	Bulb	Depth (m)	Meter RDG (K ohms)	Temp (°C)	Bulb	Depth (m)	Meter RDG (K ohms)	Temp (°C)	Bulb	Depth (m)	Meter RDG (K ohms)	Temp (°C)
	1	0.5	16.4	-0.1	1	0.5			1	0.5		
	2	1.0	16.6	-0.3	2	1.0			2	1.0		
	3	1.5	16.8	-0.6	3	1.5			3	1.5		
	4	2.0	17.3	-1.3	4	2.0			4	2.0		
	5	3.0	18.7	-2.6	5	3.0			5	3.0		
	6	4.0	20.3	-4.2	6	4.0			6	4.0		
	7	6.0	22.5	-6.1	7	6.0			7	6.0		
	8	8.0	24.3	-7.6	8	8.0			8	8.0		
	9	10.0	25.6	-8.6	9	10.0			9	10.0		

6.5 Foundation Considerations

As for Site 1, the following foundation options were considered for the WTP and tanks to be constructed on Site 3:

(1) Spread and strip footings on permafrost;

(2) Adfreeze piles;

(3) End bearing piles; and

(4) Spread and strip footings founded in below ground engineered fill pad with insulation and thermosyphons (if required).

Options 1 to 3 are not considered feasible at the site for reasons given previously.

Based on a review of the geotechnical conditions encountered at the site and the structural requirements of the slab-on-grade WTP building which would be heated to 22°C and the water tanks which will be heated to 5°C to 10°C, it is considered that the most suitable type of foundation for the proposed structures is spread and strip footings or slabs founded in the below ground engineered fill pad with insulation and thermosyphons.

A geothermal analysis was not undertaken for this site as Site 1 is considered to be the most suitable of the three sites examined. However, the foundation requirements at this site are expected to be similar to that of Site 1 as discussed in Section 5.6 of the report. Therefore, they have not been repeated here. If this site is to be considered for construction, it is recommended that a geothermal analysis should be undertaken so that any design changes, if required, can be implemented.

6.6 Site Classification and Seismic Site Response

It is considered that the proposed WTP may be founded on spread and strip footings and the wastewater and treated water tanks on slabs set on an inground engineered fill pad. The WTP footings should be underlain by insulation and thermosyphons and the storage tank slab with insulation to maintain the founding soil in a permanently frozen state. The frozen soil will be hard. Therefore, site classification for seismic site response may be assumed as Class 'D' in accordance with the requirements of Section 4.1.8.4 of the National Building code of Canada, 2015. The on-site soils are also not susceptible to liquefaction during a seismic event.

6.7 Site Grading and Drainage

A review of Figure 5b indicates that the ground surface elevations at the site vary from Elevation 12.5 m at the southwest corner to Elevation 27.5 m at the northeast corner. The site slopes down to the south at an inclination of 7.7H:1V approximately. In order to found the proposed structures on level ground, fairly extensive site grading would be required. This may be feasible by using the select on-site soils from higher ground to fill the low-lying areas. The compactibility of the soil from the potential borrow areas would have to be assessed to determine its suitability as fill. The fill would be compactible provided its moisture content is within 2 percent of the optimum moisture content as determined from Standard Proctor maximum dry density tests. It should be compacted to 100 percent Standard Proctor maximum dry density.

The fill to be used for construction of the engineered fill pad should meet the gradation requirements of Table 5, be free draining granular fill (with less than 10 percent moisture passing No. 200 sieve) which is frost stable and compactible. This fill may have to be imported if suitable fill cannot be located on-site.

The satisfactory performance of the foundation system depends on eliminating or minimizing the subsurface flow of water under the structures to prevent degradation of the permafrost. As the site slopes down to the south, construction of drainage ditches or cut-offs (trenches filled with clay) may be required along the north side and partway along the east and west sides of the site. The drainage ditches or cut-offs would have to be deep enough to intercept the subsurface water during spring freshet.

Down spouts of the structures should preferably discharge into the drainage ditches or should discharge at least 2 m beyond the perimeter of the structures. The finished grade around the structures should be sloped away from the structures at an inclination of at least 2 percent to prevent ponding of surface water close to the structure.

6.8 Subsurface Concrete Requirements

Chemical tests limited to the determination of pH, sulphates, chlorides, and electrical resistivity were performed on selected samples. The results have been summarized on Table 11. A review of this table indicates that the on-site soils contained 0.0021 percent to 0.0657 percent water soluble sulphates in the soil. This concentration of sulphates in the soil is considered to have a negligible potential of sulphate attack on subsurface concrete. Therefore, General Use (GU) Portland cement may be used in the concrete. The concrete mix should be designed in accordance with the requirements of CSA A.23-14.

The concentration of chlorides in the soil is above the threshold level. The concrete mix should be designed incorporating all the mitigating measures required by CSA A23.1-14.

The resistivity of the soil varies from 392 ohm-cm to 5350 ohm-cm. These values indicate that the soil at the site is mildly to very corrosive to steel. It is therefore recommended that a corrosion specialist should be consulted to provide recommendations to mitigate the affect of corrosion if steel is to be buried in the ground.

Table 11: Results of Chemical Tests, Arctic Bay Site 3

Borehole #	Depth (m)	pH	Sulphates (%)	Chlorides (%)	Electric Resistivity (ohm-cm)	Remarks
1	1 – 2	6.82	0.0021	0.0069	5350	Mildly corrosive
2	2 – 3	6.85	0.0061	0.0179	2580	Moderately corrosive
3	2 – 3	7.06	0.0116	0.0121	2750	Moderately corrosive
4	4 – 5	7.18	0.0657	0.1320	392	Very corrosive
5	1 – 2	6.54	0.0018	0.0076	5080	Mildly corrosive
Threshold Values		< 5	> 0.1	> 0.04	< 750	Very corrosive

7.0 Site 4 Considerations

7.1 Site Description

This site is located adjacent to the community on the road to the existing Water Treatment Plant and is approximately 8.0 km from Lake Merci reservoir. The site is 100 m x 110 m in plan and is located at an altitude of 17 m to 36 m above the sea level. The site slopes down steeply to the southwest at an inclination of 5.9H:1V approximately. A hill is located along the north property boundary.

7.2 Geotechnical Investigation Procedure

The fieldwork for the geotechnical investigation was undertaken with an air track drill and a backhoe between October 2, 2021, and October 3, 2021. It was supervised on a full-time basis by a senior geotechnician experienced in permafrost soils and northern construction.

The fieldwork consisted of drilling five boreholes, each to 10 m depth and excavating two test pits with a front-end loader to refusal at 0.9 m and 1.2 m depth. The locations of the boreholes and test pits are shown on Figure 5C. Bulk soil samples were obtained from the boreholes at 1 m depth intervals.

Table 12: Coordinates of Boreholes and Test Pits, Arctic Bay, Site 4

Test Pit #	Eastings	Northings	Elevation (m)
TP1	560728	8105647	34.1
TP2	560736	8105514	14.8
BH1	560727	8105634	31.06
BH2	560795	8105584	32.79
BH3	560742	8105526	17.56
BH4	560690	8105576	19.89
BH5	560737	8105584	25.81

On completion of drilling, multi-bead thermistor string was installed in Borehole No. 5. A 19 mm diameter PVC standpipe was installed to the bottom of the borehole and the thermistor string was placed in the standpipe. Initial readings were taken 24 hours after installation. All other boreholes were backfilled to the surface with drill cuttings on completion.

The soil samples were visually examined for textural classification and logged in accordance with the Standard Practice of Description and Classification of Soils Visual Manual Procedure (ASTM 2488) and Standard Practice for Description of Frozen Soils Visual Manual Procedure (ASM D4083). Part of each soil sample was placed in a plastic bag, sealed and weighed on-site for moisture content determination. The remainder of the soil sample was placed in another plastic bag, sealed and identified for visual examination by a senior geotechnical engineer and additional laboratory testing.

Representative soil samples were also obtained from the test pits and the test pits logged. The samples were examined for visual classification, preserved in plastic bags, and identified. The test pits were backfilled on completion.

The locations of the boreholes and test pits were established using a commercial grade handheld GPS device and are approximate. The coordinates of the boreholes and test pits have been listed on Table 12. The elevations of the boreholes were established in the office based on GPS locations and topographic surveys of the site. The elevations refer to the Geodetic Datum.

On completion of the fieldwork, all samples were transported to the EXP laboratory in the City of Ottawa, Ontario where they were visually examined by a senior geotechnical engineer and borehole logs prepared. The engineer also assigned laboratory testing which consisted of performing natural moisture content tests on all the samples and grain size analyses, Atterberg Limit tests, pH, sulphate, chloride, and electrical resistivity tests on selected samples.

7.3 Soil Description

A detailed description of the subsurface soil and groundwater conditions determined from the boreholes and test pits are given on the attached Borehole Logs, Figures 51 to 57 inclusive. The borehole and test pit logs and related information depict subsurface conditions only at the specific locations and times indicated. Subsurface conditions and water levels at other locations may differ from conditions at the locations where sampling was conducted. The passage of time also may result in changes in the conditions interpreted to exist at the locations where sampling was conducted. Boreholes were drilled and test pits excavated to provide representation of subsurface conditions as part of a geotechnical exploration program and are not intended to provide evidence of potential environmental conditions.

It should be noted that the soil boundaries indicated on the borehole logs are inferred from non-continuous sampling and observations during drilling. These boundaries are intended to reflect approximate transition zones for the purpose of geotechnical design and should not be interpreted as exact planes of geological change. The “Note on Sample Descriptions” preceding the borehole logs form an integral part of this report and should be read in conjunction with this report. The soil stratigraphy encountered at the site is discussed below in descending order from the existing ground surface. Grain size analyses and soil classification is given on Table 13.

7.3.1 Topsoil / Tundra

The site is covered with approximately 50 mm of topsoil / tundra.

7.3.2 Fill

Beneath the topsoil, fill or reworked soil was encountered in all the boreholes and test pits and extended to the entire depth investigated in Test Pit 1 (Elevation 33.2 m) and to 0.8 m depth in Test Pit 2 (Elevation 14.0 m). In the boreholes it extends to a depth of 1.0 m to 4.0 m (Elevation 13.7 to 30.1 m). The fill is considered to be comprised of material that has sloughed form the hill located along the north boundary of the site. This fill consists of silt and sand to silty sand with gravel and some clay. It comprises of 36 to 54 percent clay and silt, 42 to 54 percent sand, and 4 to 21 percent gravel (Figures 58 to 60). It is black in colour. Its moisture content varied from 13.2 percent to 46.7 percent.

7.3.3 Sand and Gravel (GM)

The fill in Borehole 1 is underlain by bouldery silty sand and gravel which extends to 3 m depth (Elevation 28.1). It is comprised of 20 percent silt and clay, 41 percent sand, and 39 percent gravel (figure 61). Its moisture content varies from 17.5 percent to 20.9 percent.

7.3.4 Silty Sand (SM)

The fill in Boreholes 2 to 5 is underlain by silty sand which extends to a depth of 4 m and 9 m in Boreholes 2 and 4 respectively (Elevation 18.5 m and 10.6 m) and to the entire depth investigated in Boreholes 3 and 5 (i.e., 10 m depth, Elevation 9.9 m and 10.9 m). This stratum contains frequent cobbles and boulders and ice crystals or lenses. It consists of 22 to 30 percent silt and clay, 43 to 62 percent sand, and 16 to 31 percent gravel (Figures 62 to 67). Its liquid and plastic limits vary from 18.9 to 23.5 percent and from 13.1 to 15.6 percent respectively. Its plasticity index varies from 5.5 to 7.9 percent. It has a moisture content of 4.2 to 24.2 percent.

7.3.5 Sand to Gravelly Sand

The sand and gravel in Borehole 1 and the silty sand in Boreholes 2 and 4 are underlain by poorly graded sand which extends to the entire depth investigated in all the boreholes, i.e., 10 m depth (Elevation 21.1 m to 7.6 m). This stratum is black to gray in colour. It contains some ice crystals and ice lenses. It comprises of 11 to 16 percent clay and silt, 55 to 79 percent sand, and 8 to 34 percent gravel (Figures 68 to 71). It is non-plastic. Its moisture content varies from 3.7 to 8.4 percent.

Table 13: Results of Laboratory Tests, Arctic Bay Site 4

Borehole or Test Pit #	Depth (m)	Grain Size Analyses (%)			Atterberg Limits (%)			USCS Classification
		Clay & Silt	Sand	Gravel	Liquid Limit	Plastic Limit	Plasticity Index	
TP1	0.1 – 0.9	36	43	21				SM
BH1	1 – 2	20	41	39	23.9	Non-plastic		GM
BH1	4 – 5	15	62	23				SP
BH1	7 – 8	13	79	8				SP
BH2	2 – 3	22	62	16		Non-plastic		SM
BH2	9 - 10	16	63	21		Non-plastic		SP
BH3	1 – 2	41	54	5	21.7	Non-plastic		SM
BH3	3 - 4	30	49	21	20.5	13.6	6.9	SM
BH3	9 – 10	23	59	18				SM
BH4	4 -5	26	43	31	23.5	15.6	7.9	SM
BH4	7 – 8	11	55	34				SP
BH5	1 – 2	54	42	4	30.6	19.0	11.6	ML
BH5	4 – 5	29	54	17	19.3	13.1	6.1	SM
BH5	6 - 7	27	51	22	18.9	13.4	5.5	SM

7.3.6 Groundwater

Water level observations were made in the boreholes on completion of drilling. The observations made have been recorded on Table 14. A review of this table indicates that the groundwater was recorded in Boreholes 2, 4 and 5 at 3.7 m to 7.0 m depth (Elevation 12.6 to 13.9 m) whereas Boreholes 1 and 3 were dry. The groundwater table is subject to seasonal fluctuations.

Table 14: Groundwater Observations in Boreholes, Arctic Bay Site 4				
Borehole #	**Date of Observation**	**Depth to Water (m)**	**Hole Open to (m)**	**Elevation (m)**
1	October 3, 2021	Dry	10.0	-
2	October 3, 2021	3.7	10.0	18.8
3	October 3, 2021	Dry	10.0	-
4	October 3, 2021	5.0	10.0	12.6
5	October 3, 2021	7.0	10.0	13.9

7.4 Ground Temperatures and Active Layer Thickness

A multi-bead thermistor string was installed in Borehole 5 on completion of drilling of the borehole. Thermistor beads were set at 0.5 m, 1.0 m, 1.5 m, 2.0 m, 3.0 m, 4.0 m, 6.0 m, 8.0 m, and 10.0 m depth below the ground surface. Initial readings were taken 24 hours after installation of the thermistor beads. The temperatures recorded have been tabulated on Table 15.

A review of Table 15 indicates that the ground temperature varied between -0.1°C and -3.5°C. These readings indicate that the freeze back had commenced.

7.4.1 Active Layer Thickness

As indicated above, the active layer thickness could not be established during the fieldwork as the freeze back had commenced. It is recommended that additional readings should be undertaken in 2022 to establish the active layer thickness. It is noted that Ednie and Smith (2015) have reported a measured deep thaw depth of 1.3 m for Arctic Bay.

Table 15: Temperature Records in Multi-Bead Thermistors, Arctic Bay Site 4												
Borehole # **Observation Date**			**5** **October 3, 2021**				**5**				**5**	
	Bulb	**Depth (m)**	**Meter RDG (K ohms)**	**Temp (°C)**	**Bulb**	**Depth (m)**	**Meter RDG (K ohms)**	**Temp (°C)**	**Bulb**	**Depth (m)**	**Meter RDG (K ohms)**	**Temp (°C)**
	1	0.5	16.4	-0.1	1	0.5			1	0.5		
	2	1.0	16.5	-0.2	2	1.0			2	1.0		
	3	1.5	16.3	-0.3	3	1.5			3	1.5		
	4	2.0	17.2	-1.0	4	2.0			4	2.0		
	5	3.0	18.1	-2.0	5	3.0			5	3.0		
	6	4.0	19.7	-3.6	6	4.0			6	4.0		
	7	6.0	17.3	-1.3	7	6.0			7	6.0		
	8	8.0	18.6	-2.3	8	8.0			8	8.0		
	9	10.0	16.5	-0.2	9	10.0			9	10.0		

7.5 Foundation Considerations

The following foundation options were considered for this site:

1) Spread and strip footings on permafrost;
2) Adfreeze piles;
3) End bearing piles; and
4) Spread and strip footings / slabs set on a below ground engineered fill pad with insulation and thermosyphons (if required).

Of the four options considered, Option 4 is considered to be the most suitable option which may be feasible for this site. Of the three sites examined (Sites 1, 3 and 4), this site is considered to be the least suitable. The reasons are:

(1) The site is located at a very steep gradient (5.9H:1V).
(2) The site contains surficially disturbed material or fill which extends to 1 m to 4 m depth. This material is not suitable for construction purposes and would have to be removed from the building and tank areas and disposed off-site, resulting in additional costs.

Because of the low suitability of this site, a geothermal analysis was not undertaken to make site specific foundation recommendations although they are expected to be similar to Site 1 (Section 5.5). However, if this site is to be considered for construction purposes, a geothermal analysis would be required to make site specific design recommendations.

7.6 Site Classification and Seismic Site Response

It is considered that the most suitable foundation option for this site will also be spread and strip footing founded in below ground engineered fill pad with insulation and thermosyphons (if required) to permanently maintain the founding soil in a frozen state. The frozen soil will be hard. Therefore, the site classification for seismic site response will likely be Class 'D' in accordance with the requirements of Section 4.1.8.1 of the National Building Code of Canada, 2015.

The frozen soils are also not expected to be susceptible to liquefaction during a seismic event.

7.7 Site Grading and Drainage

As indicated previously, the site is at a very steep gradient (5.9H:1V) and it contains surficially disturbed material or fill which extends to a depth of 1 m to 4 m. This soil is not considered to be suitable for construction purposes and would have to be disposed off site. Therefore, it is anticipated that extensive earth works would be required to render this site suitable for construction.

It may be feasible to use the material from higher ground to backfill low-lying areas in order to obtain level ground for construction of the structure and the storage tanks. The fill to be placed at the site would have to be compactible and would require that it is compacted to 100 percent of Standard Proctor maximum dry density. It is noted that the fill used for construction of engineered fill pads would have to be compactible, free-draining, and frost stable. It would also require compaction to 100 percent Standard Proctor maximum dry density. It should meet the gradation requirements of Table 5.

In order to maintain the soils below the founding level in a constantly frozen state, it would be necessary to ensure that there is no surface or subsurface flow of water at the site. As the site slopes down steeply to the southwest, drains or cut-offs would be required along the north and east sides of the site to minimize or prevent subsurface flow of water under the structures. For this purpose, the drains or cut-offs would have to be sufficiently deep to draw all the water during spring freshet and during the summer months.

The grade surrounding the structures should be sloped away from the structures at an inclination of at least 2 percent to prevent accumulation of water close to the structures. Down spouts should preferably discharge into the drains or at least 2 m away from the structures.

7.8 Subsurface Concrete Requirements

Chemical tests limited to determination of pH, sulphates, chlorides, and electrical resistivity were undertaken on selected samples. The test results have been given on Table 16.

A review of the table indicates that the soil at the site contains 0.036 percent to 0.166 percent water-soluble sulphates. This concentration of sulphates is considered to have a moderate degree of potential of sulphate attack on subsurface concrete.

The concentration of the chlorides in the soil also exceeds the threshold value.

It is recommended that the subsurface concrete to be used at the site should be designed in accordance with the requirements of CSA A.23.1-14, taking into consideration all the mitigating measures required due to the presence of high sulphates and chlorides in the soil.

The on-site soils are also corrosive to very corrosive to steel. It is therefore recommended that a corrosion specialist should be consulted to provide mitigating measures if steel is to be buried on the site.

Table 16: Results of Chemical Tests, Arctic Bay Site 4

Borehole #	Depth (m)	pH	Sulphates (%)	Chlorides (%)	Electric Resistivity (ohm-cm)	Remarks
1	1 – 2	7.30	0.0653	0.0209	943	Corrosive to steel
2	2 – 3	7.21	0.1620	0.0415	488	Very corrosive to steel
3	1 - 2	7.25	0.0360	0.0491	794	Corrosive to steel
4	4 – 5	7.33	0.1660	0.1120	345	Very corrosive to steel
5	1 – 2	7.27	0.0633	0.0896	521	Very corrosive to steel
TP1	0 – 0.3	7.23	0.0384	0.0030	1810	Corrosive to steel
Threshold Values		< 5	> 0.1	> 0.04	< 750	Very corrosive

8.0 Comparison of Sites 1, 3, and 4 from Geotechnical Perspective

The geotechnical and site conditions encountered at the three sites have been summarized on Table 17. A review of this table indicates that the soils encountered on Site 1 are coarse grained and well drained compared to the other two sites. The soils on Site 1 also contain less ice crystals or lenses compared to the other two sites. Site 1 slopes very gently to the west whereas Sites 3 and 4 slope steeply to the south and southwest respectively. Site 4 also contains surficial fill/disturbed material which is not suitable for construction and would require excavation and disposal, resulting in additional costs.

Table 17: Comparison of Sites 1, 3, and 4, Arctic Bay

Site Features	Site 1	Site 3	Site 4
Geotechnical Conditions	Surficial soils sand and gravel to sandy gravel to gravelly sand. Well drained (except BH3), mostly free of ice crystals or lenses.	Randomly distributed layered soils varying from sand and gravel to gravelly sand to silty sand and clayey silty sand. Frequent ice crystals and lenses in fine grained soils.	Randomly distributed layered soils varying from sand and gravel to gravelly sand to sand and silty sand. Frequent ice lenses and crystals in fine grained soils.
Presence of Fill or Disturbed Soils	No fill or disturbed soil encountered except in BH7 to 2 m depth (crusher run limestone fill, well compacted)	No fill or disturbed soils encountered.	Surficial soil in all boreholes disturbed or fill extending to 1 m to 4 m depth. Would require excavation and disposal elsewhere.
Effect of sulphates and chlorides in soil and soil resistivity on subsurface concrete and steel	Sulphates in on-site soils have negligible potential of sulphate attack on subsurface concrete. Chlorides in on-site soil exceed threshold value. Special concrete mix would be required for subsurface concrete. On-site soils non-corrosive to very corrosive to steel. Mitigative measures would be required for steel buried inground.	Sulphates in soil have negligible potential of sulphate attack on subsurface concrete. Chlorides in on-site soil exceed threshold value. Special concrete mix would be required for subsurface concrete. On-site soils mildly to very corrosive to steel. Mitigative measures may be required if steel buried inground.	Sulphates in soil have moderate potential of sulphate attack on subsurface concrete. Special concrete mix would be required. Chlorides in on-site soil exceed threshold value. Special concrete mix would be required for subsurface concrete. Soils corrosive to very corrosive to steel. Mitigative measures may be required if steel buried inground.
Site Gradient	Very gentle slope. Inclination 39.7H:1V to the west. Would require minimal site grading.	Steep slope. Inclination 7.7H:1V to the south. Would require extensive site grading.	Very steep slope. Inclination 5.9H:1V to the southwest. Would require extensive site grading, more than Site 3.
Location	Located 8 km from community at raw water reservoir.	Located approximately 1.3 km from community and 6.7 km from new water reservoir.	Located adjacent to the community but 8 km from raw water reservoir.
Recommended Foundations	Spread and strip footings on inground engineered fill pad underlain by insulation and thermosyphons for WTP. Slabs on engineered fill pad constructed for WTP underlain by insulation. Thermosyphons will not be required.	Same as Site 1 but would require confirmation by geothermal analysis.	Same as Site 1 but would require confirmation by geothermal analysis.

Based on the above analysis, it is considered that from a geotechnical perspective, Site 1 is the most suitable site for construction of the WTP. However, north part of the site contains roadway fill, existing WTP, and Environment Canada Weather Station. South half of the site is expected to be most suitable location for construction of the new WTP. Site 4 is the least suitable because of the very steep slope and the presence of surficial fill / disturbed material which is unsuitable for construction and would have to be excavated and disposed off site.

9.0 General Comments

The comments given in the report are preliminary in nature and are intended only for the guidance of design engineers. The number of boreholes and test pits required to determine the localized underground conditions between boreholes / test pits affecting construction costs, techniques, sequencing, equipment, scheduling, etc., would be much greater than has been carried out for the design purposes. Contractors bidding on or undertaking the works should, in this light, decide on their own investigations, as well as their own interpretations of the factual borehole / test pit results, so that they may draw their own conclusions as to how the subsurface conditions may affect them.

The information contained in this report is not intended to reflect on environmental aspects of the subsurface soils, bedrock, and groundwater.

We trust that the information contained in this report will be satisfactory for your purposes. Should you have any questions, please do not hesitate to contact this office.

REGISTERED PROFESSIONAL ENGINEER
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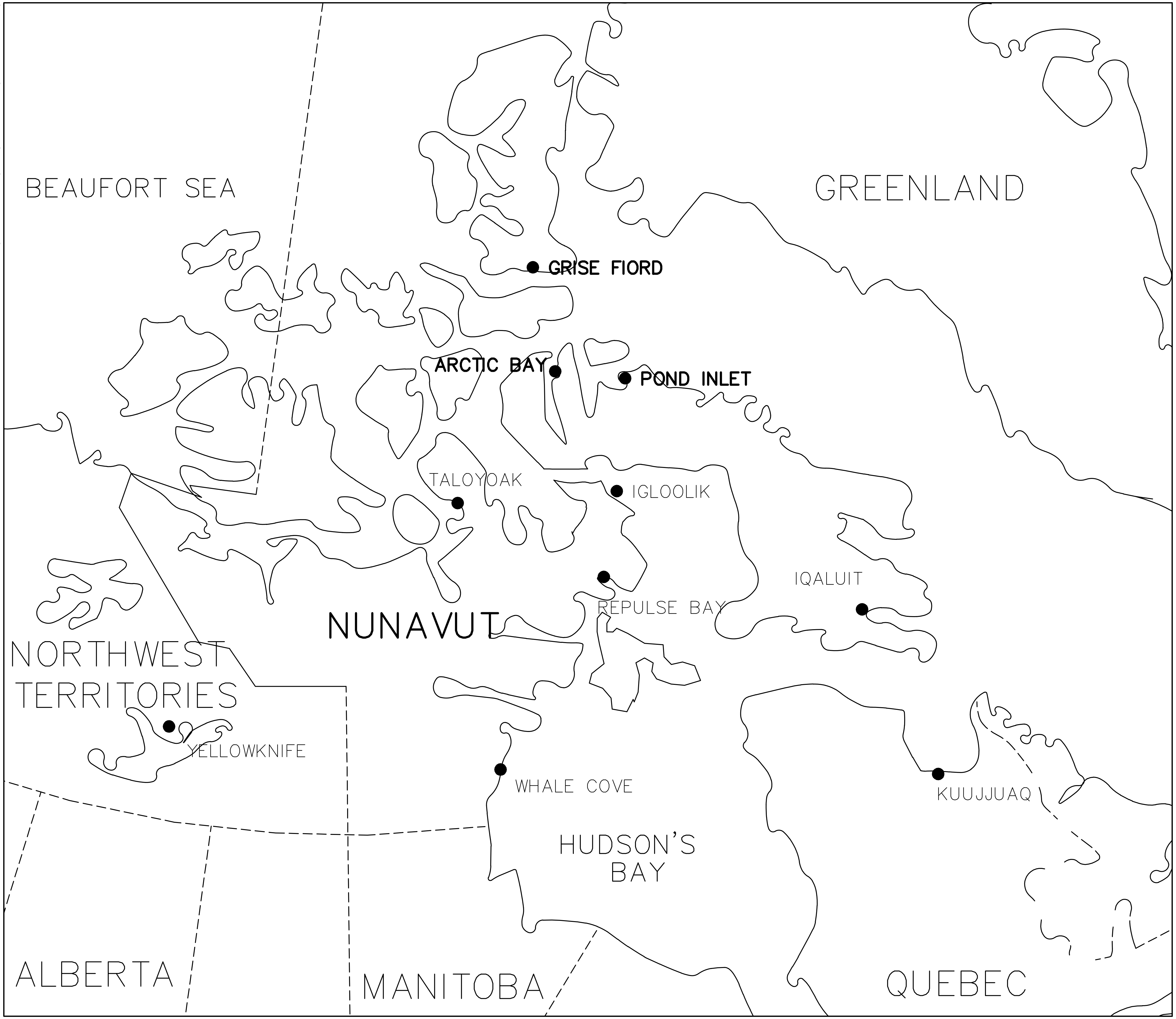
Figures



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Dwg Standards Ckd By:	
Designed By:	IT
Design Checked By:	
Scale: 1:7500	0 150 300 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
LOCATION PLAN

Project No.

FRN-21016638-A0

Dwg. No.	Rev. No.
FIG. 1	0

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APPROXIMATE GEOTECHNICAL SITE EXTENTS - POINT TABLE (UTM ZONE 16)

SITE	POINT	EASTING	NORTHING
1	1-1	564866.368	8100568.480
1	1-2	564877.326	8100868.020
1	1-3	564977.259	8100864.365
1	1-4	564966.291	8100564.565
3	3-1	561869.994	8105140.846
3	3-2	561877.221	8105040.688
3	3-3	561777.580	8105033.796
3	3-4	561770.262	8105133.528
4	4-1	560738.257	8105656.109
4	4-2	560808.431	8105584.866
4	4-3	560737.188	8105514.691
4	4-4	560666.699	8105586.254

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Scale: 1:25000 — 0 500 1000 m

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY GEOTECH PROGRAM OVERALL PLAN

Project No. FRN-21016638-A0

Dwg. No. **FIG. 2**

Rev. No. 0

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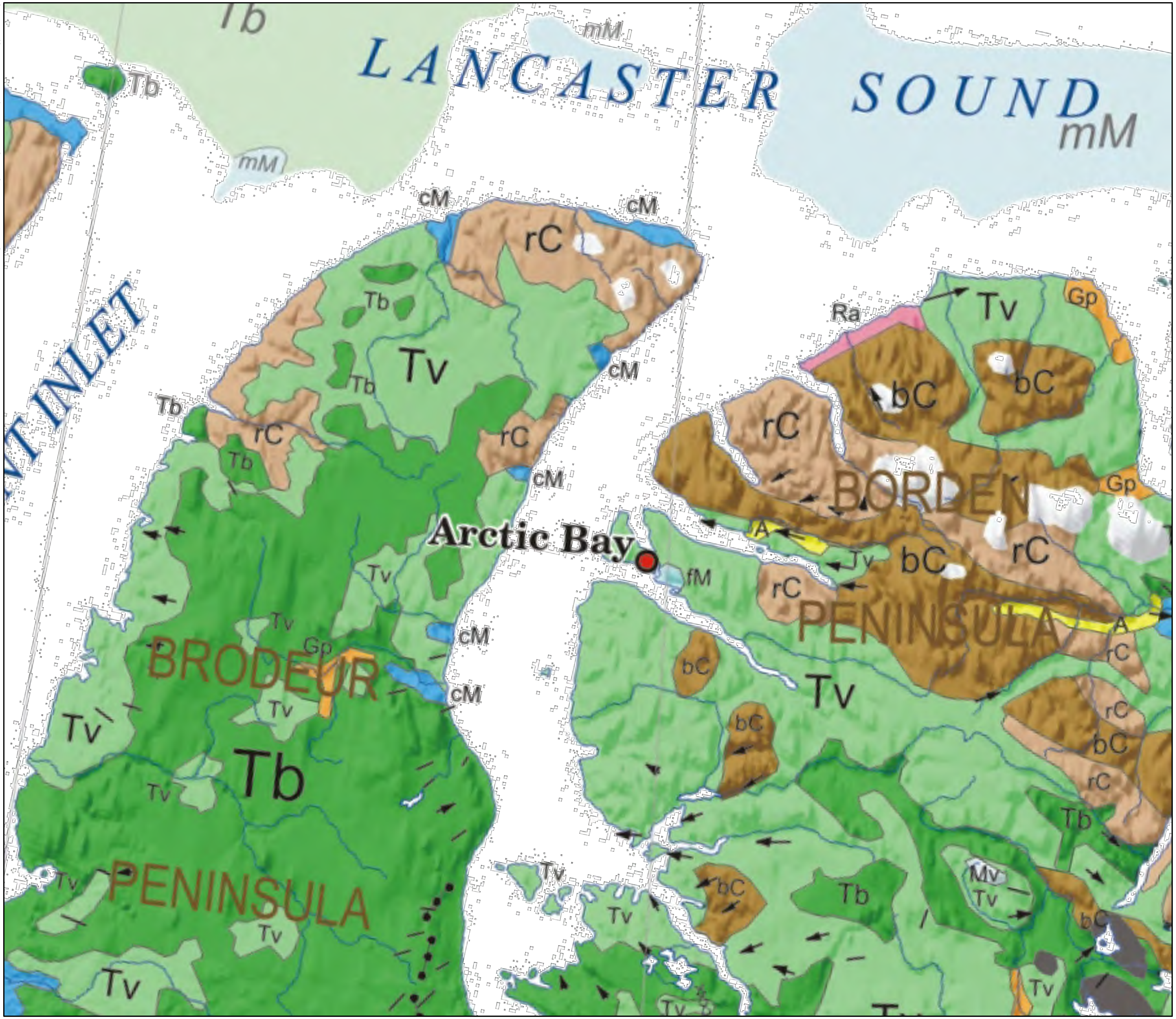

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Tv **TILL VENEER**: THIN AND DISCONTINUOUS TILL; MAY INCLUDE EXTENSIVE AREAS OF ROCK OUTCROP

fM **FINE GRAINED**: DOMINANTLY SILT AND CLAY, LOCALLY CONTAINING STONES; DEPOSITED AS QUIET WATER SEDIMENTS

No.	Revision	Date

PRELIMINARY

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Dwg Standards Ckd By:

Designed By: IT

Design Checked By:

Scale: 1:1 000 000 — 0, 20, 40 km

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

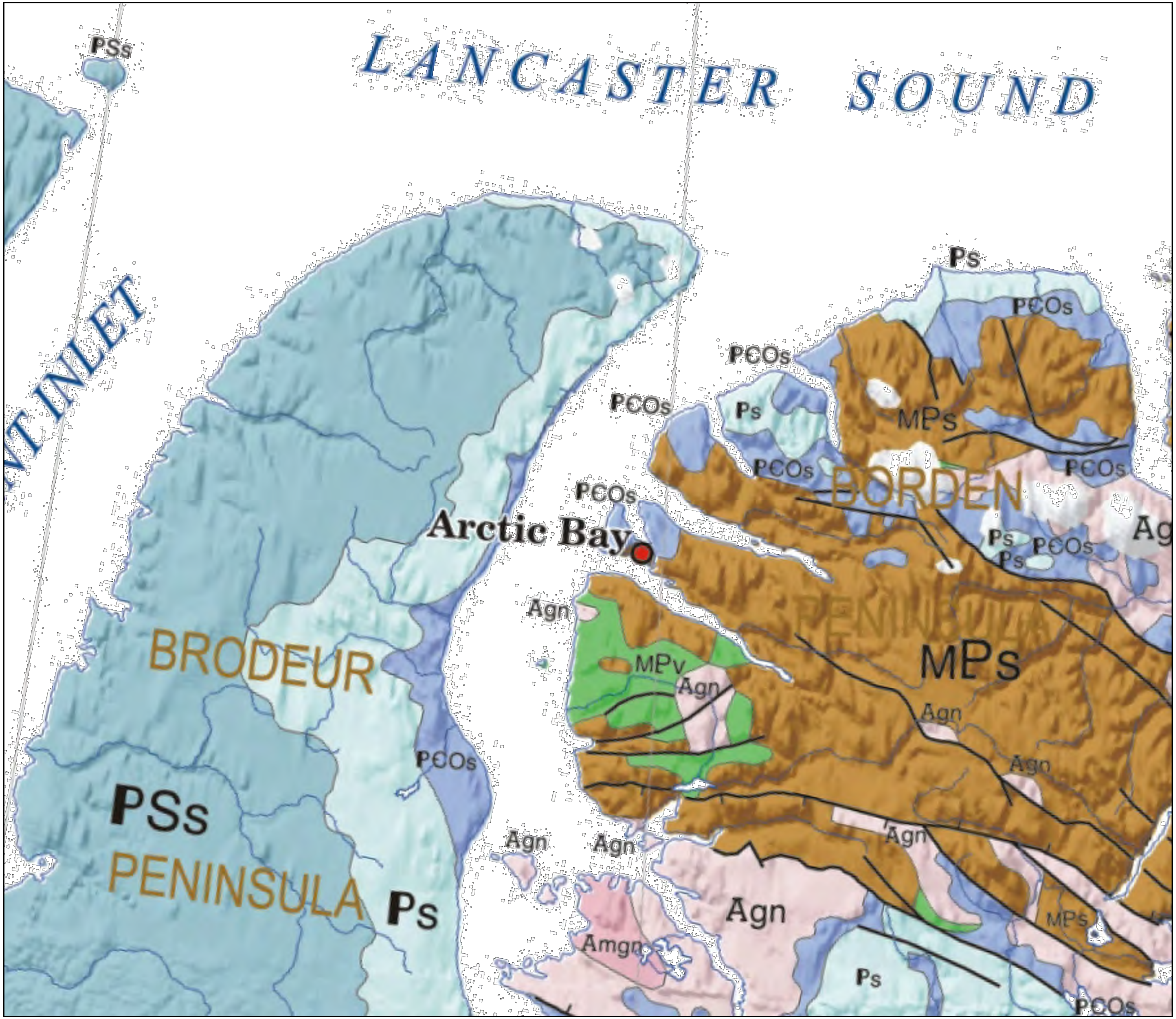
ARCTIC BAY SURFICIAL GEOLOGY OVERALL PLAN

Project No.

FRN-21016638-A0

Dwg. No. **FIG. 3**

Rev. No. 0



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MPs UNDIVIDED SEDIMENTARY ROCKS

PЄOs CAMBRIAN-ORDOVICIAN CARBONATE AND SILICICLASTIC ROCKS

No.	Revision	Date

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Project Title

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**ARCTIC BAY
BEDROCK GEOLOGY
OVERALL PLAN**

Project No.
FRN-21016638-A0

Dwg. No. **FIG. 4**

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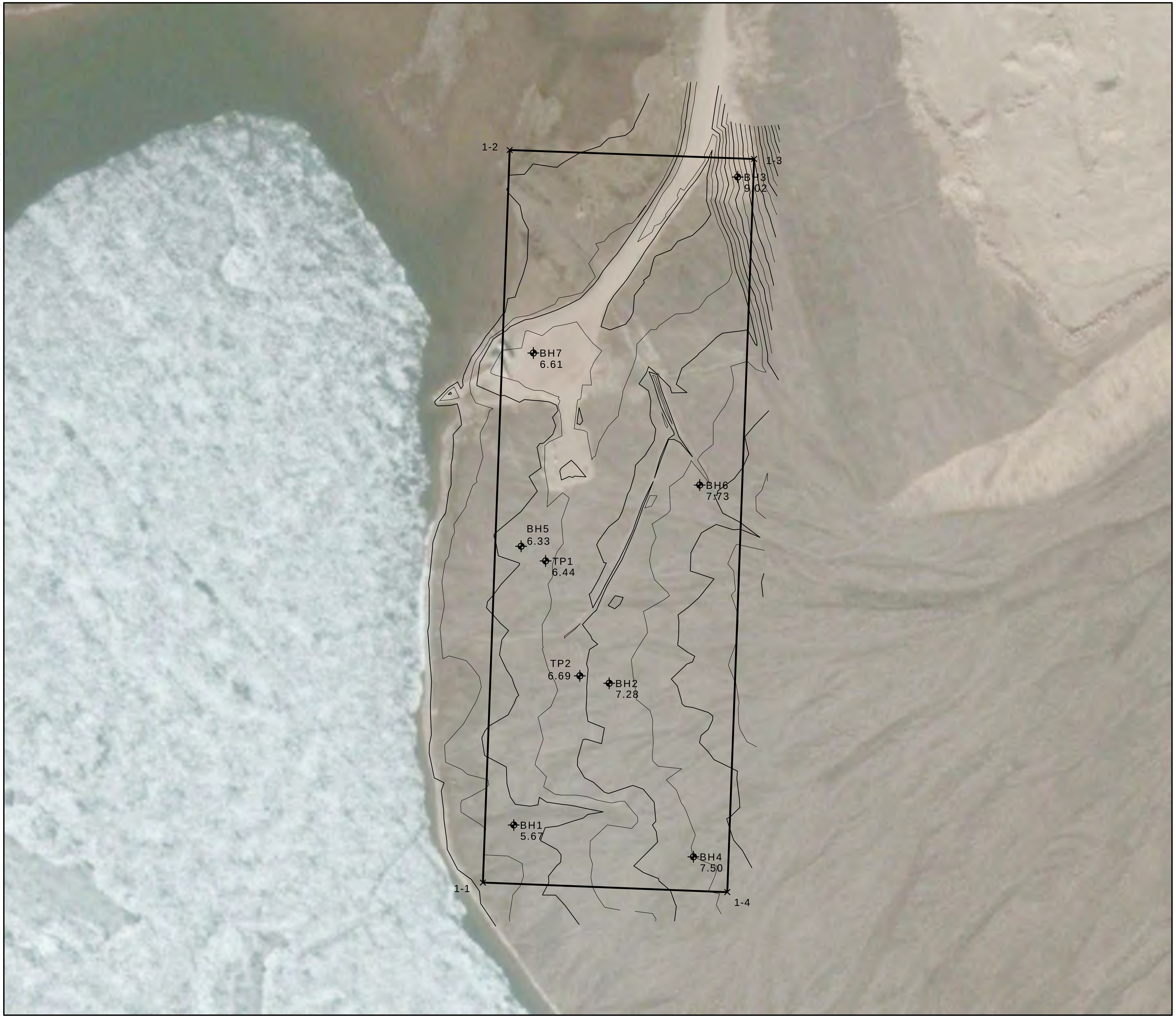

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WTP BUSINESS CASE

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**ARCTIC BAY
GEOTECH PROGRAM
SITE 1**

Project No.
FRN-21016638-A0

Dwg. No.
FIG. 5a

Rev. No.
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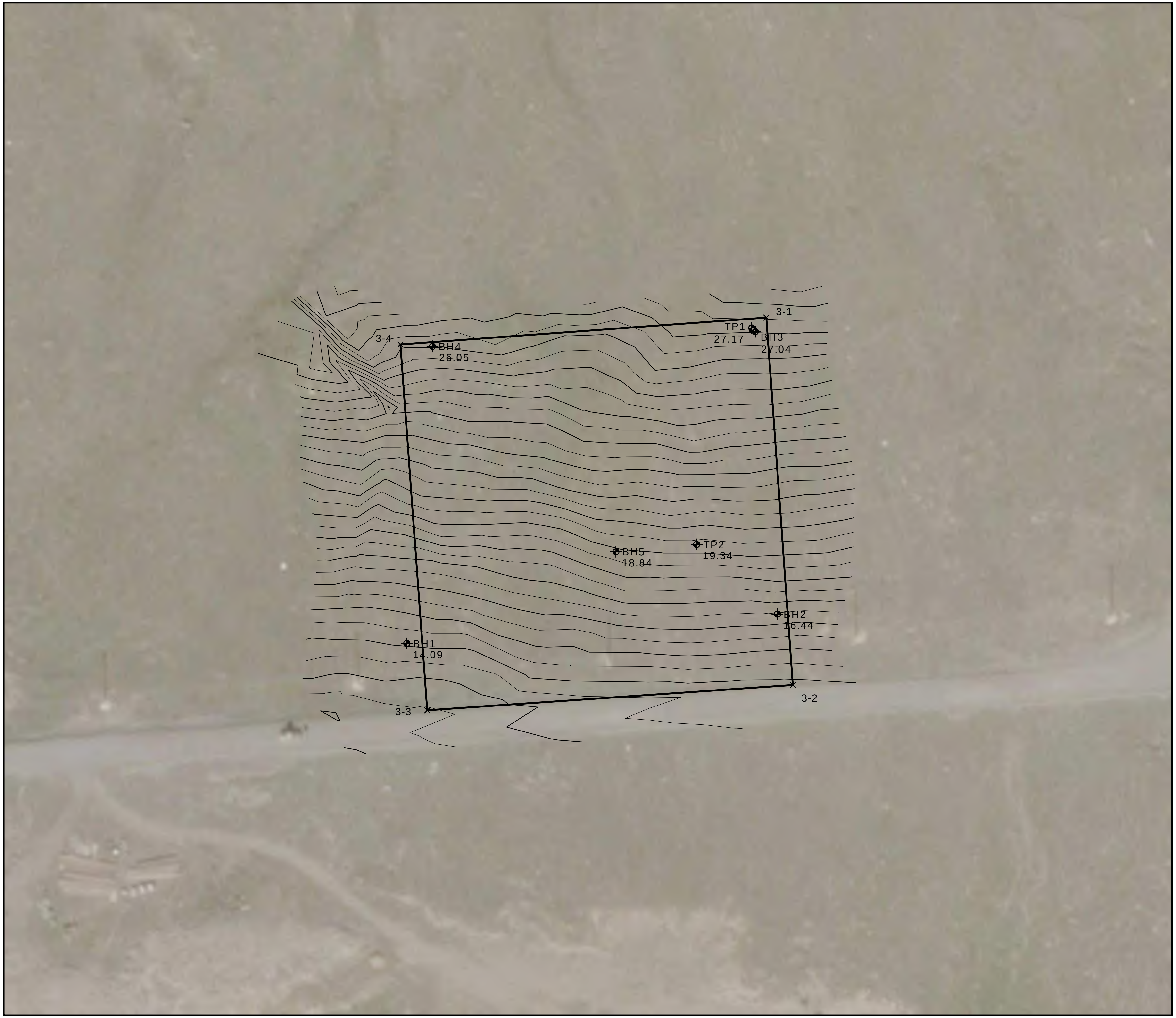

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Dwg Standards Ckd By:

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Design Checked By:

Scale: 1:1000 — 0, 20, 40 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
GEOTECH PROGRAM
SITE 3**

Project No.
FRN-21016638-A0

Dwg. No.
FIG. 5b

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Dwg Standards Ckd By:

Designed By: IT

Design Checked By:

Scale: 1:1000 (0, 20, 40 m)

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
GEOTECH PROGRAM
SITE 4**

Project No.
FRN-21016638-A0

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FIG. 5c

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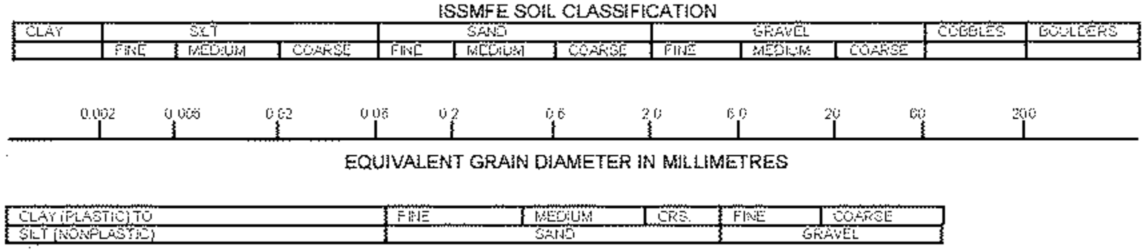
Notes On Sample Descriptions

1. All sample descriptions included in this report follow the Canadian Foundations Engineering Manual soil classification system. This system follows the standard proposed by the International Societv for Soil Mechanics and Foundation Engineering. Laboratory grain size analyses provided by **exp** Services Inc. also follow the same system. Different classification systems may be used by others; one such system is the Unified Soil Classification. Please note that, with the exception of those samples where a grain size analysis has been made, all samples are classified visually. Visual classification is not sufficiently accurate to provide exact grain sizing or precise differentiation between size classification systems.

ISSMFE SOIL CLASSIFICATION



UNIFIED SOIL CLASSIFICATION

2. Fill: Where fill is designated on the borehole log it is defined as indicated by the sample recovered during the boring process. The reader is cautioned that fills are heterogeneous in nature and variable in density or degree of compaction. The borehole description may therefore not be applicable as a general description of site fill materials. All fills should be expected to contain obstruction such as wood, large concrete pieces or subsurface basements, floors, tanks, etc., none of these may have been encountered in the boreholes. Since boreholes cannot accurately define the contents of the fill, test pits are recommended to provide supplementary information. Despite the use of test pits, the heterogeneous nature of fill will leave some ambiguity as to the exact composition of the fill. Most fills contain pockets, seams, or layers of organically contaminated soil. This organic material can result in the generation of methane gas and/or significant ongoing and future settlements. Fill at this site may have been monitored for the presence of methane gas and, if so, the results are given on the borehole logs. The monitoring process does not indicate the volume of gas that can be potentially generated nor does it pinpoint the source of the gas. These readings are to advise of the presence of gas only, and a detailed study is recommended for sites where any explosive gas/methane is detected. Some fill material may be contaminated by toxic/hazardous waste that renders it unacceptable for deposition in any but designated land fill sites; unless specifically stated the fill on this site has not been tested for contaminants that may be considered toxic or hazardous. This testing and a potential hazard study can be undertaken if requested. In most residential/commercial areas undergoing reconstruction, buried oil tanks are common and are generally not detected in a conventional geotechnical site investigation.

3. Till: The term till on the borehole logs indicates that the material originates from a geological process associated with glaciation. Because of this geological process the till must be considered heterogeneous in composition and as such may contain pockets and/or seams of material such as sand, gravel, silt or clay. Till often contains cobbles (60 to 200 mm) or boulders (over 200 mm). Contractors may therefore encounter cobbles and boulders during excavation, even if they are not indicated by the borings. It should be appreciated that normal sampling equipment cannot differentiate the size or type of any obstruction. Because of the horizontal and vertical variability of till, the sample description may be applicable to a very limited zone; caution is therefore essential when dealing with sensitive excavations or dewatering programs in till materials.

Log of Borehole BH-01

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 6

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

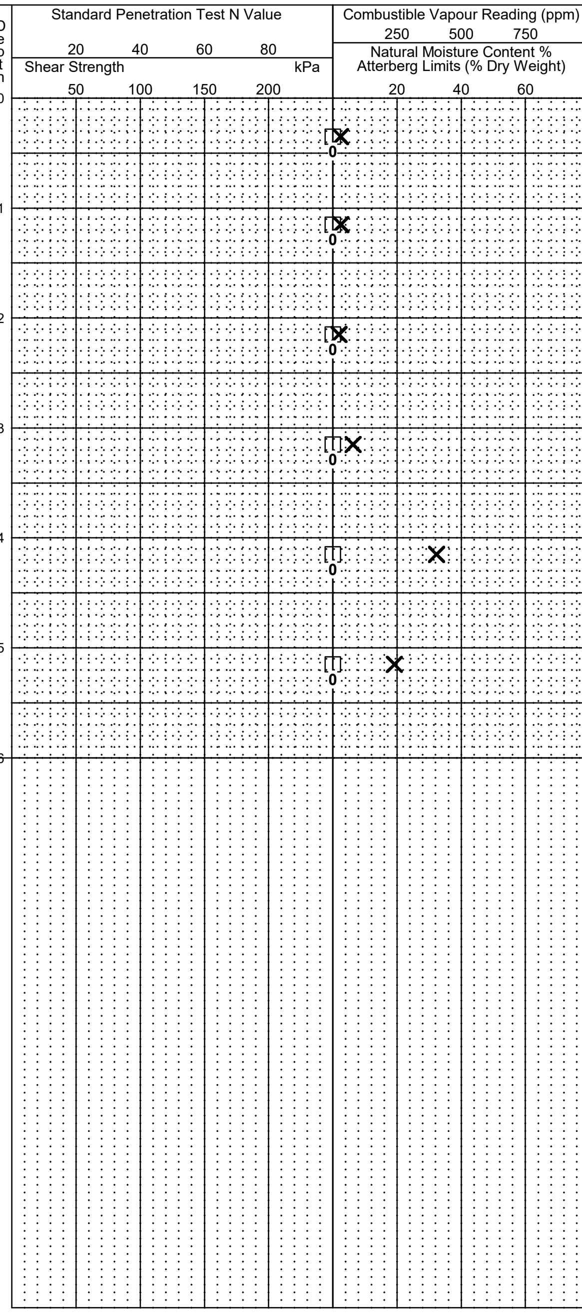
Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend		Legend	
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◫	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├──○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	SAMPLES	Natural Unit Wt. kN/m³
			5.7	0		
		TOPSOIL ~50mm	5.7			
		SAND AND GRAVEL (GP) With boulders and cobbles, brown, moist to wet				1-1
				1		1-2
				2		1-3
				3		1-4
		wet at 3.7 m depth	1.7			
		SAND AND GRAVEL (SP) With silt, grey, wet		4		1-5
				5		1-6
			-0.3	6		
		Borehole Terminated at 6 m depth Due to cave-in				



NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.0	5.0

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-02

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 7

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol
Split Spoon Sample	⊠
Auger Sample	◫
SPT (N) Value	○
Dynamic Cone Test	—
Shelby Tube	■
Shear Strength by Vane Test	+ S
Combustible Vapour Reading	□
Natural Moisture Content	×
Atterberg Limits	⊢○
Undrained Triaxial at % Strain at Failure	⊕
Shear Strength by Penetrometer Test	▲

Column headings: GWL | SYMBOL | SOIL DESCRIPTION | Geodetic m | Depth | Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200) | Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %; Atterberg Limits (% Dry Weight) (20, 40, 60) | SAMPLES | Natural Unit Wt. kN/m³

Soil Description	Geodetic (m)	Depth (m)
TOPSOIL ~50mm	7.3 / 7.3	0
GRAVELLY SAND (SP) With boulders and cobbles, brown, moist. With silt, brown to dark brown, frozen below 8 m depth	-1.5	
SILTY SAND (SM) Brown, wet, frozen	-2.7	10
Borehole Terminated at 10 m depth		

Sample	Depth (m, approx.)	Combustible Vapour Reading
2-1	0.35	0
2-2	1.15	0
2-3	2.15	0
2-4	3.15	0
2-5	4.15	0
2-6	5.15	0
2-7	6.15	0
2-8	7.15	0
2-9	8.15	0
2-10	9.15	0

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2. Multi-bead thermistor string installed to 10.0 m depth upon completion
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-03

Project No:	FRN-21016638-A0
Project:	New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1
Location:	ARCTIC BAY, NU
Date Drilled:	'Sept 30, 2021
Drill Type:	
Datum:	Geodetic
Logged by:	C.H.
Checked by:	S.K.A

Figure No. 8

Page. 1 of 1

Legend	Symbol	Legend	Symbol
Split Spoon Sample	☒	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├──○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Standard Penetration Test N Value: 20, 40, 60, 80; Shear Strength (kPa): 50, 100, 150, 200

Combustible Vapour Reading (ppm): 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight): 20, 40, 60

Depth (m)	Geodetic (m)	SOIL DESCRIPTION	Combustible Vapour Reading (ppm)	Samples	Natural Unit Wt. kN/m³
0	9 / 9.0	**TOPSOIL** ~50mm			
		SAND AND GRAVEL With cobbles, brown, low moisture content	0	Auger	3-1
1	8.0	**SILTY SAND (SM)** Trace gravel, brown, wet	0	Auger	3-2
2		At 2 m, some small boulders, ice crystals and lenses	0	Auger	3-3
3			0	Auger	3-4
4			0	Auger	3-5
5	4.0	Large limestone boulder at 5 m depth			
		SAND AND GRAVEL (SW) Reddish brown, very moist	0	Auger	3-6
6			0	Auger	3-7
7			0	Auger	3-8
8			0	Auger	3-9
9	0.0	**SANDY GRAVEL (GP)** Some boulders, reddish brown, very moist, ice crystals and lenses	0	Auger	3-10
10	-1.0	**Borehole Terminated at 10 m depth**			

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-04

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 9

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◫	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	⊢○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Depth (m)	SOIL DESCRIPTION	Geodetic m	Combustible Vapour Reading (ppm)	Natural Moisture Content	Samples	Natural Unit Wt. kN/m³
0	**TOPSOIL** ~50mm	7.5 / 7.5				
0–2.5	**SANDY GRAVEL (GP)** Well to poorley graded, some cobbles and small boulders, brown, slightly moist		0	✕	4-1, 4-2, 4-3, 4-4, 4-5	
5–10	**GRAVELLY SAND (SP)** Trace silt, brown, very moist. With cobbles and some boulders at 7 m	2.5 / -2.5	0	✕	4-6, 4-7, 4-8, 4-9, 4-10	
10	**Borehole Terminated at 10 m depth**					

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

LOG OF BOREHOLE FRN-21016638 ARCTIC BAY SITE 1 BH LOGS.GPJ TROW OTTAWA.GDT 1/27/22

Log of Borehole BH-05

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 10

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol
Split Spoon Sample	⊠
Auger Sample	◨
SPT (N) Value	○
Dynamic Cone Test	—
Shelby Tube	■
Shear Strength by Vane Test	+ S
Combustible Vapour Reading	□
Natural Moisture Content	×
Atterberg Limits	├─○
Undrained Triaxial at % Strain at Failure	⊕
Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			6.3	0				
		TOPSOIL ~50mm	6.3					
		SANDY GRAVEL (GP) With cobbles and small boulders, brown, slightly moist				0		5-1
				1		0		5-2
				2		0		5-3
				3		0		5-4
		dark brown, wet below 4 m depth		4		0		5-5
		GRAVELLY SAND (SP) Trace silt, brown, very moist	1.3	5		0		5-6
				6		0		5-7
				7		0		5-8
				8		0		5-9
				9		0		5-10
		Borehole Terminated at 10 m depth	-3.7	10				

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-06

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 11

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol
Split Spoon Sample	☒
Auger Sample	◨
SPT (N) Value	○
Dynamic Cone Test	—
Shelby Tube	■
Shear Strength by Vane Test	+ S
Combustible Vapour Reading	□
Natural Moisture Content	X
Atterberg Limits	⊢○
Undrained Triaxial at % Strain at Failure	⊕
Shear Strength by Penetrometer Test	▲

Column headings: GWL | SYMBOL | SOIL DESCRIPTION | Geodetic m | Depth | Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200) | Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %; Atterberg Limits (% Dry Weight) (20, 40, 60) | SAMPLES | Natural Unit Wt. kN/m³

Geodetic (m)	Soil Description	Sample	Depth (m)
7.7 / 7.7	**TOPSOIL** ~50mm		0
	SANDY GRAVEL (GP) With cobbles and small boulders, brown to greyish brown, damp	6-1	
		6-2	1
		6-3	2
		6-4	3
3.7	**SILTY SAND (SM)** Some gravel, occasional cobbles, dark grey, wet	6-5	4
		6-6	5
		6-7	6
		6-8	7
		6-9	8
		6-10	9
-2.3	**Borehole Terminated at 10 m depth**		10

LOG OF BOREHOLE FRN-21016638 ARCTIC BAY SITE 1 BH LOGS.GPJ TROW OTTAWA.GDT 1/27/22

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-07

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 12

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Depth (m)	Soil Description	Geodetic (m)	Sample	Combustible Vapour Reading (ppm)	Natural Moisture Content % (approx.)
0	**GRANULAR FILL (GP)** Crusher run 3/4" limestone, grey, moist, well compacted	6.6	7-1 (0.35 m)	0	~2
			7-2 (1.15 m)	0	~2
2.0	**GRAVELLY SAND (SP)** Poorly graded, with cobbles and boulders, brown, moist	4.6	7-3 (2.15 m)	0	~3
3.0	**SILTY SAND (SM)** Some gravel, dark grey, moist to wet below 4 m depth	3.6	7-4 (3.15 m)	0	~14
			7-5 (4.15 m)	0	~20
5.0	**SAND AND GRAVEL (GP)** Some cobbles and boulders, becomes silty with depth, reddish brown, moist	1.6	7-6 (5.15 m)	0	~6
			7-7 (6.15 m)	0	~7
			7-8 (7.15 m)	0	~8
8.0	**SAND (SW)** Trace silt, trace gravel, black, wet	-1.4	7-9 (8.15 m)	0	~18
			7-10 (9.15 m)	0	~18
10.0	**Borehole Terminated at 10 m depth**	-3.4			

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	3.7	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-1

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 13

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H.   Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├──○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			6.4	0				
		TOPSOIL ~50mm	6.4					
		SANDY GRAVEL (GP) With small boulders and cobbles, approximately 70% oversize materials, brown, moist, not frozen. Large boulders at 1.2 m depth.				X		TP1
			5.2	1				
		Backhoe Shovel Refusal at 1.2 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-2

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 14

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			6.7	0				
		TOPSOIL ~50mm	6.7					
		SANDY GRAVEL (GP) With small boulders and cobbles, approximately 70% oversize materials, brown, moist, not frozen. Large boulders at 1.2 m depth.	5.5	1		✕		TP2
		Backhoe Shovel Refusal at 1.2 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

EXP Services Inc.
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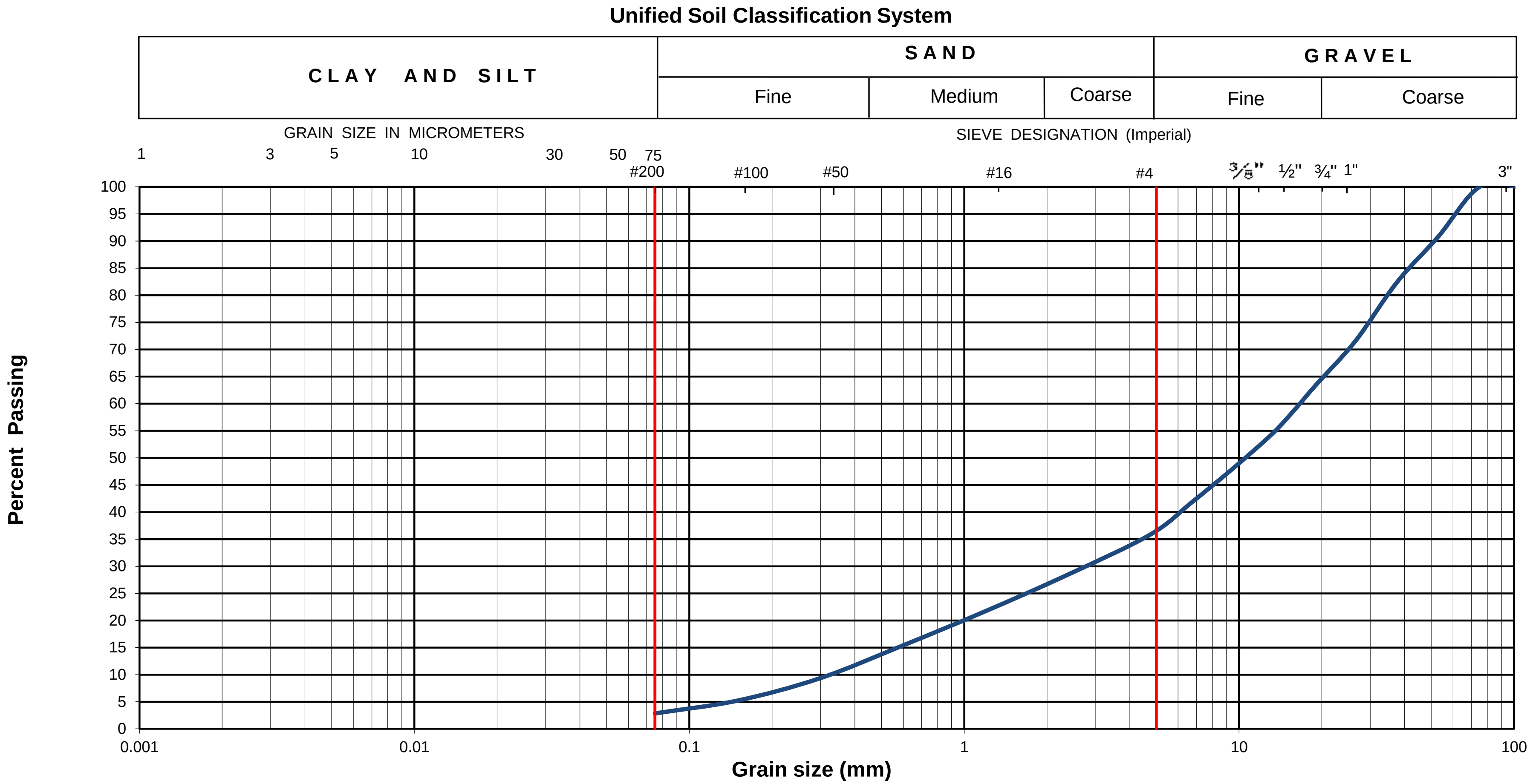
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment				
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1				
Date Sampled :	September 29, 2021	Borehole No:	TP1	Sample:	n/a	Depth (m) :	0-1.2
Sample Composition :		Gravel (%) 64	Sand (%) 33	Silt & Clay (%) 3		Figure :	15
Sample Description :	Well Graded Sandy Gravel (GW)						

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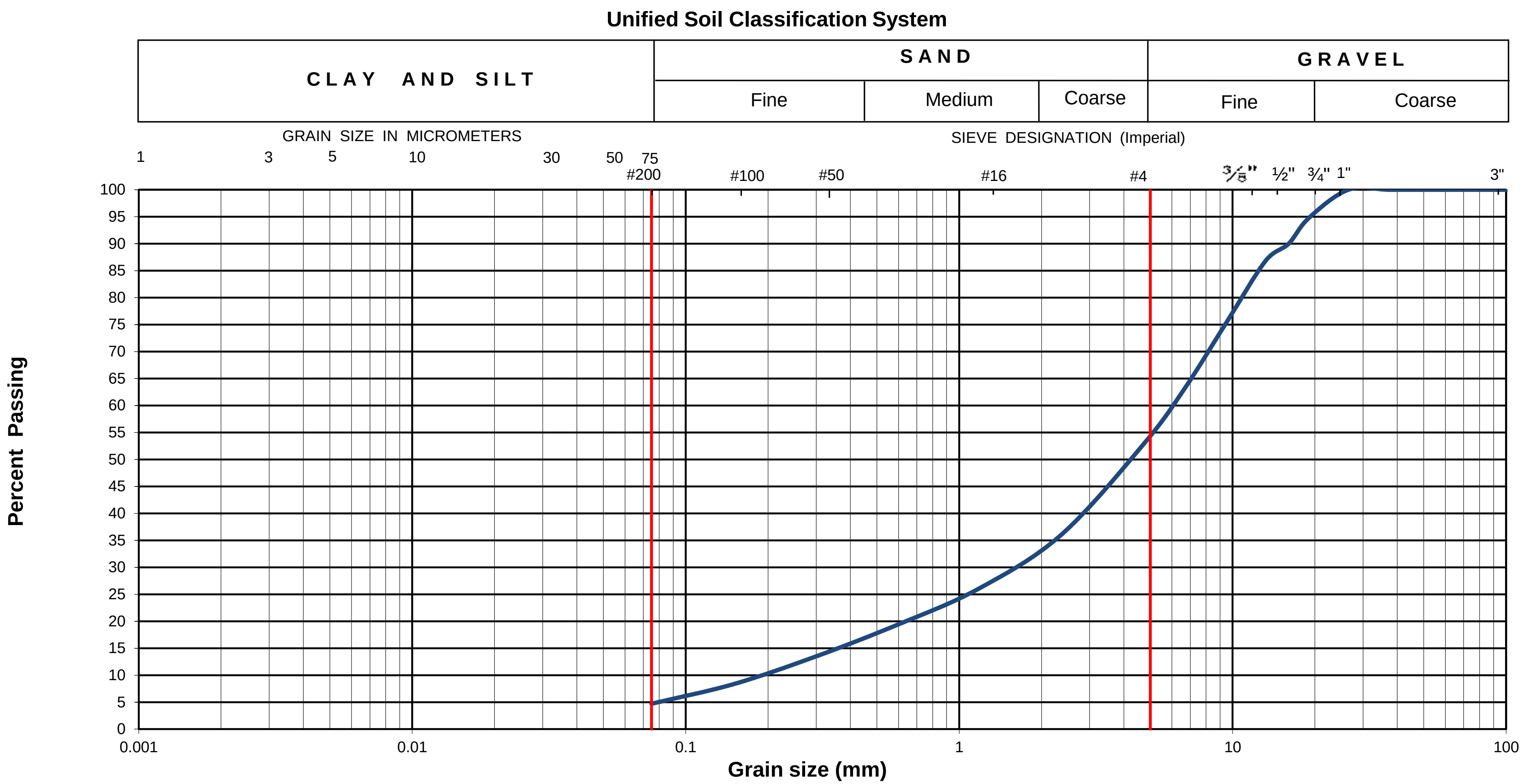
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**					
Date Sampled :	**September 29, 2021**	**Borehole No:**	**BH1**	**Sample:**	**S2**		**Depth (m) :**	**1-2**
Sample Composition :		**Gravel (%)**	**47**	**Sand (%)**	**48**	**Silt & Clay (%)** **5**	**Figure :**	**16**
Sample Description :	**Poorly Graded Sand and Gravel (GP)**							

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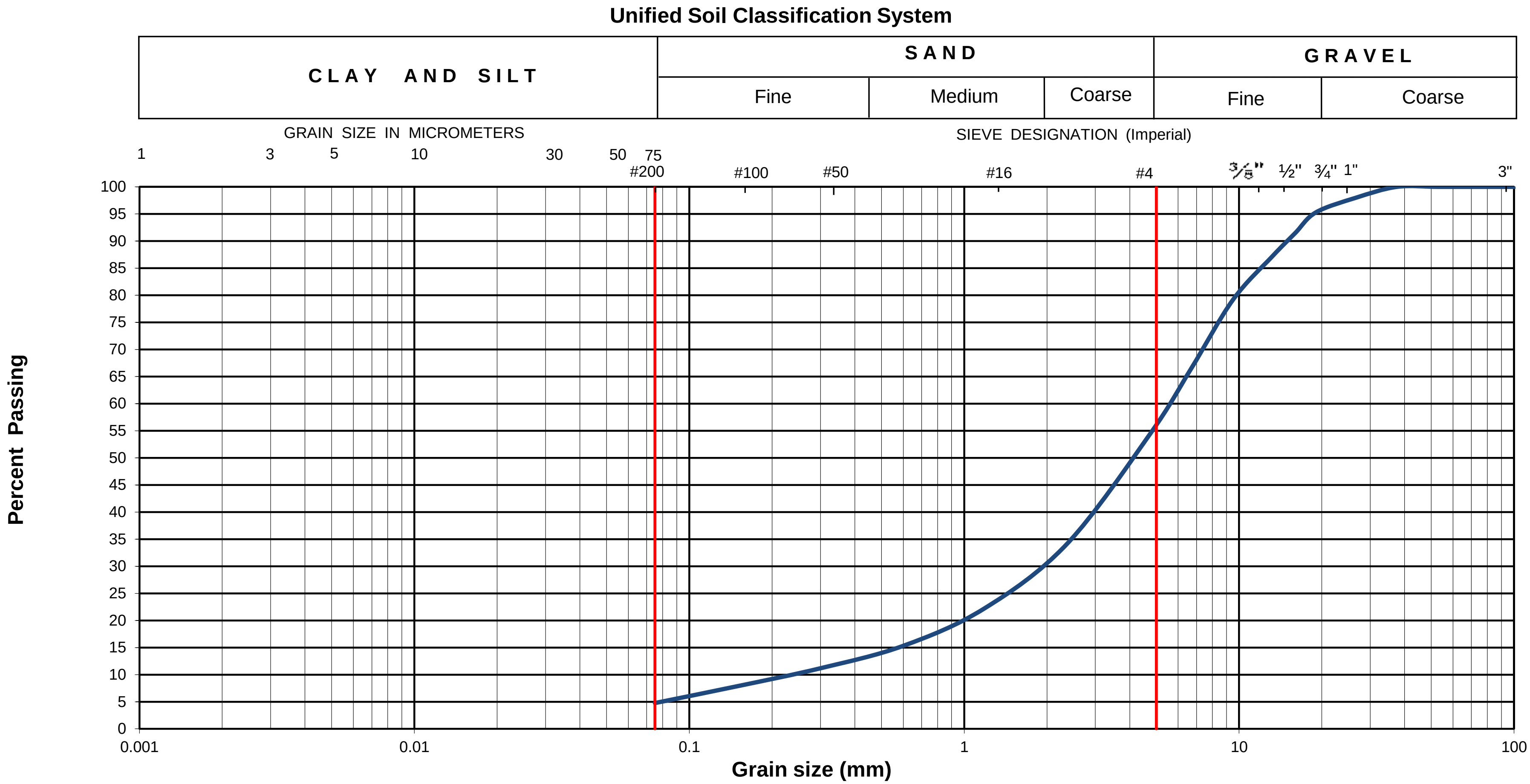
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment				
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1				
Date Sampled :	September 29, 2021	Borehole No:	BH1	Sample:	S5	Depth (m) :	4-5
Sample Composition :		Gravel (%)	46	Sand (%) 49	Silt & Clay (%) 5	Figure :	17
Sample Description :	Poorly Graded Sand and Gravel (GP)						

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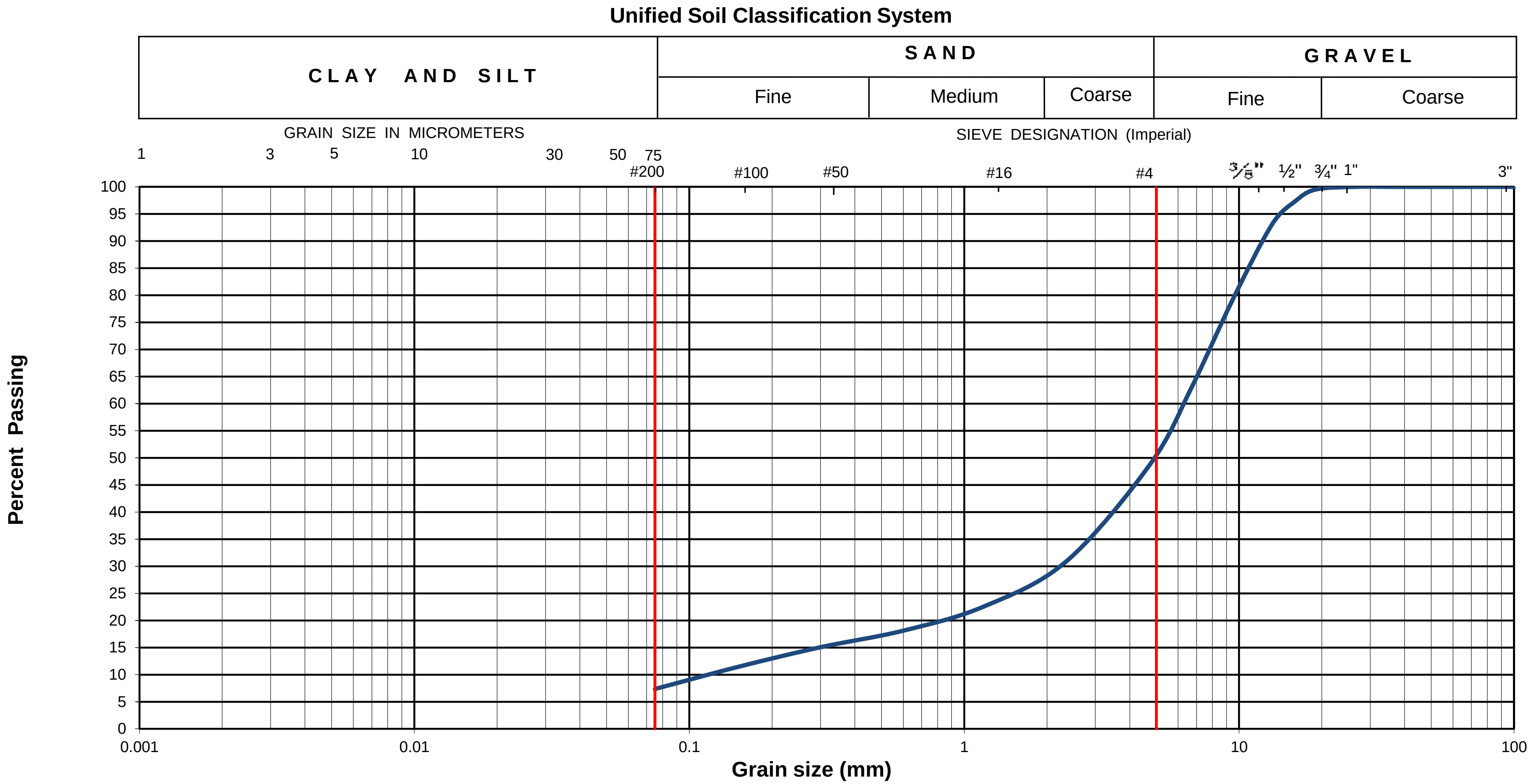
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**					
Date Sampled :	**September 29, 2021**	**Borehole No:**	**BH4**	**Sample:**	**S4**	**Depth (m) :**	**3-4**	
Sample Composition :		**Gravel (%)**	**51**	**Sand (%)**	**42**	**Silt & Clay (%)**	**7**	**Figure : 18**
Sample Description :	**Poorly Graded Sandy Gravel (GP)**							

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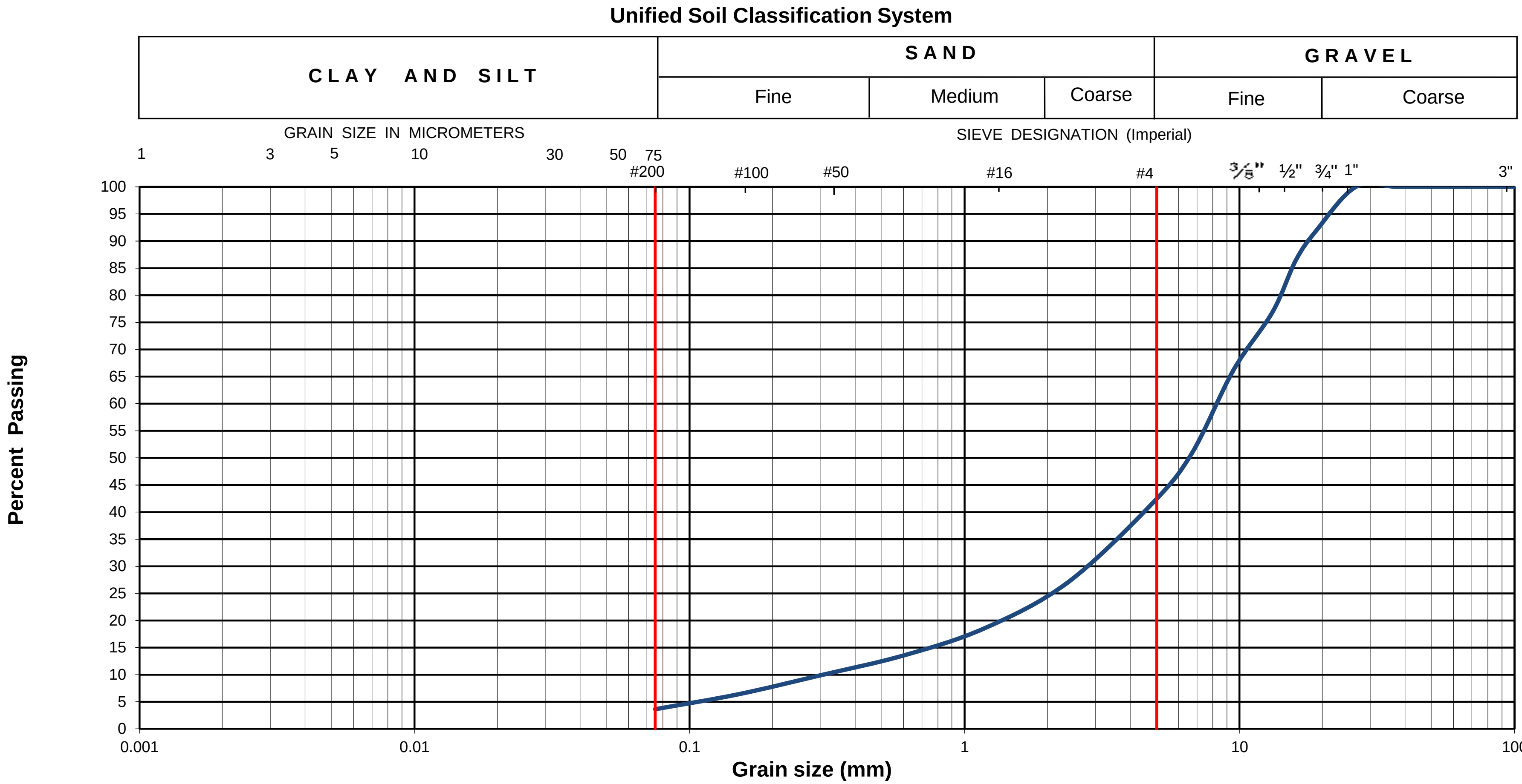
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**				
Date Sampled :	**September 30, 2021**	**Borehole No:**	**BH5**	**Sample:**	**S2**	**Depth (m) :**	**1-2**
Sample Composition :		**Gravel (%)** 59	**Sand (%)** 37	**Silt & Clay (%)**	**4**	**Figure :**	**19**
Sample Description :	**Poorly Graded Sandy Gravel (GP)**						

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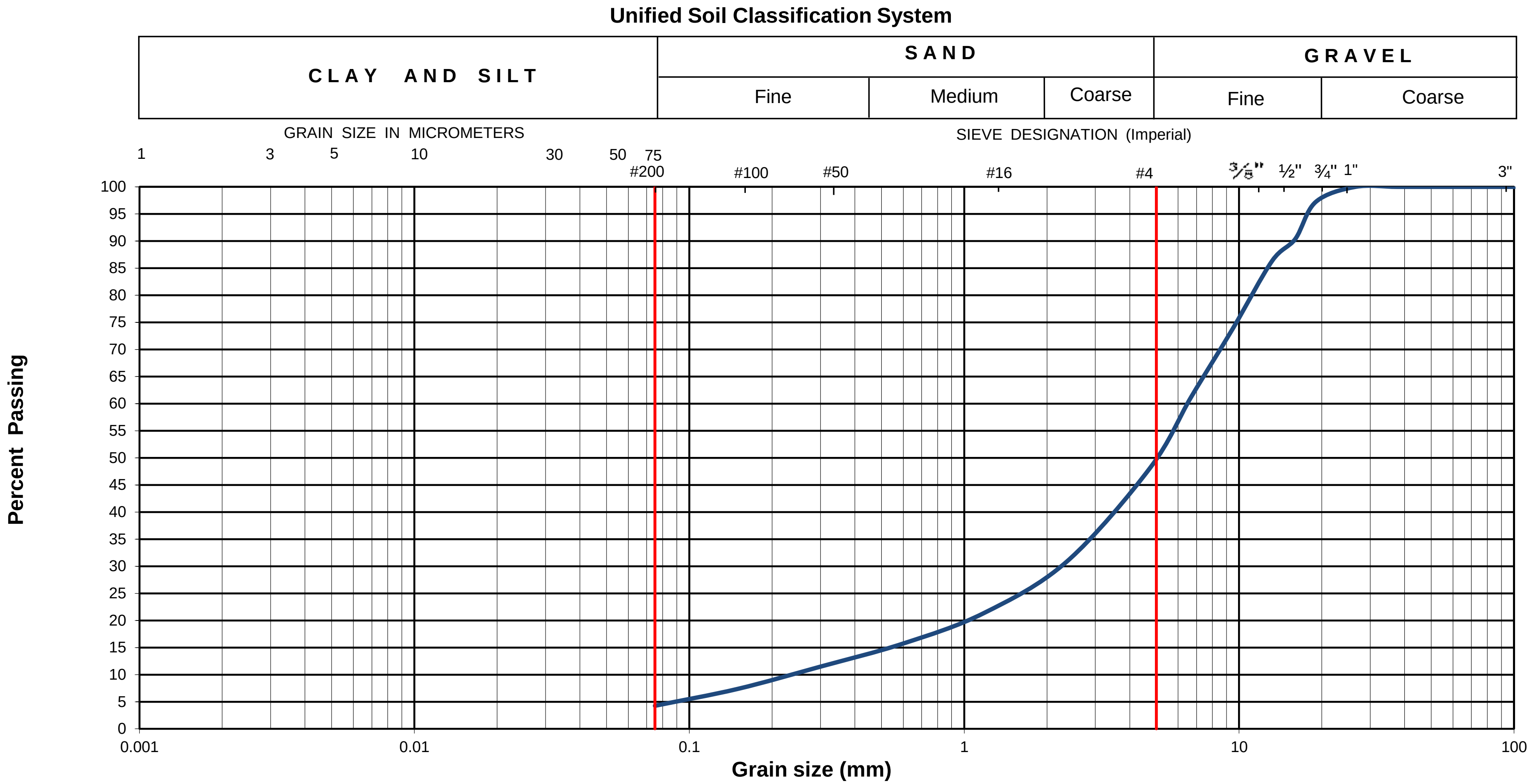
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**				
Date Sampled :	**September 30, 2021**	**Borehole No:**	**BH6**	**Sample:**	**S2**	**Depth (m) :**	**1-2**
Sample Composition :		**Gravel (%)** 52	**Sand (%)** 44	**Silt & Clay (%)**	**4**	**Figure :**	**20**
Sample Description :	**Poorly Graded Sandy Gravel (GP)**						

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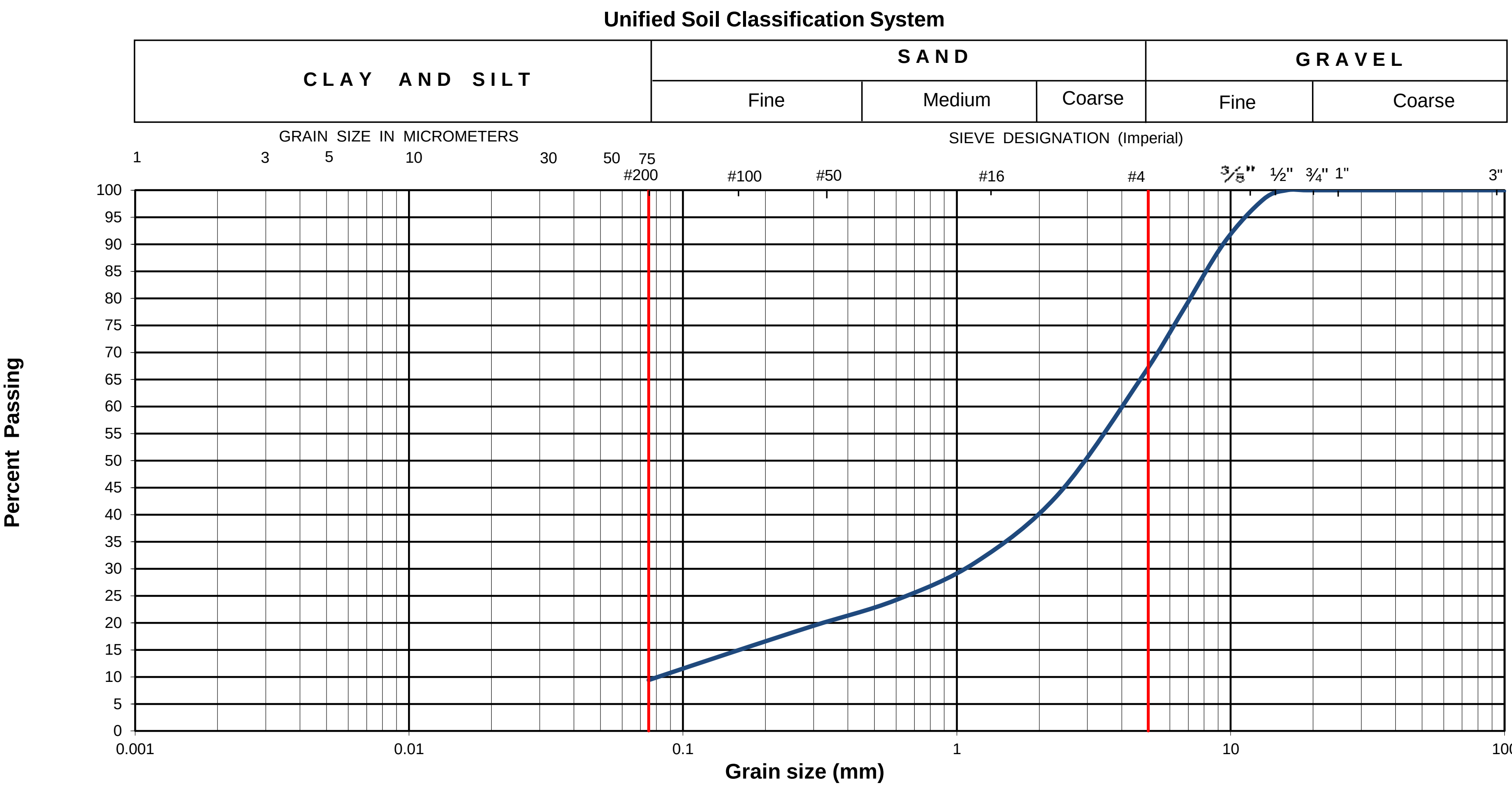
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**				
Date Sampled :	**September 30, 2021**	**Borehole No:**	**BH2**	**Sample:**	**S6**	**Depth (m) :**	**5-6**
Sample Composition :		**Gravel (%)**	**35**	**Sand (%)**	**56**	**Silt & Clay (%)**	**9**
Sample Description :	**Poorly Graded Gravelly Sand (SP)**					**Figure :**	**21**

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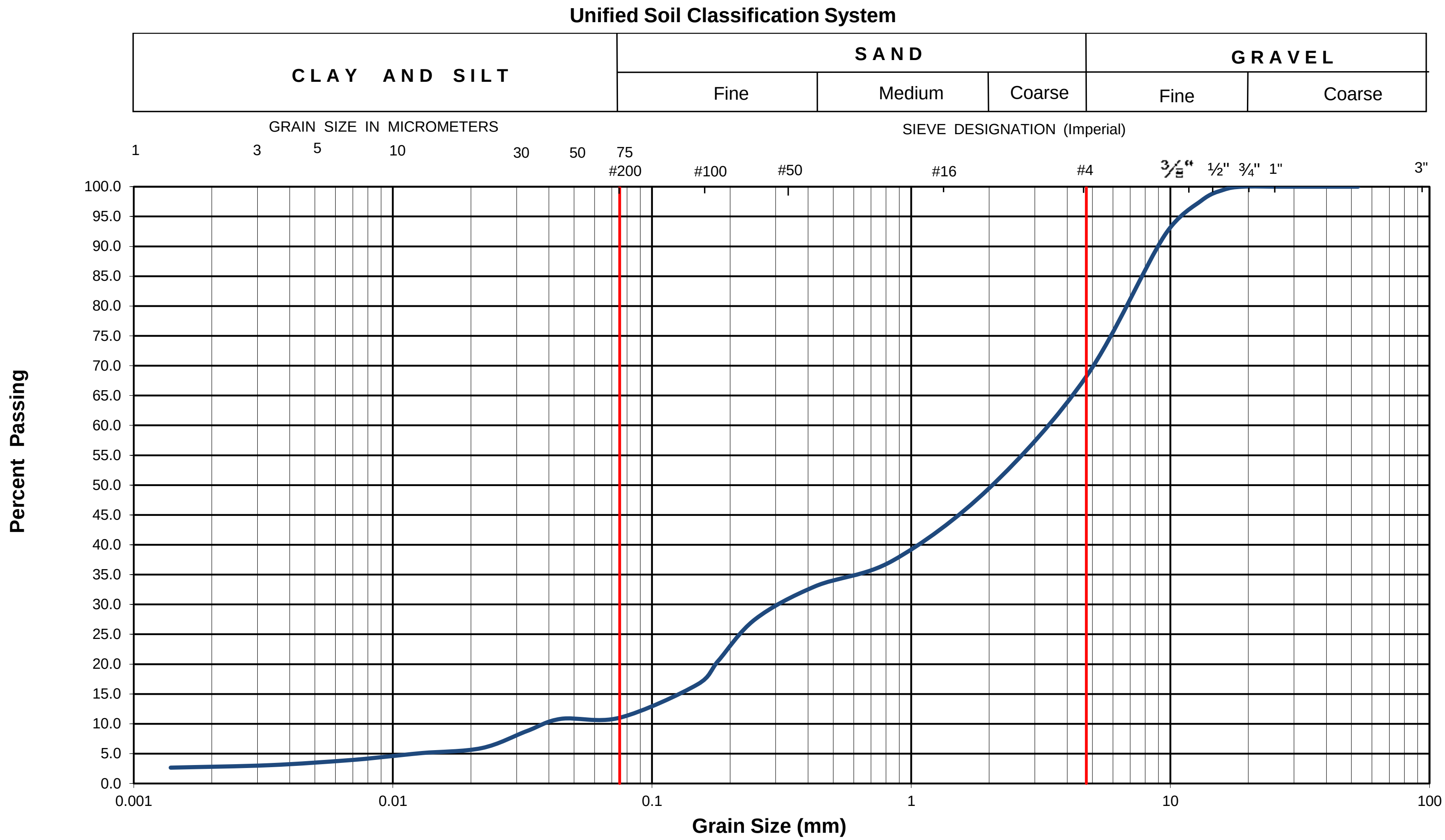
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**					
Date Sampled :	**September 30, 2021**	**Borehole No:**	**BH4**	**Sample No.:**	**S8**		**Depth (m) :**	**7-8**
Sample Description :		**% Silt and Clay**	**11**	**% Sand**	**57**	**% Gravel**	**32**	**Figure : 22**
Sample Description :	**Poorly Graded Gravelly Sand (SP)**							

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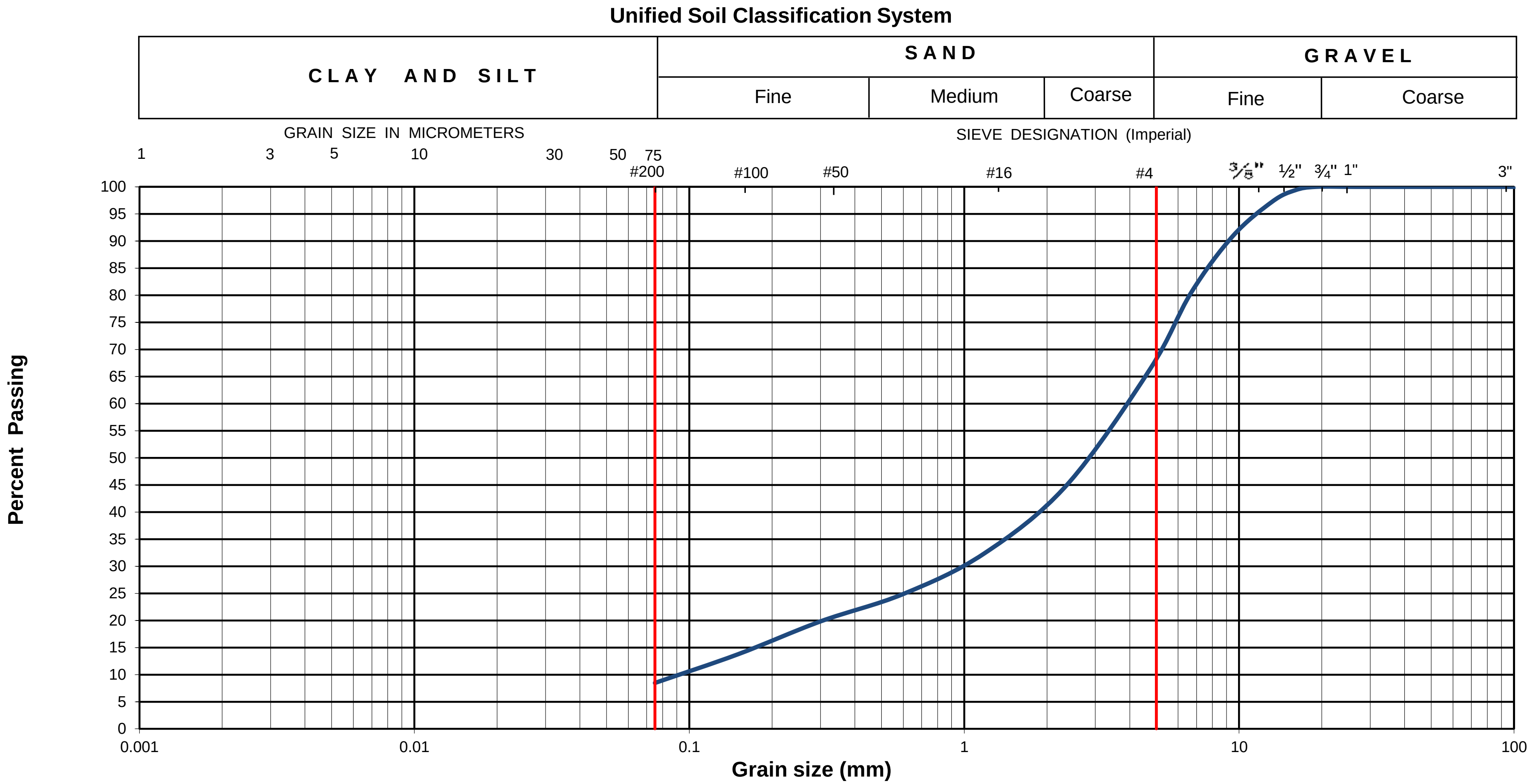
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**				
Date Sampled :	**September 30, 2021**	**Borehole No:**	**BH5**	**Sample:**	**S7**	**Depth (m) :**	**6-7**
Sample Composition :		**Gravel (%)**	**34**	**Sand (%)**	**57**	**Silt & Clay (%)**	**9**
Sample Description :	**Well Graded Gravelly Sand (SW)**					**Figure :**	**23**

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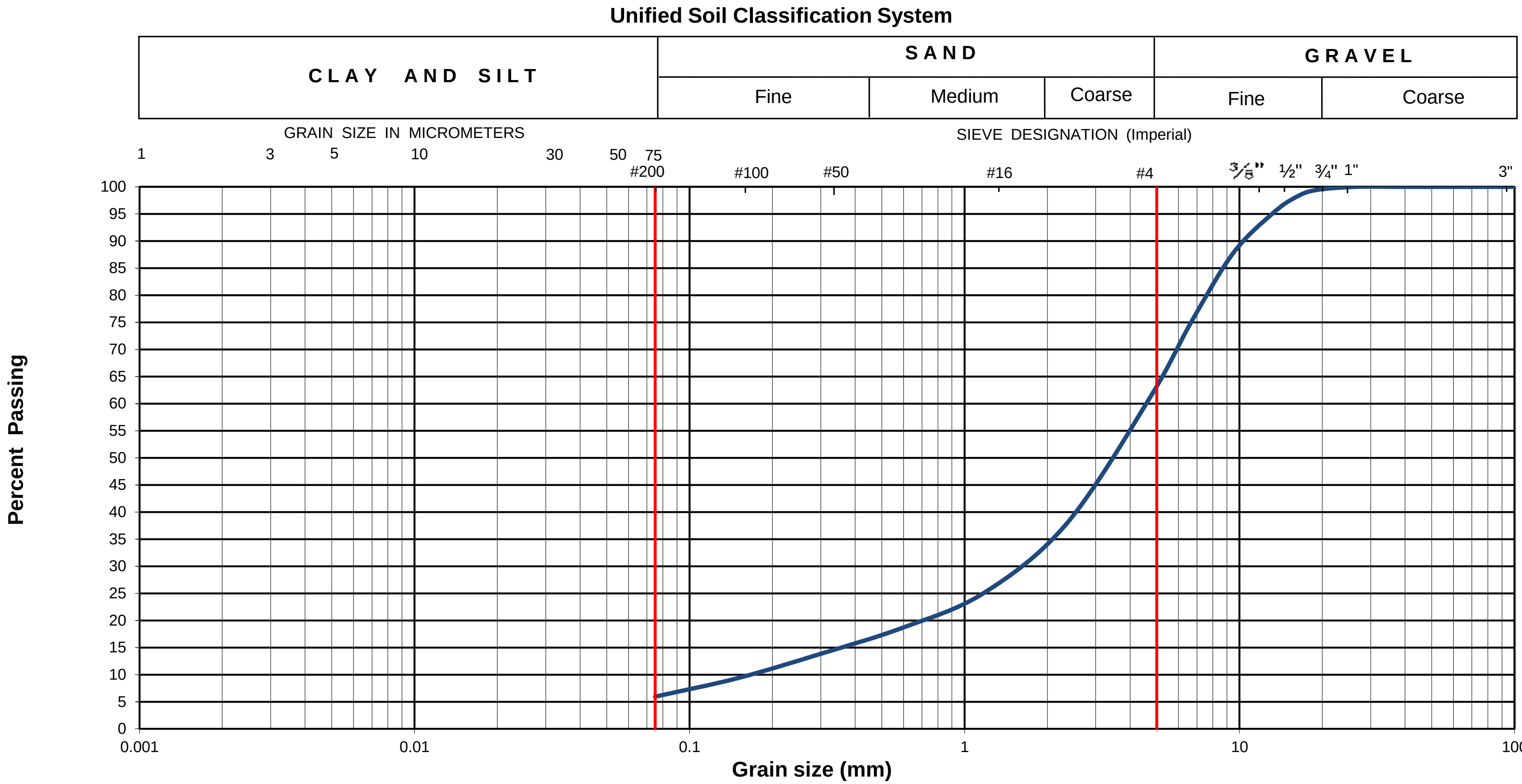
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**				
Date Sampled :	**September 30, 2021**	**Borehole No:**	**BH7**	**Sample:**	**S3**	**Depth (m) :**	**2-3**
Sample Composition :		**Gravel (%)**	**39**	**Sand (%)**	**55**	**Silt & Clay (%)**	**6**
Sample Description :	**Poorly Graded Gravelly Sand (SP)**					**Figure :**	**24**

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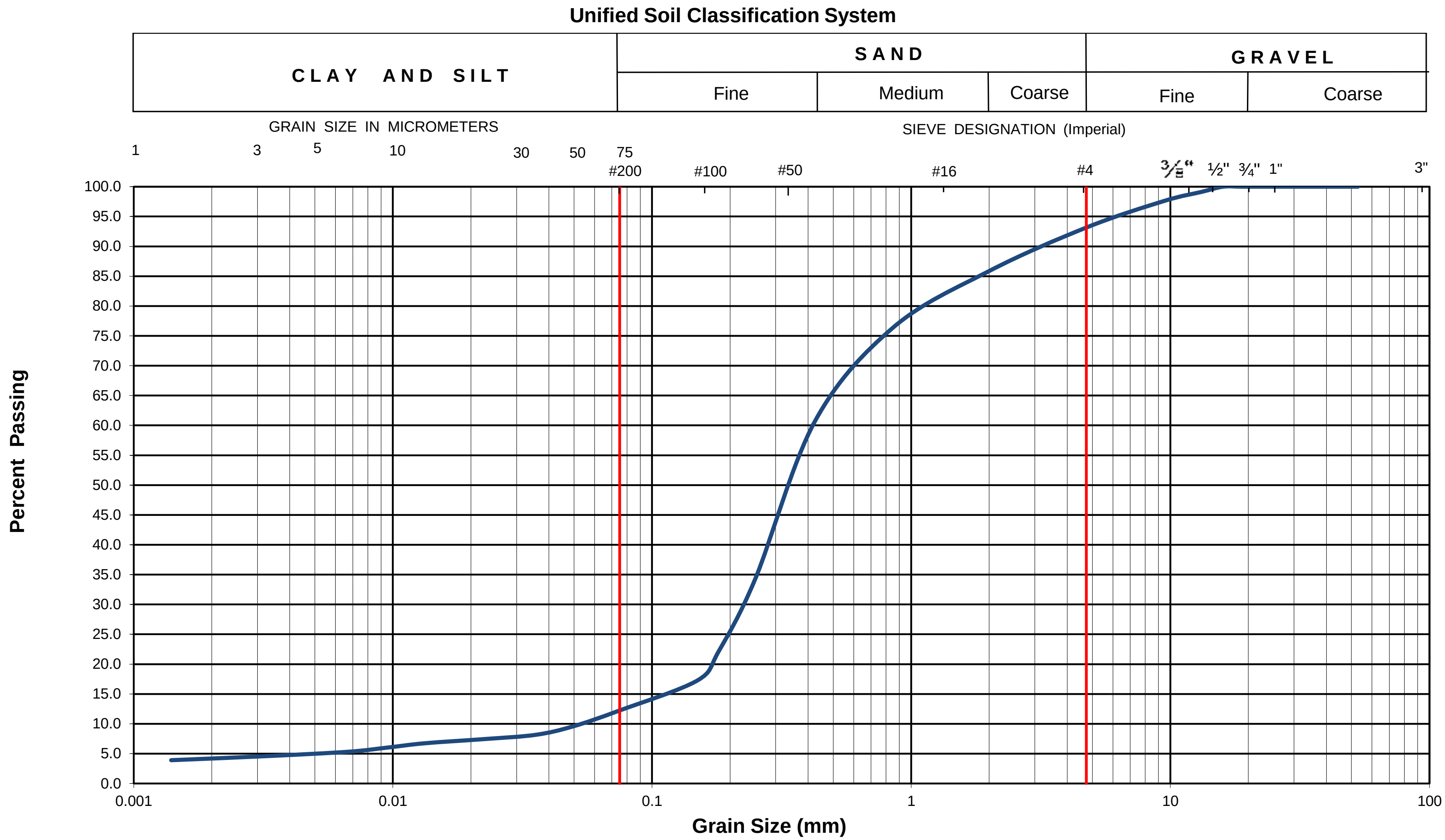
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1						
Date Sampled :	September 30, 2021	Borehole No:		BH7	Sample No.:		S9	Depth (m) :	8-9
Sample Description :		% Silt and Clay	12	% Sand	81	% Gravel	7	Figure :	25
Sample Description :		Well Graded Sand (SW)							

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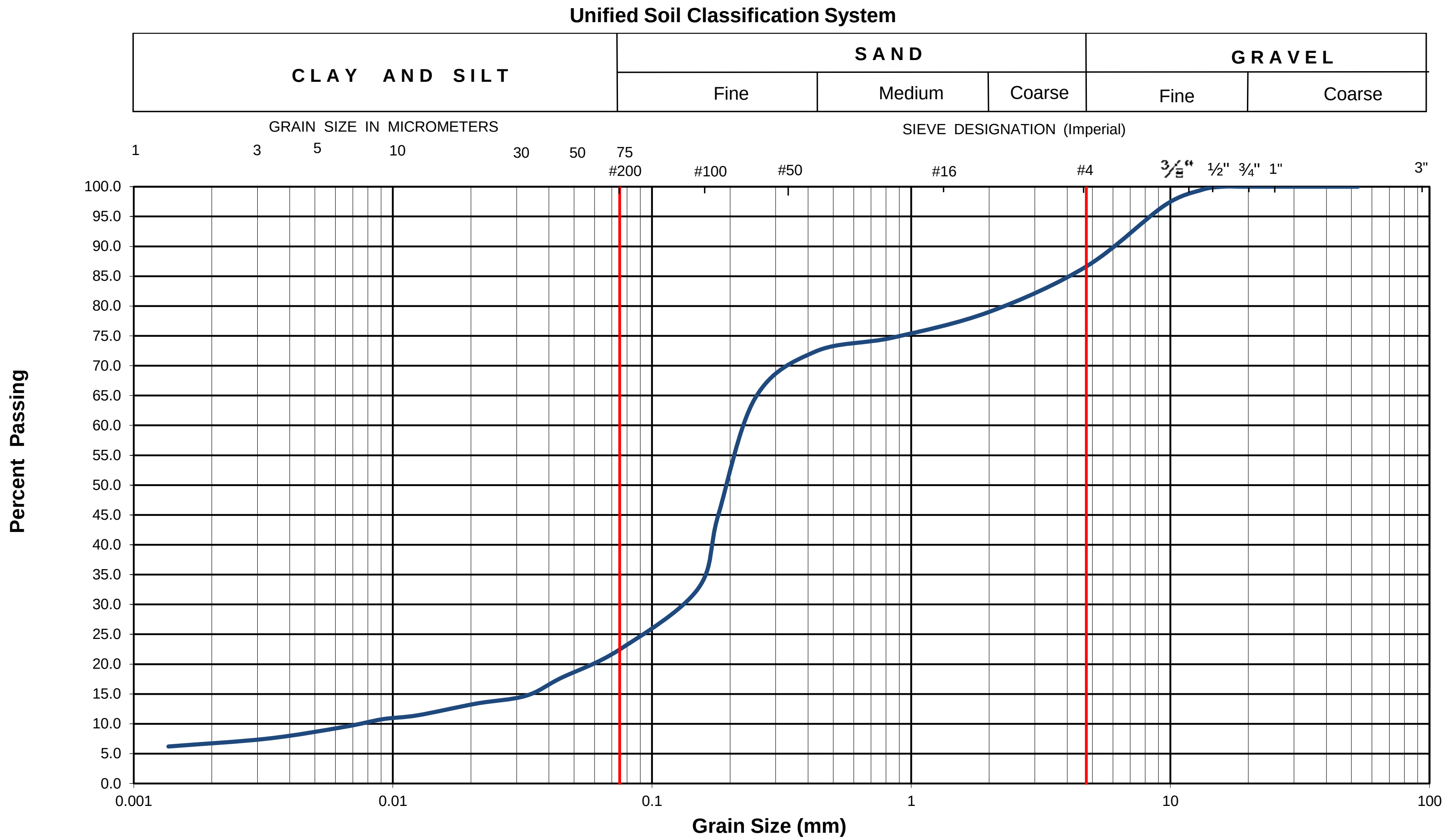
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1						
Date Sampled :	September 30, 2021	Borehole No:	BH2		Sample No.:	S10		Depth (m) :	9-10
Sample Description :		% Silt and Clay	23	% Sand	64	% Gravel	13	Figure :	26
Sample Description :	Silty Sand (SM)								

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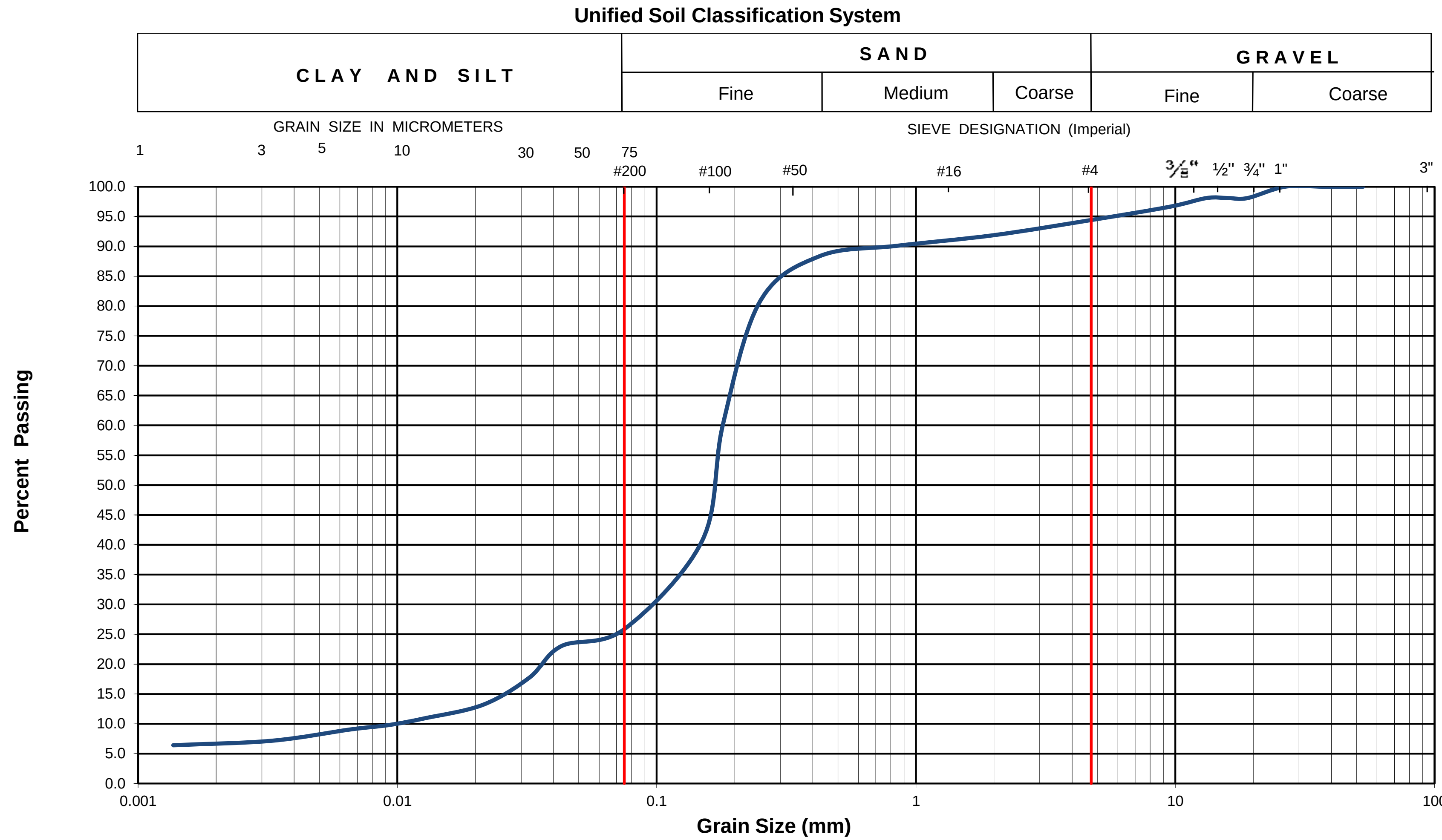
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1					
Date Sampled :	September 30, 2021	Borehole No:	BH3		Sample No.:	S3	Depth (m) :	2-3
Sample Description :		% Silt and Clay	26	% Sand	68	% Gravel 6	Figure :	27
Sample Description :	Silty Sand (SM)							

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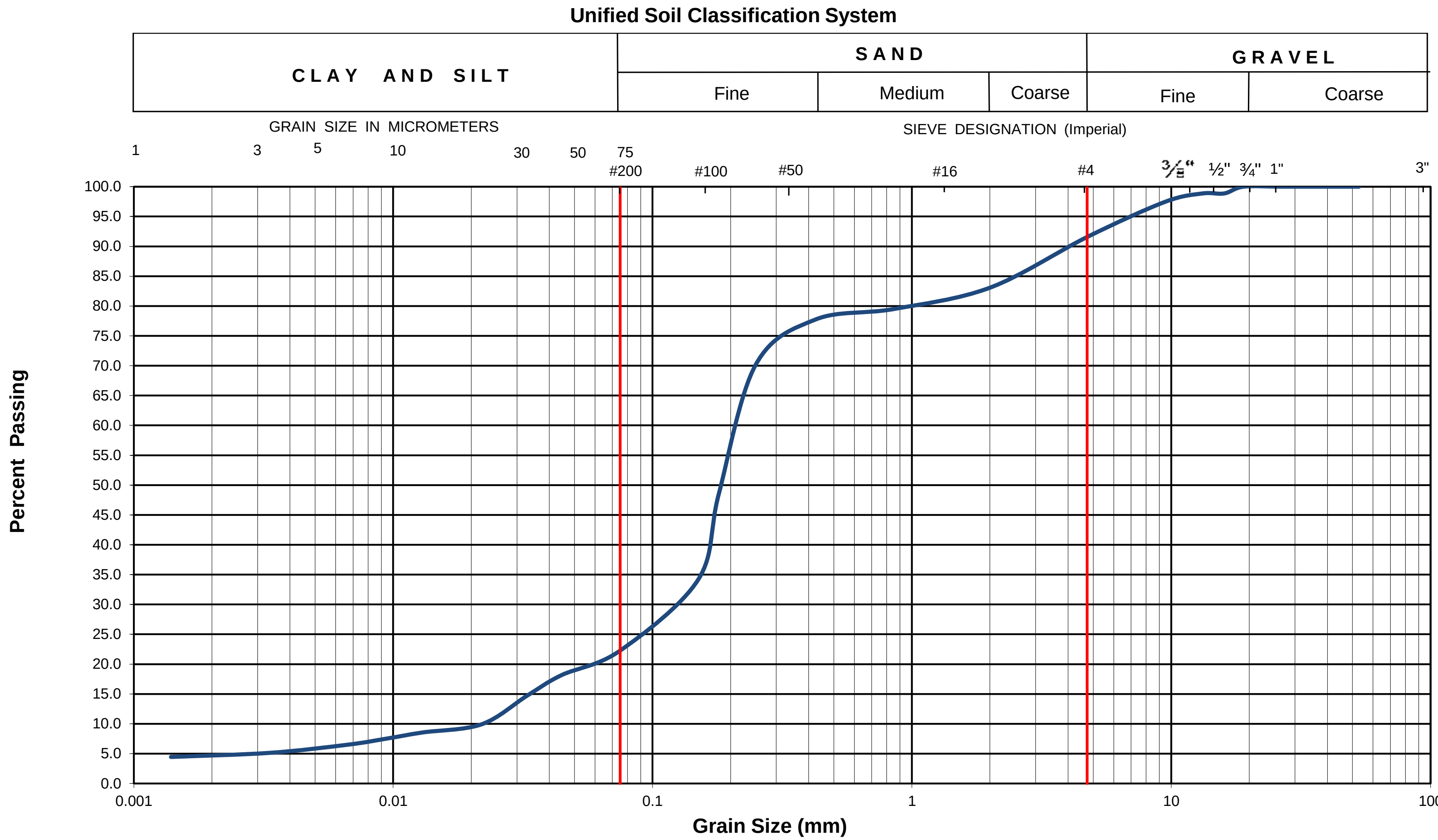
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**						
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 1**						
Date Sampled :	**September 30, 2021**	**Borehole No:**		**BH3**	**Sample No.:**	**S5**		**Depth (m) :**	**4-5**
Sample Description :		**% Silt and Clay**	**22**	**% Sand**	**70**	**% Gravel**	**8**	**Figure :**	**28**
Sample Description :		**Silty Sand (SM)**							

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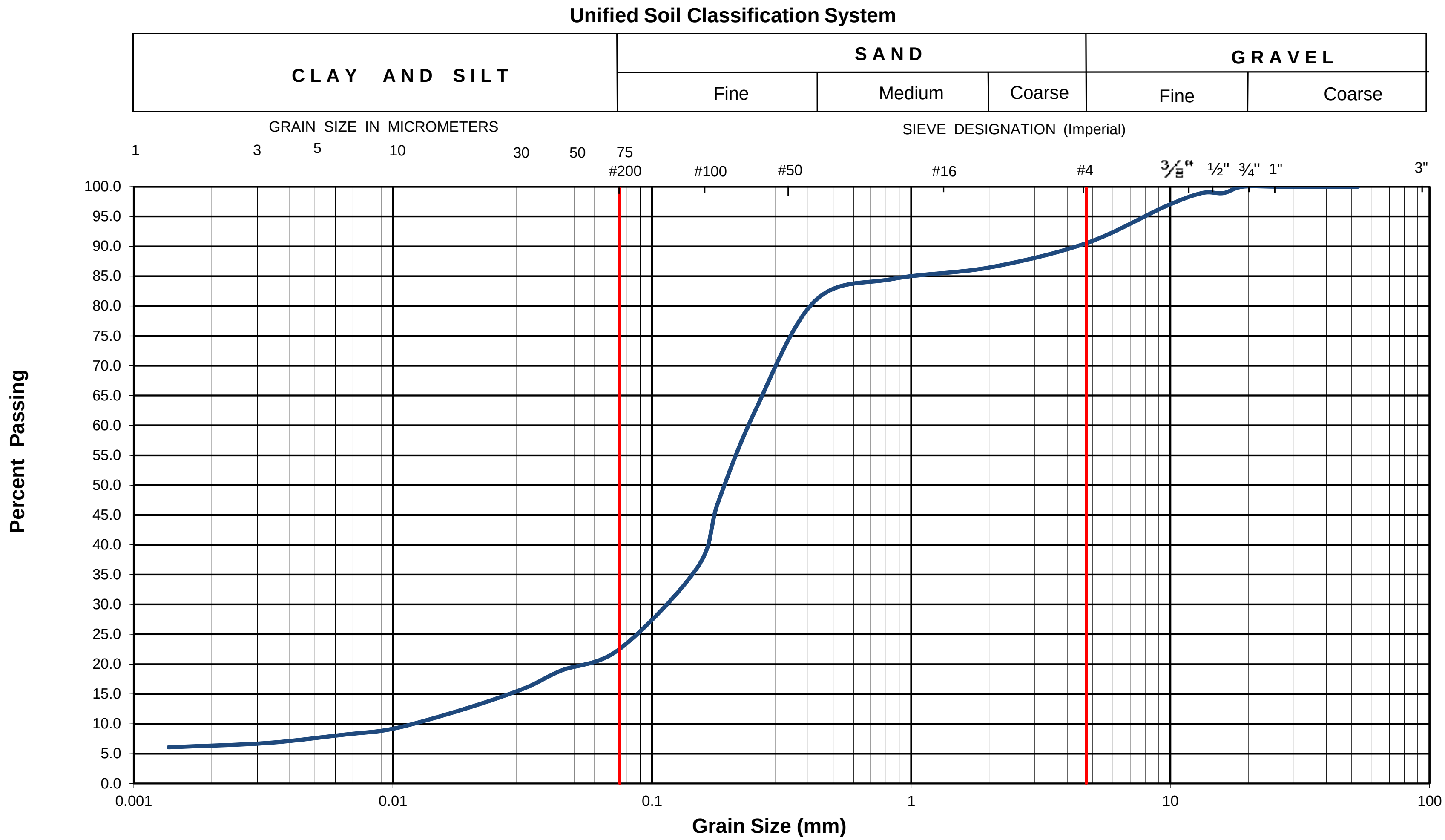
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1					
Date Sampled :	September 30, 2021	Borehole No:	BH6	Sample No.:	S9		Depth (m) :	8-9
Sample Description :		% Silt and Clay	23	% Sand	67	% Gravel 10	Figure :	29
Sample Description :	Silty Sand (SM)							

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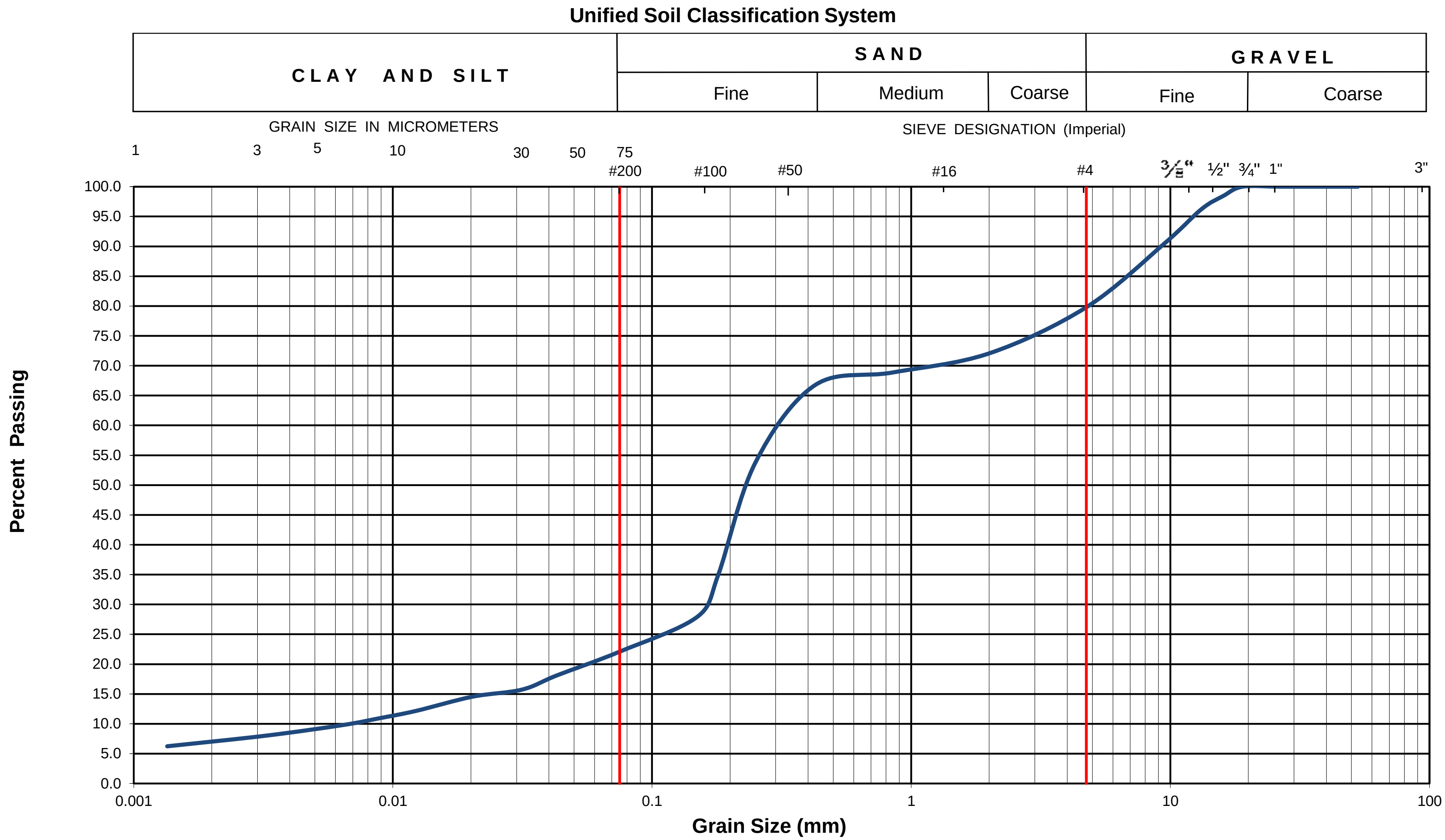
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment				
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 1				
Date Sampled :	September 30, 2021	Borehole No:	BH7	Sample No.:	S5	Depth (m) :	4-5
Sample Description :		% Silt and Clay	22	% Sand	58	% Gravel	20
Sample Description :	Silty Sand (SM)					Figure :	30

Log of Borehole BH-01

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 31

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SOIL DESCRIPTION	Geodetic m	Depth (m)	Combustible Vapour Reading (ppm)	Natural Moisture Content %	SAMPLES	Natural Unit Wt. kN/m³
		14.1	0				
	TOPSOIL ~50mm	14.1					
	SAND AND GRAVEL (GM) With small boulders and cobbles, reddish brown, moist to wet			0	✕	Grab	1-1
	SILTY SAND (SM) Trace gravel, reddish brown, moist	13.1	1	0	✕	Grab	1-2
	CLAYEY SILTY SAND (SM-SC) Trace to some gravel, cohesive, reddish brown, wet to moist	12.1	2	0	✕	Grab	1-3
			3	0	✕	Grab	1-4
			4	0	✕	Grab	1-5
	occassional boulders around 5 m to 6 m depth		5	0	✕	Grab	1-6
	SAND AND GRAVEL (GM) Trace silt, reddish brown, moist to very moist, occasional cobbles/boulders	8.1	6	0	✕	Grab	1-7
			7	0	✕	Grab	1-8
			8	0	✕	Grab	1-9
			9	0	✕	Grab	1-10
	Borehole Terminated at 10 m depth Due to cave-in	4.1	10				

Standard Penetration Test N Value: 20, 40, 60, 80
Shear Strength (kPa): 50, 100, 150, 200
Combustible Vapour Reading (ppm): 250, 500, 750
Natural Moisture Content % / Atterberg Limits (% Dry Weight): 20, 40, 60

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-02

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 32

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	☒	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SOIL DESCRIPTION	Geodetic m	Depth (m)	Samples	Natural Unit Wt. kN/m³
		16.4	0		
	TOPSOIL ~50mm	16.4			
	SAND AND GRAVEL (GM) With small boulders and cobbles, brown, moist to very moist			2-1, 2-2	
	SILTY SAND (SM) Some gravel, reddish brown, wet	14.4	2	2-3, 2-4, 2-5	
	SAND AND GRAVEL (GM) Reddish brown, moist, bouldery below 5 m depth	11.9		2-6, 2-7, 2-8	
	SILTY SAND (SM) Some gravel, occasional boulders, reddish brown, moist	8.4	8	2-9, 2-10	
	Borehole Terminated at 10 m depth	6.4	10		

Standard Penetration Test N Value: 20, 40, 60, 80
Shear Strength: 50, 100, 150, 200 kPa

Combustible Vapour Reading (ppm): 250, 500, 750
Natural Moisture Content %
Atterberg Limits (% Dry Weight): 20, 40, 60

Combustible vapour readings: 0 at all samples (2-1 to 2-10).

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-03

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 33

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◫	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Geodetic (m)	Depth (m)	Soil Description	Samples	Combustible Vapour Reading (ppm)
27 / 27.0	0	**TOPSOIL** ~50mm		
		SAND AND GRAVEL (GM) With cobbles and small boulders, brown, moist	3-1, 3-2	0, 0
25.0	2	**SILTY SAND (SM)** Some cobbles and boulders, reddish brown, moist to wet, ice lenses and crystals	3-3, 3-4	0, 0
23.0	4	**CLAYEY SILTY SAND (SM-SC)** Trace gravel, reddish brown, wet	3-5	0
22.0	5	**SILTY SAND (SM)** Some gravel, reddish brown to brown, moist	3-6, 3-7, 3-8	0, 0, 0
19.0	8	**SAND AND GRAVEL (GM)** Bouldery, grey, moist	3-9, 3-10	0, 0
17.0	10	**Borehole Terminated at 10 m depth**		

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength (kPa) 50, 100, 150, 200; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60; Natural Unit Wt. kN/m^3

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	3.0	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

LOG OF BOREHOLE FRN-21016638 ARCTIC BAY SITE 3 BH LOGS.GPJ TROW OTTAWA.GDT 1/27/22

Log of Borehole BH-04

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 34

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	⊢–○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Soil Description	Geodetic (m)	Depth (m)	Sample	Natural Unit Wt. kN/m^3
	26.1	0		
TOPSOIL ~50mm	26.1			
SAND AND GRAVEL (GM) With cobbles and small boulders, brown, moist		0.35	4-1	
		1.15	4-2	
reddish brown, bouldery at 2 m		2.15	4-3	
grey, ice lenses/crystals below 3 m depth		3.15	4-4	
CLAYEY SILTY SAND (SM-SC) Trace to some gravel, occasional boulders, reddish brown to grey, wet	22.1	4.15	4-5	
		5.15	4-6	
		6.15	4-7	
SAND AND GRAVEL (GM) Some boulders, grey, moist	19.1	7.15	4-8	
Silty sand layer from 8 m to 9 m depth		8.15	4-9	
		9.15	4-10	
Borehole Terminated at 10 m depth	16.1	10		

Chart columns: Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200); Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %, Atterberg Limits (% Dry Weight) (20, 40, 60). Combustible vapour readings of 0 recorded at each sample.

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-05

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 35

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	☒	Combustible Vapour Reading	□
Auger Sample		Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├──○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Soil Description	Geodetic (m)	Depth (m)	Combustible Vapour Reading (ppm)	Samples	Natural Unit Wt. kN/m³
	18.8	0			
TOPSOIL ~50mm	18.8				
SAND AND GRAVEL (GM) With cobbles and small boulders, trace to some silty clay, reddish brown, wet			0	5-1	
CLAYEY SILTY SAND (SM-SC) Some gravel, reddish brown, wet	17.8	1	0	5-2	
		2	0	5-3	
ice lenses and/or crystals below 2 m depth		3	0	5-4	
SAND AND GRAVEL (GM) Bouldery, reddish brown, moist	14.8	4	0	5-5	
		5	0	5-6	
SILTY SAND (SM) Some gravel, trace clay, reddish brown, moist	12.8	6	0	5-7	
		7	0	5-8	
GRAVELLY SAND (SP) Silty, some boulders, reddish brown, moist	10.8	8	0	5-9	
		9	0	5-10	
Borehole Terminated at 10 m depth	8.8	10			

Chart axes: Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200); Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %, Atterberg Limits (% Dry Weight) (20, 40, 60).

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2. Multi-bead thermistor string installed to 10.0 m depth upon completion
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	1.5	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-1

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 36

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	⊢○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			27.2	0				
		TOPSOIL ~50mm	27.2					
		SAND AND GRAVEL (GM) With silt, boulders and cobbles, less than 5% oversize materials, reddish brown, moist, not frozen. Large boulders at 1.7 m depth.		1		0 ✕		TP-1
			25.5					
		Backhoe Shovel Refusal at 1.7 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-2

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 37

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	⊢○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			19.3	0				
		TOPSOIL ~50mm	19.3					
		SAND AND GRAVEL (GM) With silt, boulders and cobbles, less than 5% oversize materials, reddish brown, moist, not frozen. Large boulders at 1.4 m depth.		1		□ 0, ✕		TP-2
			17.9					
		Backhoe Shovel Refusal at 1.4 m depth						

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

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Method of Test For Particle Size Analysis of Soil
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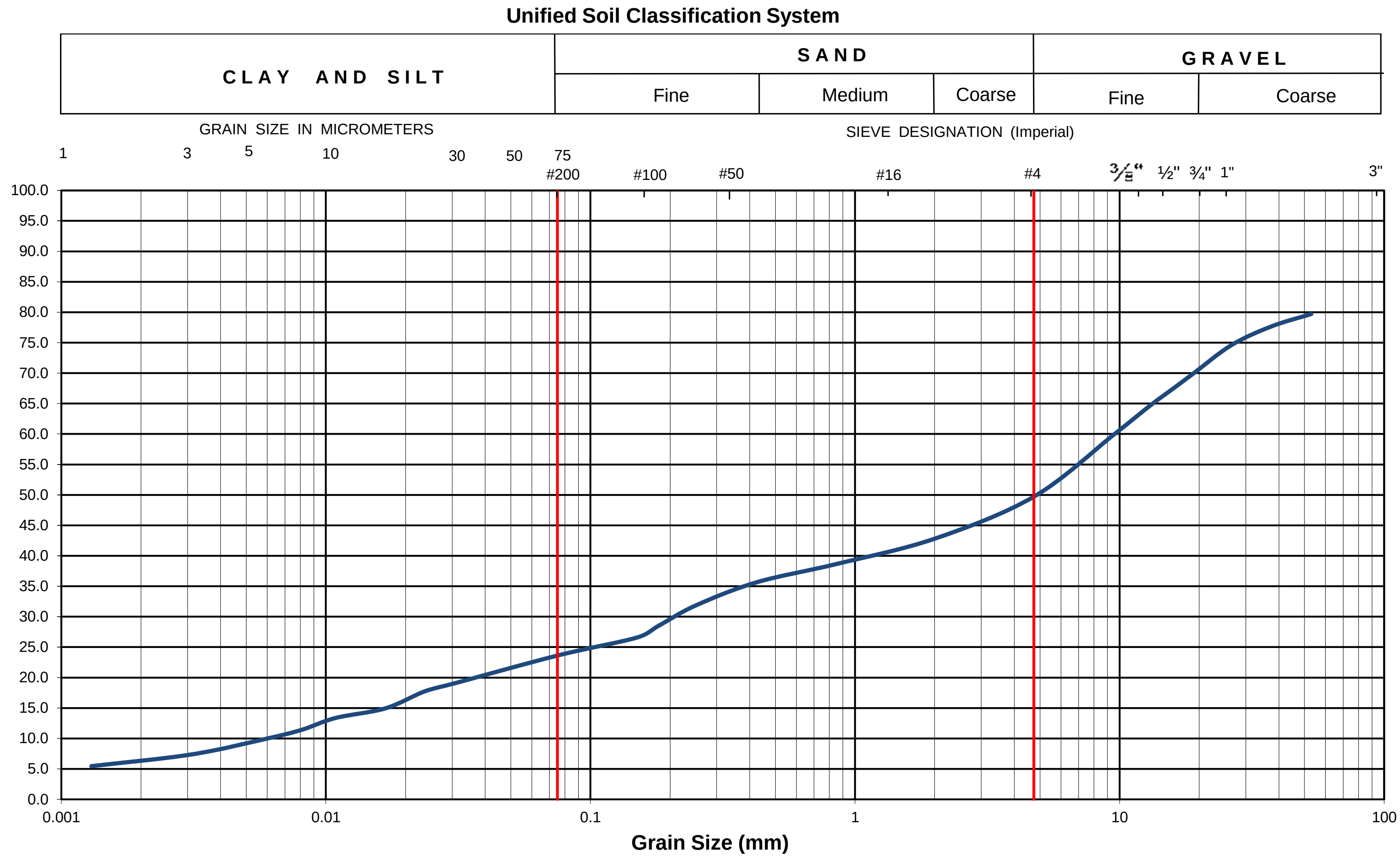

EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 3						
Date Sampled :	October 2, 2021	Borehole No:		TP2	Sample No.:	n/a		Depth (m) :	0-1.4
Sample Description :		% Silt and Clay	24	% Sand	26	% Gravel	50	Figure :	38
Sample Description :	Silty Sandy Gravel (GM)								

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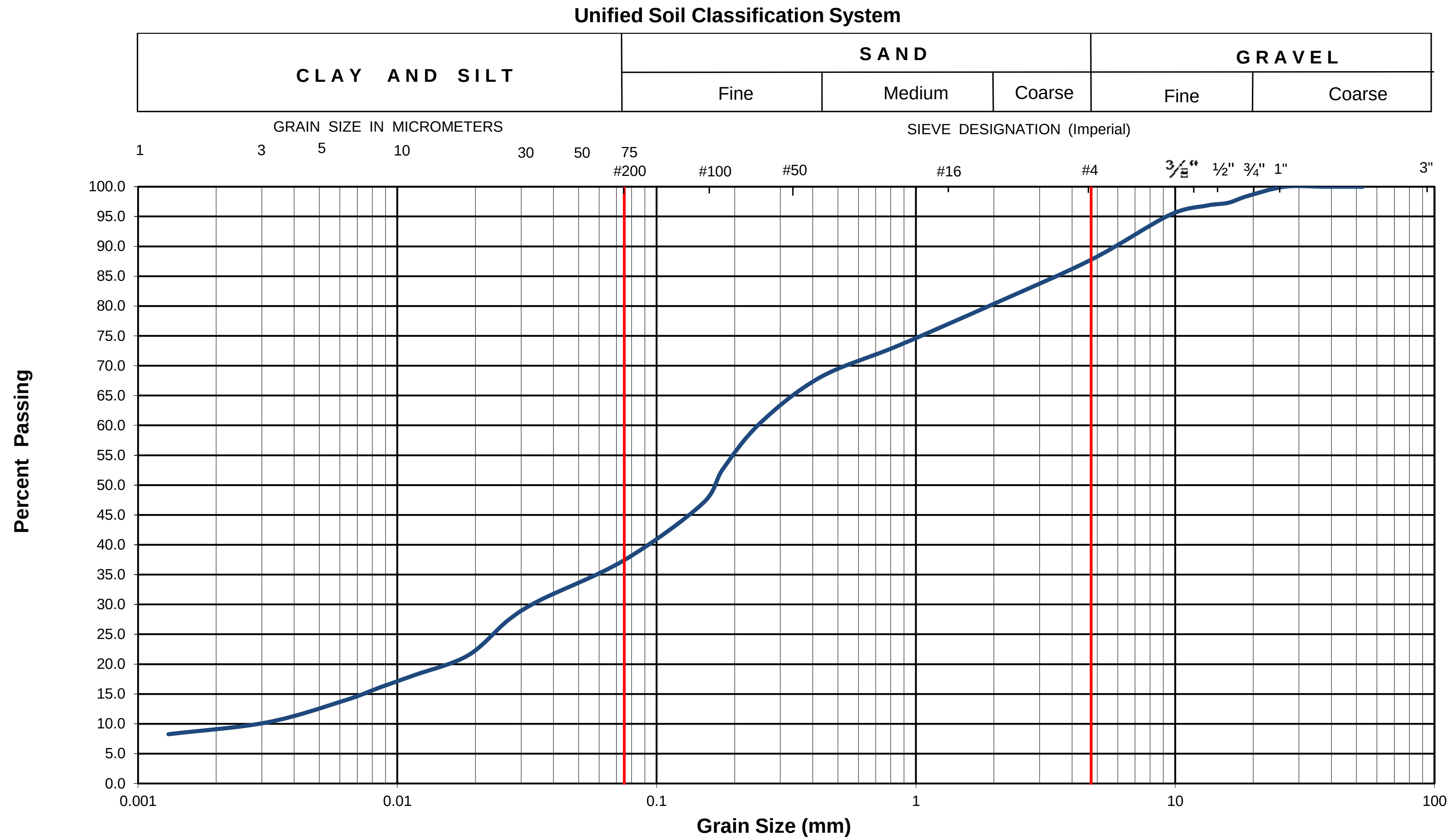
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**					
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH1**	**Sample No.:**	**S2**		**Depth (m) :**	**1-2**
Sample Description :		**% Silt and Clay**	**37**	**% Sand**	**51**	**% Gravel** **12**	**Figure :**	**39**
Sample Description :		**Silty Sand (SM)**						

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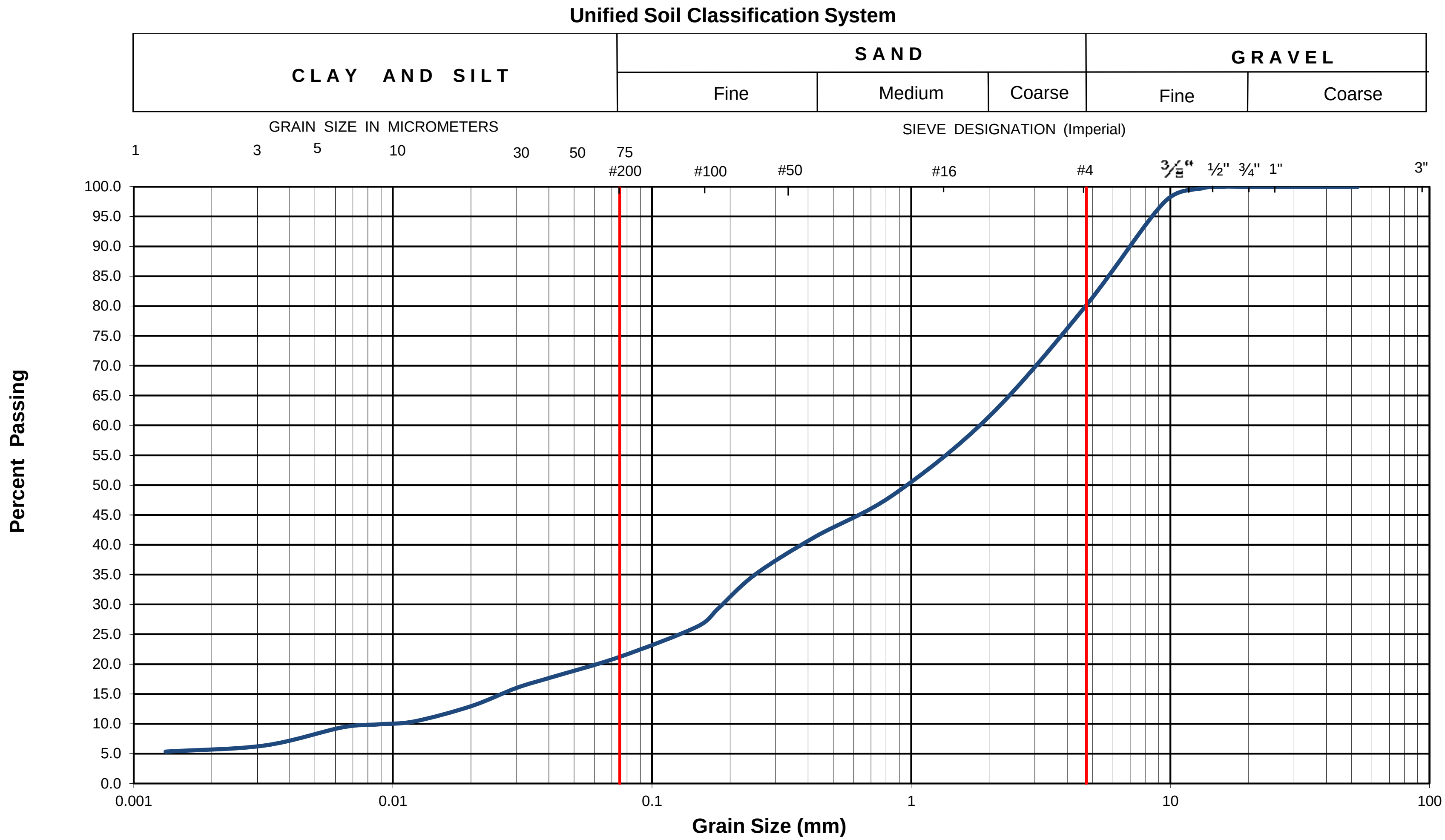
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 3					
Date Sampled :	October 1, 2021	Borehole No:	BH2		Sample No.:	S3	Depth (m) :	2-3
Sample Description :		% Silt and Clay	21	% Sand	59	% Gravel 20	Figure :	40
Sample Description :		Silty Sand with Gravel (SM)						

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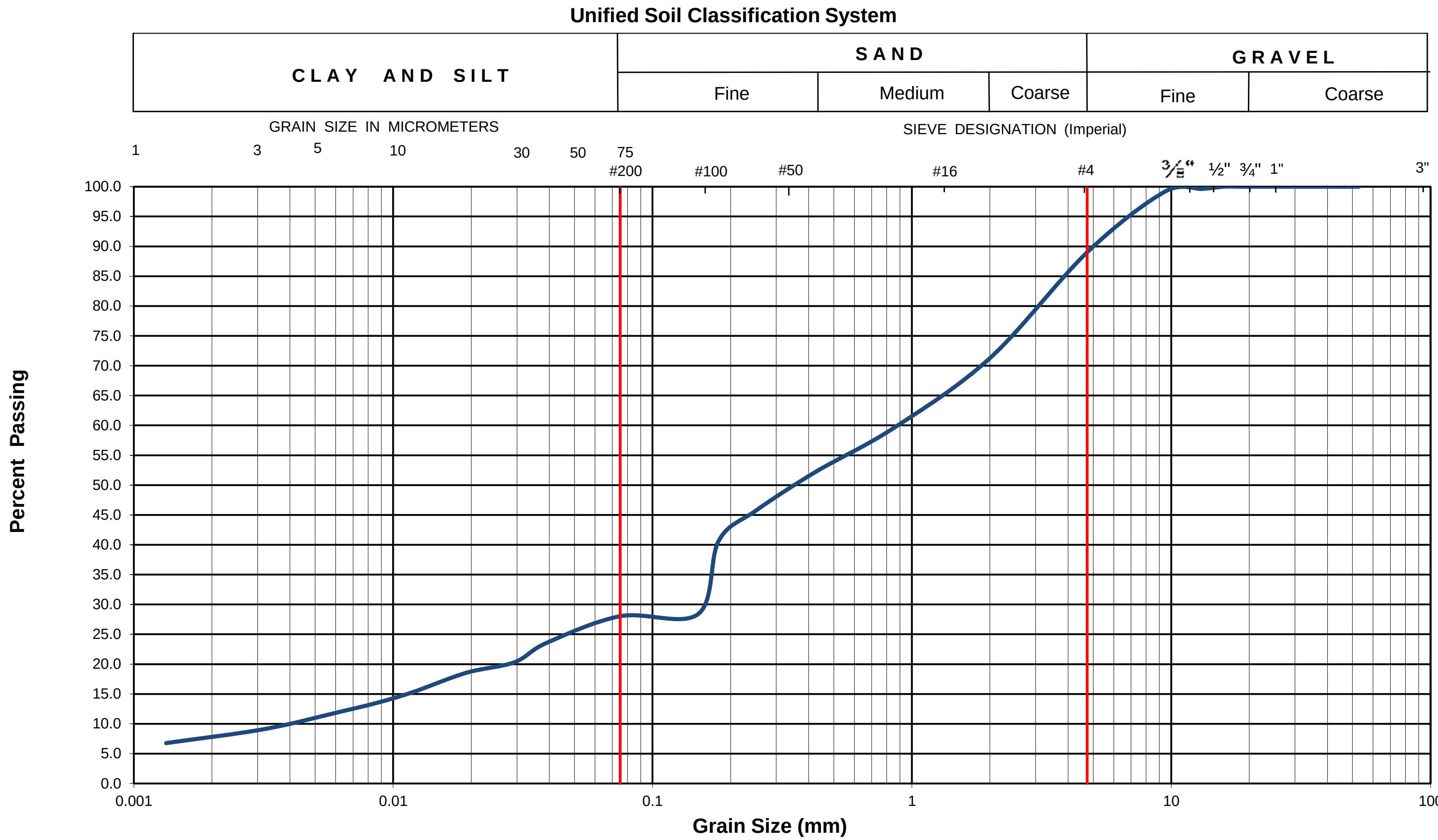
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 3					
Date Sampled :	October 1, 2021	Borehole No:	BH2	Sample No.:	S9		Depth (m) :	8-9
Sample Description :		% Silt and Clay	28	% Sand	61	% Gravel 11	Figure :	41
Sample Description :		Silty Sand (SM)						

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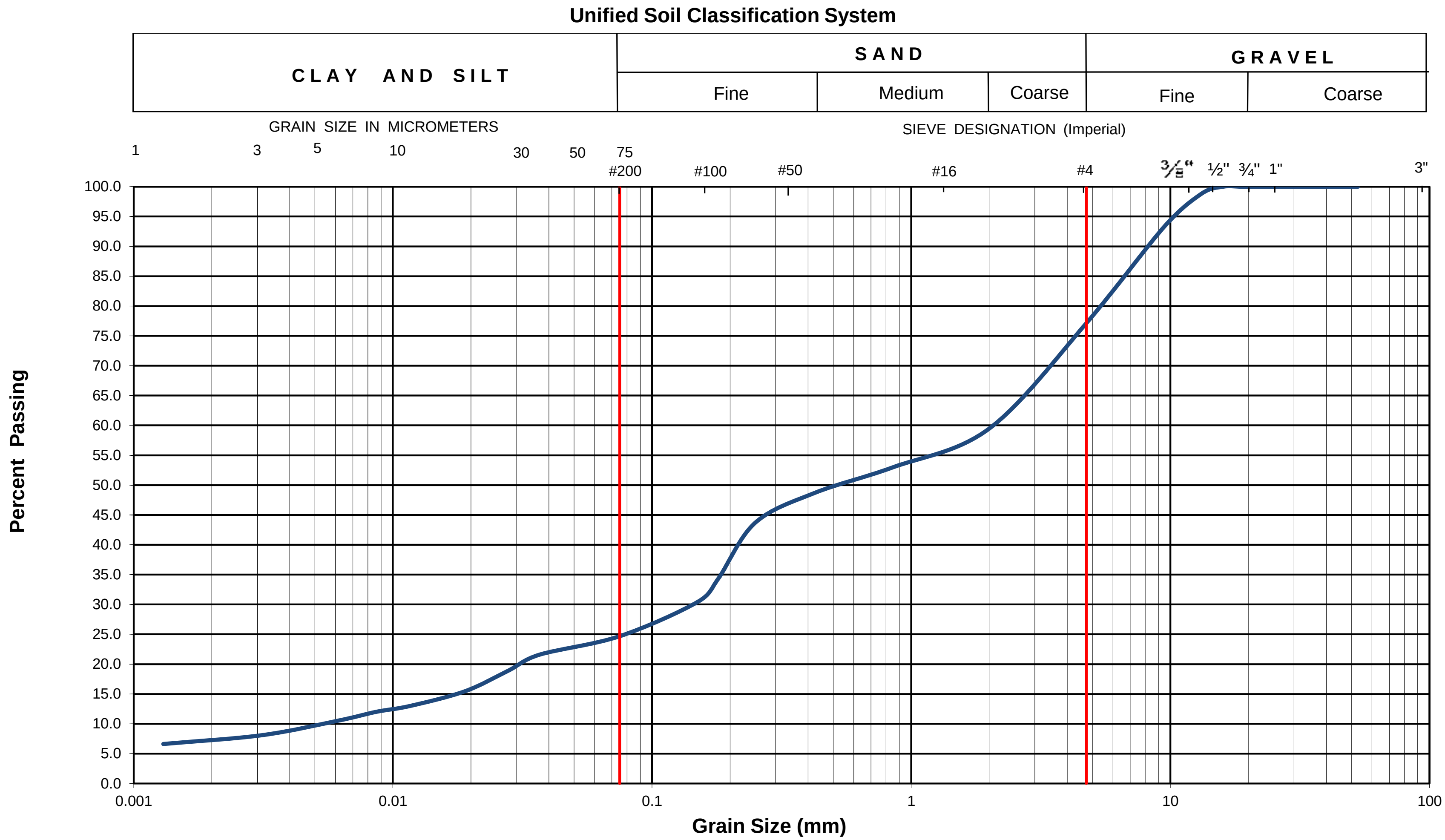
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 3						
Date Sampled :	October 1, 2021	Borehole No:	BH3	Sample No.:	S3			Depth (m) :	2-3
Sample Description :		% Silt and Clay	25	% Sand	52	% Gravel	23	Figure :	42
Sample Description :	Silty Sand with Gravel (SM)								

exp.

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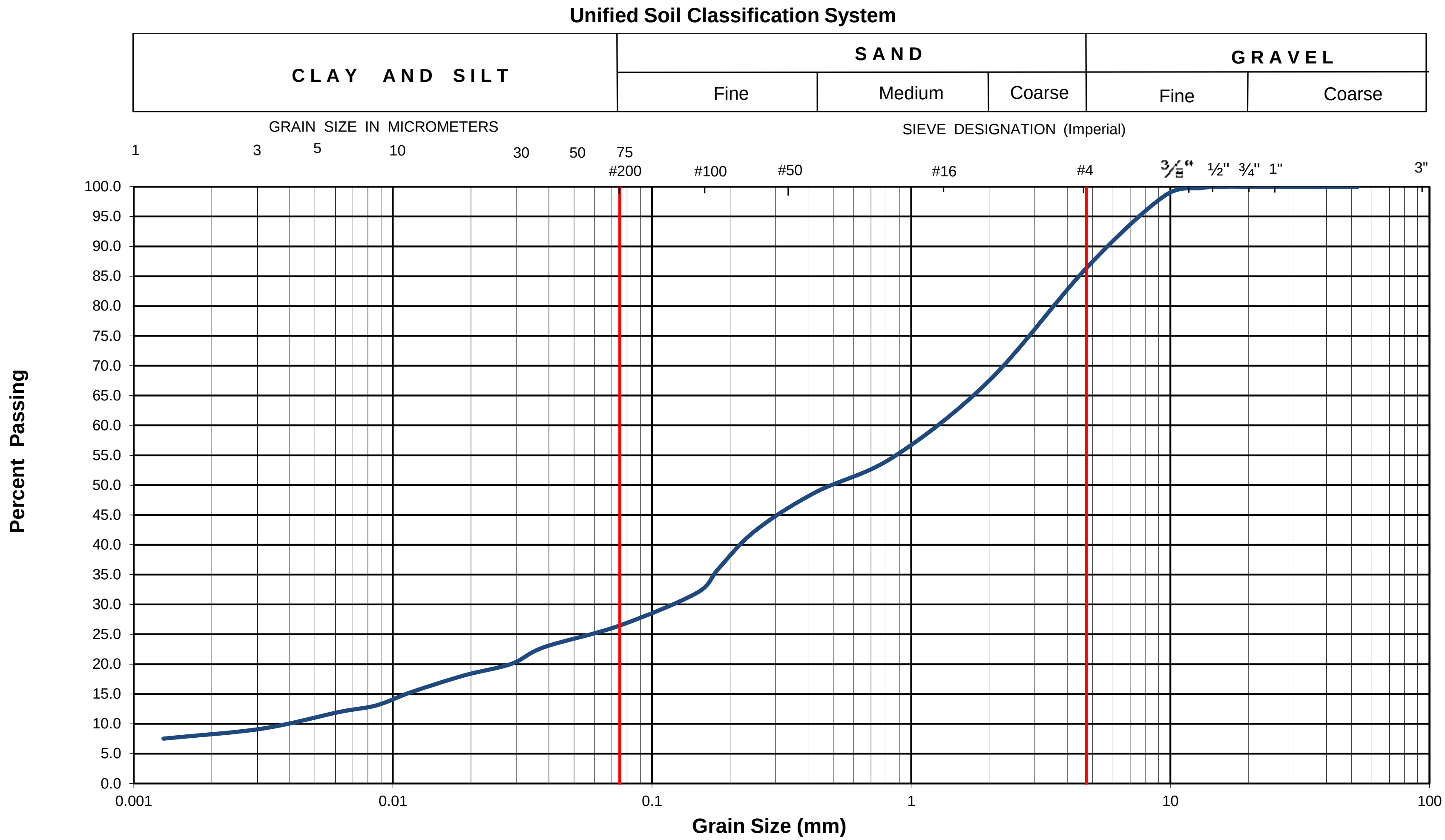
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**					
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH3**	**Sample No.:**	**S8**		**Depth (m) :**	**7-8**
Sample Description :		**% Silt and Clay**	**27**	**% Sand**	**59**	**% Gravel** **14**	**Figure :**	**43**
Sample Description :	**Silty Sand (SM)**							

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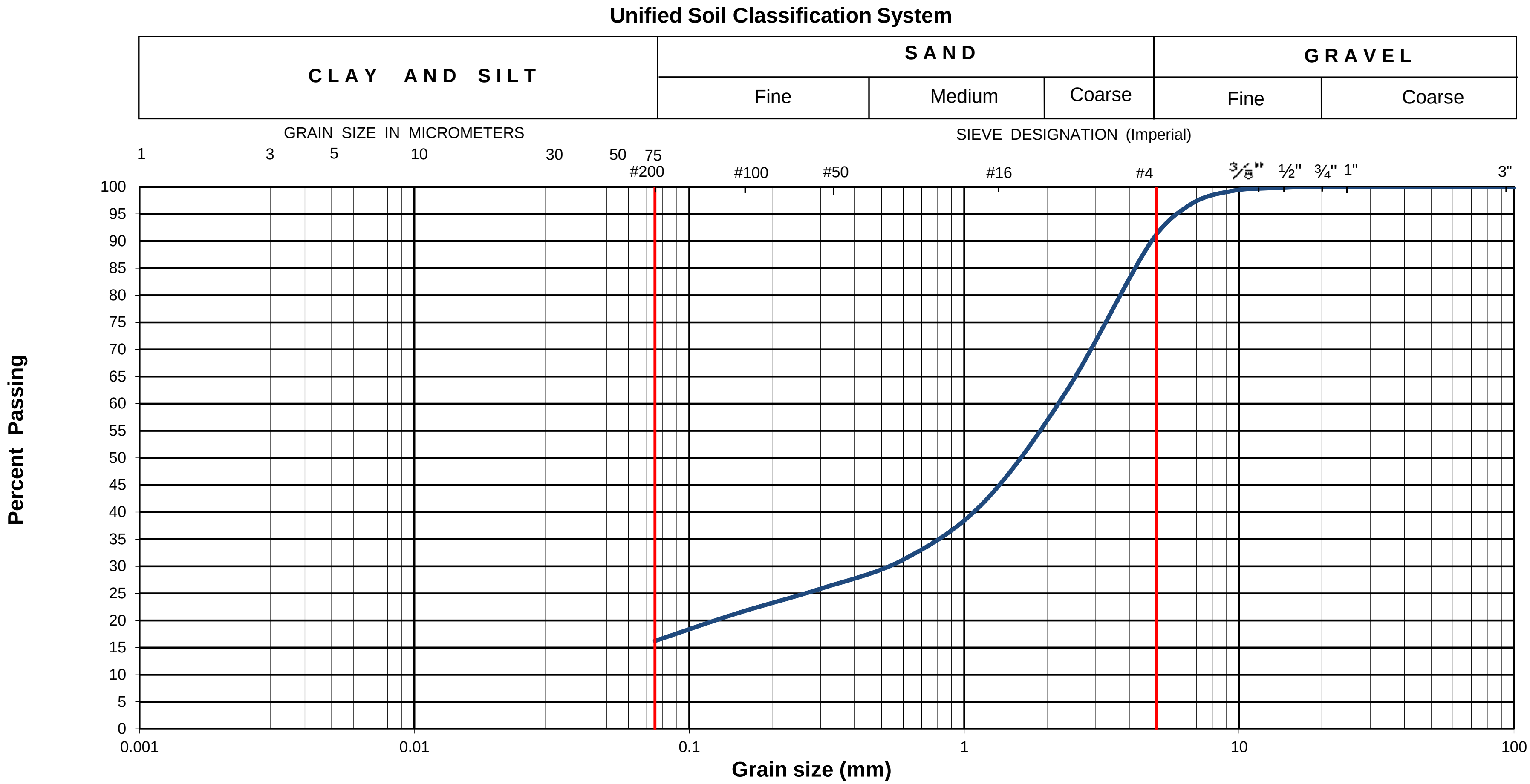
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**				
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH4**	**Sample:**	**S9**	**Depth (m) :**	**8-9m**
Sample Composition :		**Gravel (%)**	**10**	**Sand (%)**	**74**	**Silt & Clay (%)**	**16**
Sample Description :	**Silty Sand (SM)**					**Figure :**	**44**

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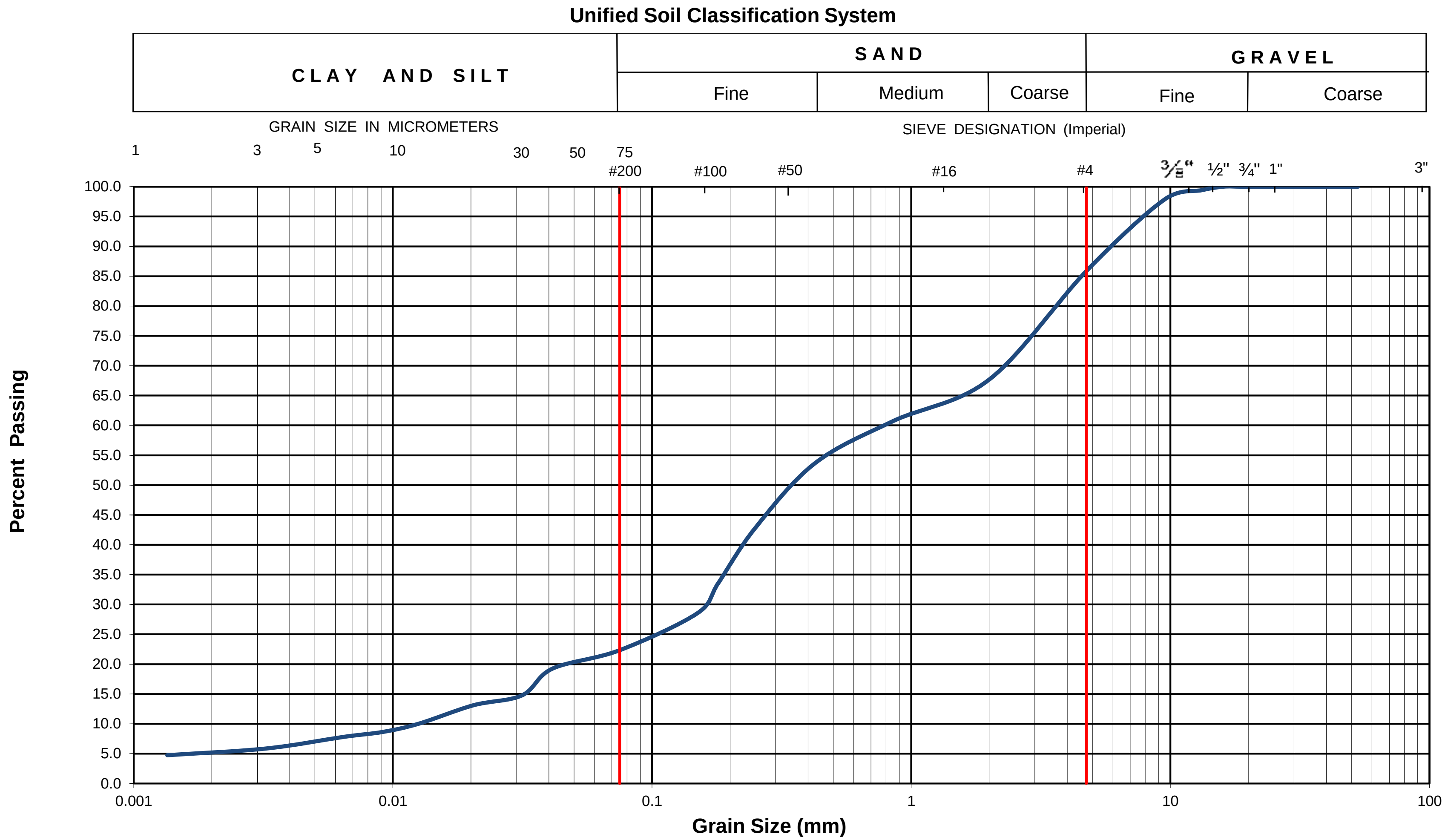
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 3						
Date Sampled :	October 1, 2021	Borehole No:		BH5	Sample No.:	S7		Depth (m) :	6-7
Sample Description :		% Silt and Clay	22	% Sand	64	% Gravel	14	Figure :	45
Sample Description :	Silty Sand (SM)								

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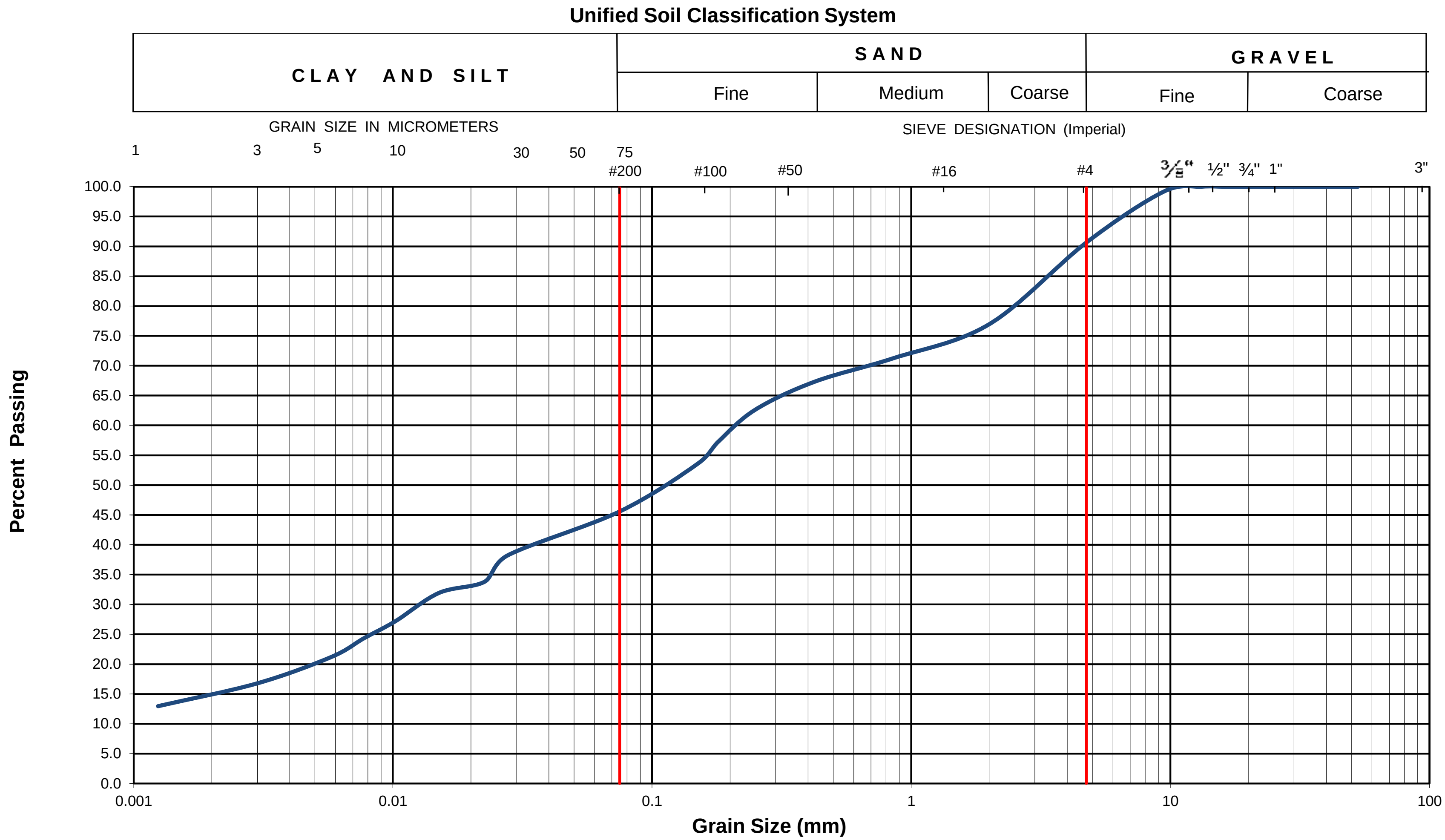
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**					
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH1**	**Sample No.:**	**S4**		**Depth (m) :**	**3-4**
Sample Description :		**% Silt and Clay**	**46**	**% Sand**	**45**	**% Gravel**	**9**	**Figure : 46**
Sample Description :	**Low to Medium Plasticity Clayey Silty Sand (SM-SC)**							

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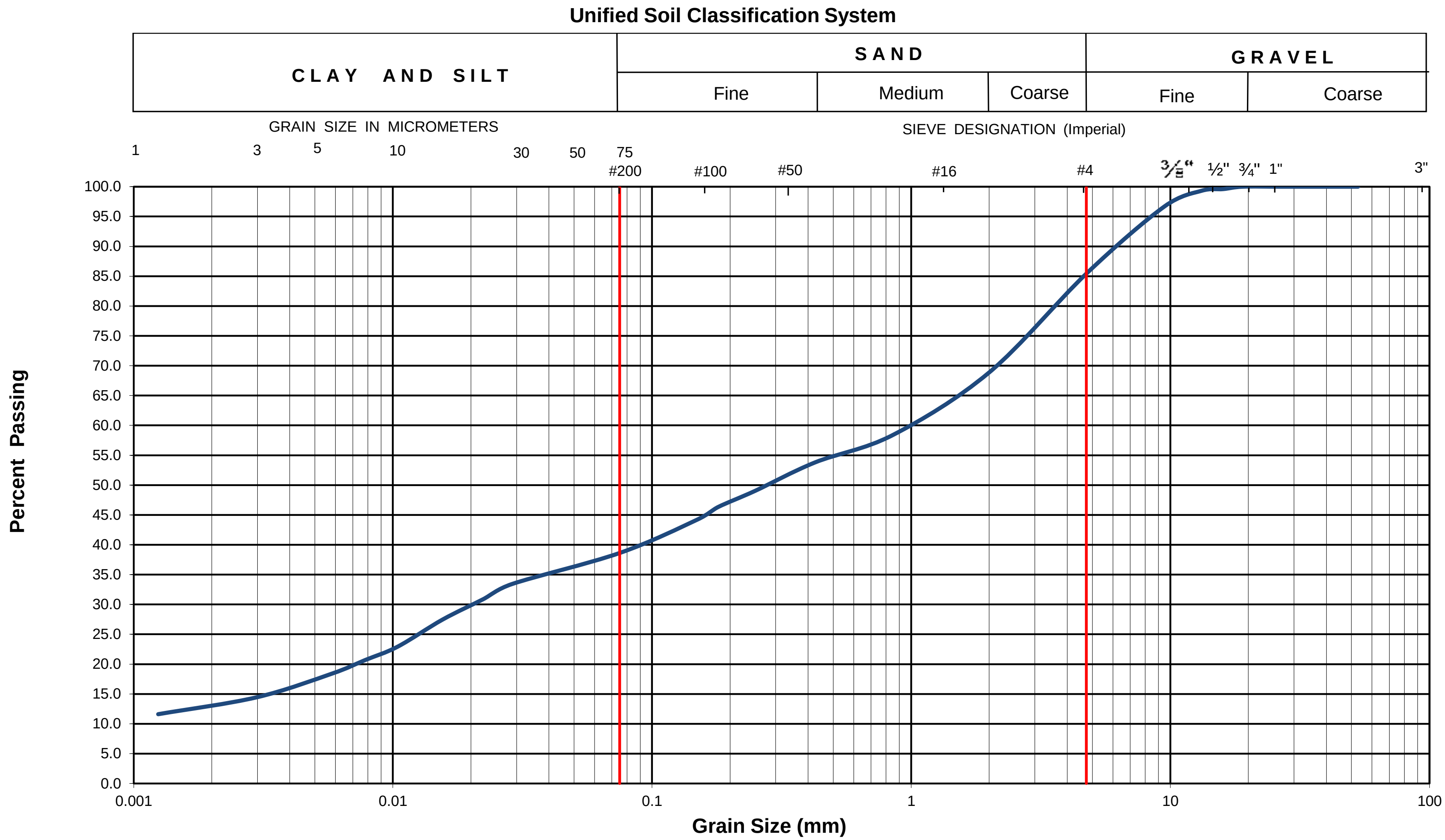
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**					
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH1**	**Sample No.:**	**S6**		**Depth (m) :**	**5-6**
Sample Description :		**% Silt and Clay**	**39**	**% Sand**	**46**	**% Gravel**	**15**	**Figure : 47**
Sample Description :	**Clayey Silty Sand (SM-SC)**							

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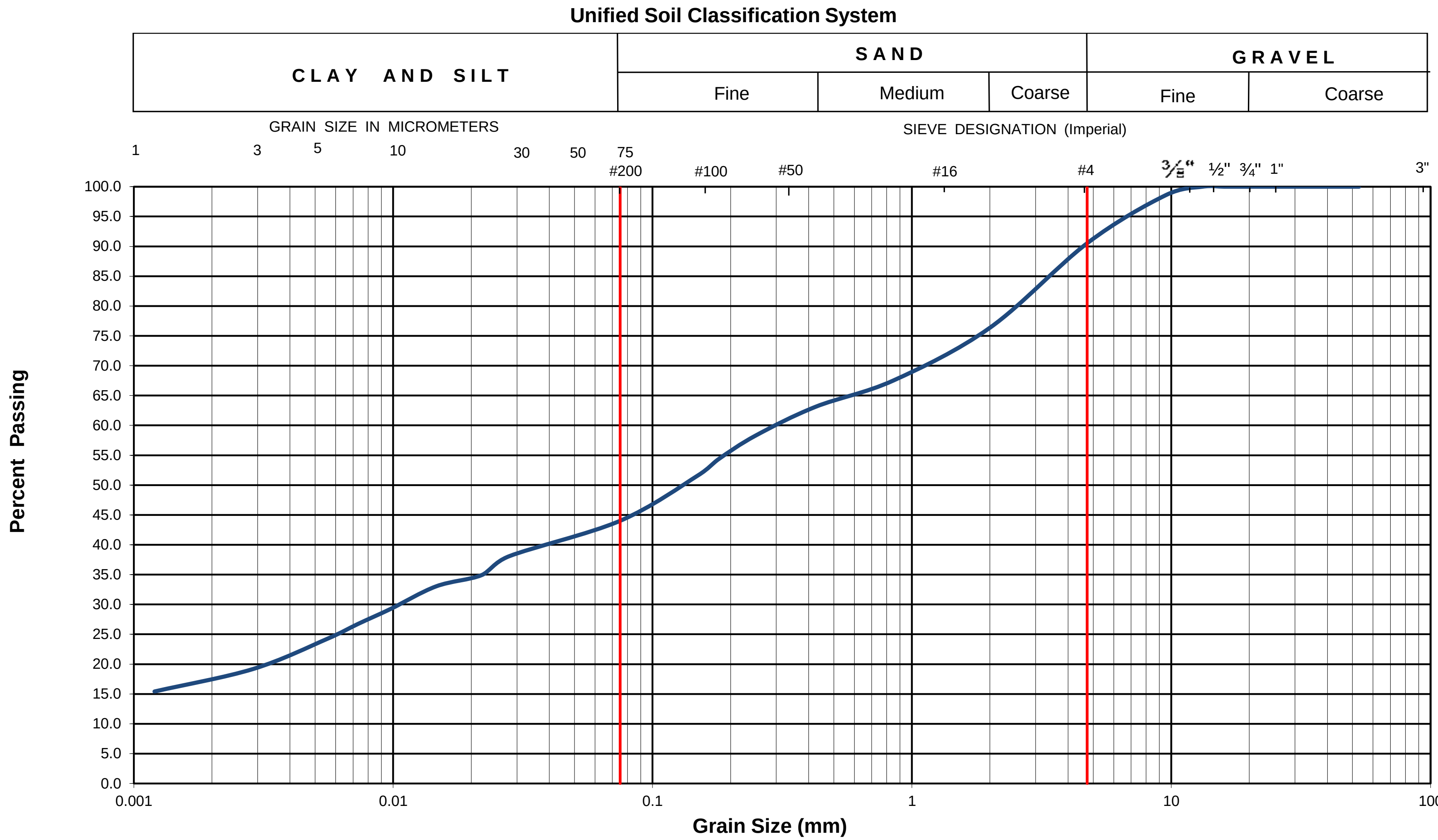
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**				
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH3**	**Sample No.:**	**S5**	**Depth (m) :**	**4-5**
Sample Description :		**% Silt and Clay**	**44**	**% Sand**	**47**	**% Gravel**	**9**
Sample Description :		**Clayey Silty Sand (SM-SC)**				**Figure :**	**48**

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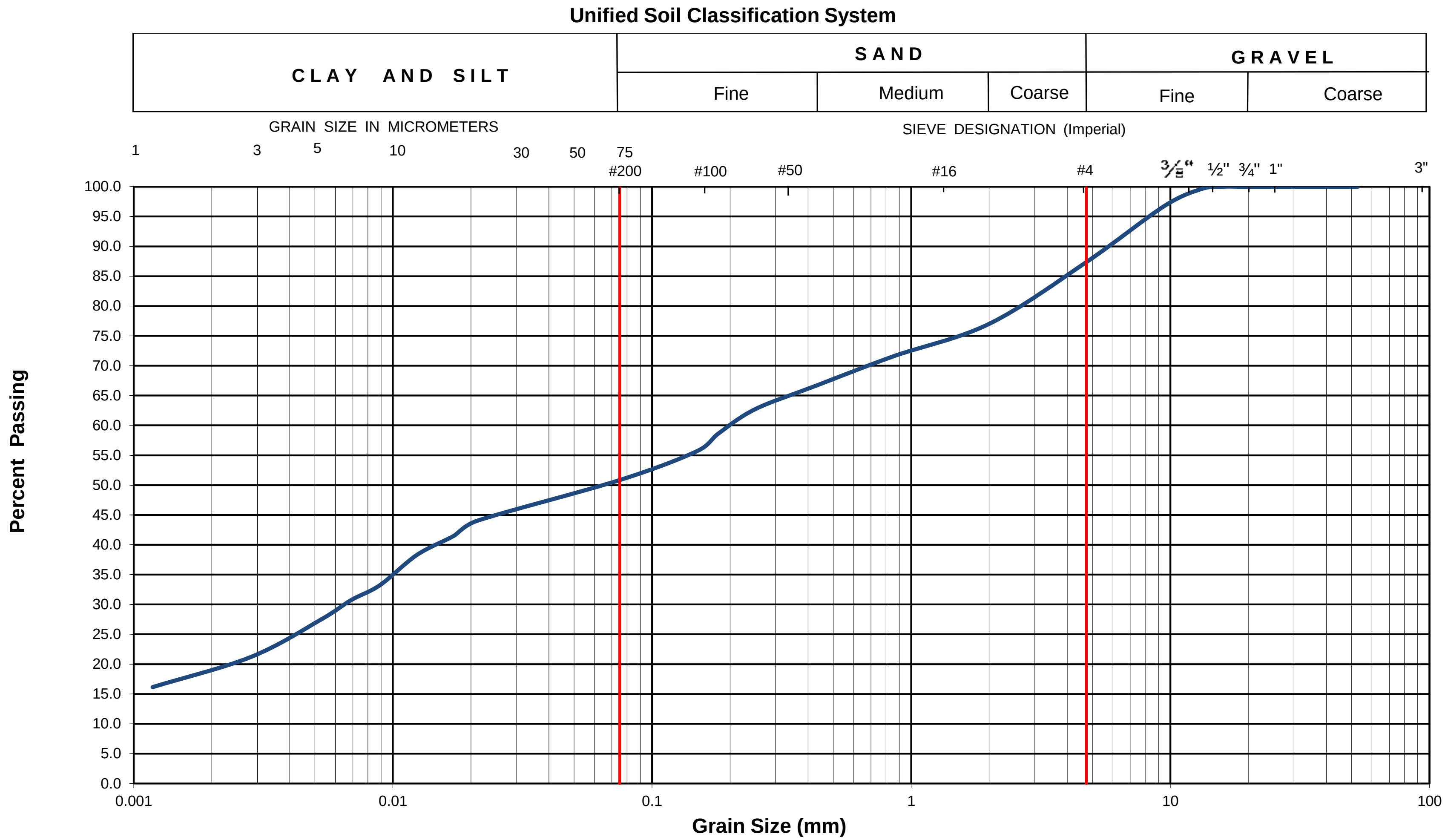
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.: OTT-21016638-A0		Project Name : Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client : Government of Nunavut		Project Location : Arctic Bay, Nunavut - Site 3					
Date Sampled : October 1, 2021		Borehole No: BH4		Sample No.: S5		Depth (m) : 4-5	
Sample Description :		% Silt and Clay	51	% Sand 36	% Gravel 13	Figure : 49	
Sample Description :	Low to Medium Plasticity Clayey Silty Sand (SM-SC)						

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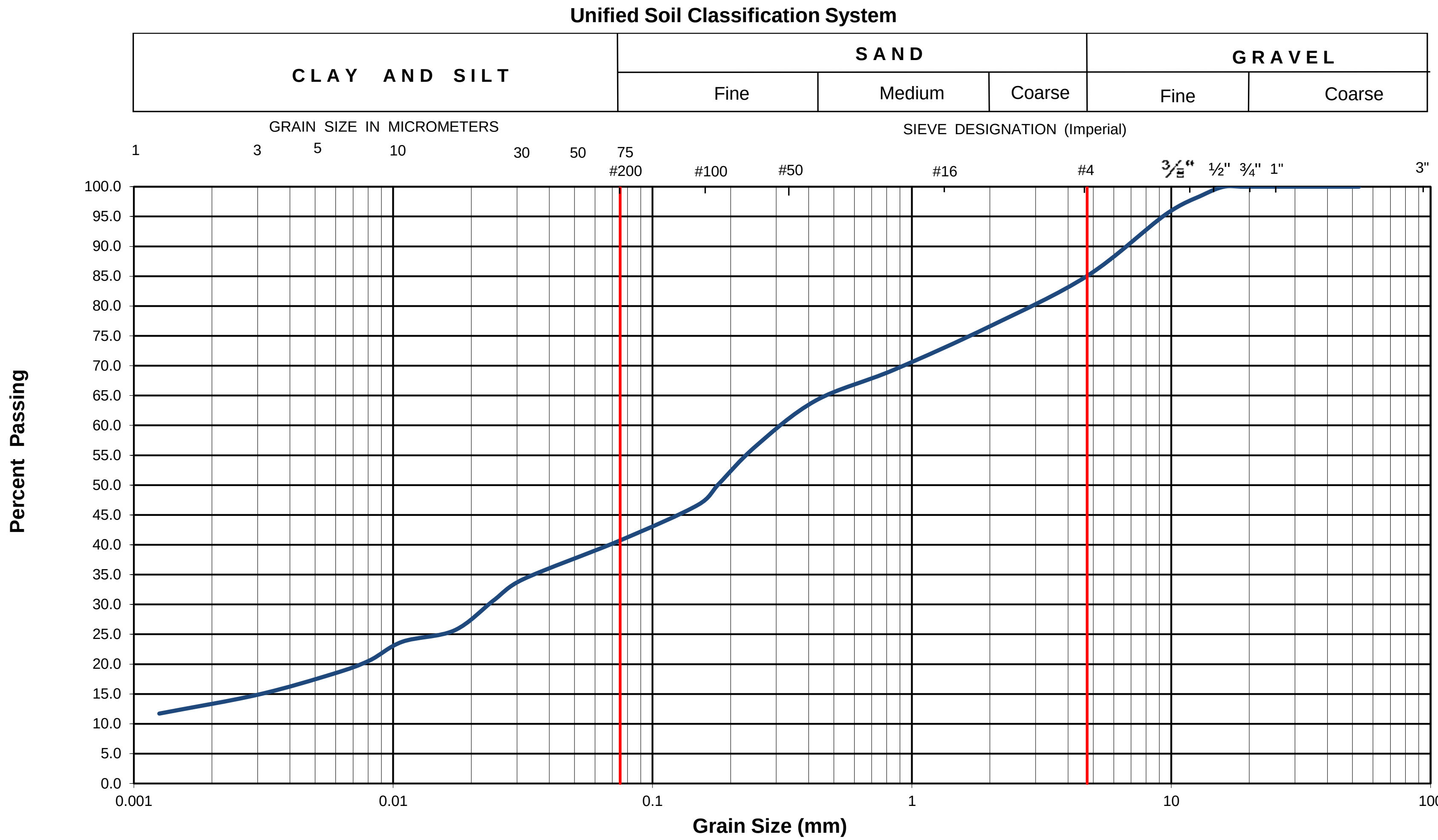
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 3**				
Date Sampled :	**October 1, 2021**	**Borehole No:**	**BH5**	**Sample No.:**	**S2**	**Depth (m) :**	**1-2**
Sample Description :		**% Silt and Clay** 41	**% Sand**	44	**% Gravel** 15	**Figure :**	**50**
Sample Description :		**Clayey Silty Sand (SM-SC)**					

Log of Borehole BH-01

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 51

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├──○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Soil Description	Geodetic m	Depth (m)	Combustible Vapour Reading (ppm)	Samples	Natural Unit Wt. kN/m³
	31.1	0			
TOPSOIL ~50mm	31.1				
FILL Silty sand with gravel, shaley, black, wet slumped from mountain face			1	Grab	1-1
SAND AND GRAVEL (GM) Silty, bouldery, dark grey, wet	30.1	1	1	Grab	1-2
		2	0	Grab	1-3
GRAVELLY SAND (SP) Bouldery, greyish brown to reddish brown, moist	28.1	3	0	Grab	1-4
		4	0	Grab	1-5
		5	0	Grab	1-6
Large white boulder at 6 m depth		6	0	Grab	1-7
SAND (SP) Trace gravel, black, moist	24.1	7	1	Grab	1-8
		8	1	Grab	1-9
		9	1	Grab	1-10
Borehole Terminated at 10 m depth	21.1	10			

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60.

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-02

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 52

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Samples	Combustible Vapour Reading (ppm)	Natural Unit Wt. kN/m³
			32.8	0			
		TOPSOIL ~50mm	32.8				
		FILL Silty sand with some gravel, shaley, black, wet slumped from mountain face			2-1	1	
		SILTY SAND (SM) Some gravel, white and grey boulders, reddish brown and dark grey, ice lenses and crystals, wet	31.8	1	2-2	0	
				2	2-3	0	
				3	2-4	0	
		GRAVELLY SAND (SP) Some silt, reddish brown, moist to wet	28.8	4	2-5	0	
				5	2-6	0	
				6	2-7	0	
				7	2-8	0	
				8	2-9	1	
		SAND (SP) Trace to some gravel, black, moist	24.3	9	2-10	1	
		Borehole Terminated at 10 m depth	22.8	10			

Chart columns: Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200); Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %, Atterberg Limits (% Dry Weight) (20, 40, 60)

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	3.7	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-03

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 53

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Depth (m)	Geodetic (m)	Soil Description	Combustible Vapour Reading (ppm)	Natural Moisture Content %	Samples	Natural Unit Wt. kN/m³
0	17.6 / 17.6	**TOPSOIL** ~50mm				
0–1.8		**FILL** Silty sand, some gravel, black, wet. Slumped from mountain face	1	~20		3-1
			1	~25		3-2
1.8	15.8	**SILTY SAND (SM)** Some gravel, reddish brown, wet, some ice lenses and crystals	0	~22		3-3
			0	~17		3-4
4.0	13.6	**SILTY SAND (SM)** Some gravel, green and white boulders, reddish brown to grey, very moist to moist, some ice lenses and crystals	0	~9		3-5
			0	~9		3-6
			0	~9		3-7
			0	~9		3-8
			0	~5		3-9
			0	~5		3-10
10	7.6	**Borehole Terminated at 10 m depth**				

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-04

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 54

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	⊢—○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Depth (m)	Geodetic (m)	SOIL DESCRIPTION	Combustible Vapour Reading (ppm)	Sample	Natural Unit Wt. kN/m^3
0	19.9 / 19.9	**TOPSOIL** ~50mm			
0 – 4		**FILL** Silty sand some gravel, black, wet slumped from mountain face	1	4-1	
			1	4-2	
			1	4-3	
			0	4-4	
4	15.9	**SILTY SAND (SM)** Gravelly, frequent boulders, greyish brown to grey, ice crystals and lenses, moist to wet	0	4-5	
			0	4-6	
			0	4-7	
7	12.9	**GRAVELLY SAND (SP)** Frequent boulders, ice lenses and crystals, grey, moist	0	4-8	
			0	4-9	
			0	4-10	
10	9.9	**Borehole Terminated at 10 m depth**			

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60.

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	5.0	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-05

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 55

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend		Legend	
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◫	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Geodetic m	Depth (m)	Soil Description	Sample	Combustible Vapour Reading (ppm)
25.8	0	**TOPSOIL** ~50mm		
25.8		**SILT AND SAND FILL (ML)** slumped from mountain face, some clay, black, wet	5-1	1
	1		5-2	1
	2		5-3	1
22.8	3	**SILTY SAND (SM)** Some gravel, bouldery, boulders are white, reddish brown, moist to very moist	5-4	0
	4		5-5	0
20.8	5	**SILTY SAND (SM)** Trace clay, some gravel and white boulders, moist to wet	5-6	0
	6	ice lenses and crystals below 6 m depth	5-7	0
	7		5-8	0
	8		5-9	0
	9		5-10	0
15.8	10	**Borehole Terminated at 10 m depth**		

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60; Natural Unit Wt. kN/m^3

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2. Multi-bead thermistor string installed to 10.0 m depth upon completion
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	7.0	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-1

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 56

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample		Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	
Dynamic Cone Test		Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			34.1	0				
		TOPSOIL ~50mm	34.1					
		FILL Silty sand, some gravel, black, wet, slumped from mountain face. Limestone boulders at 0.9 m depth.	33.2			0		TP-1
		Backhoe Shovel Refusal at 0.9 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

LOG OF BOREHOLE FRN-21016638 ARCTIC BAY SITE 4 BH LOGS.GPJ TROW OTTAWA.GDT 1/27/22

Log of Borehole TP-2

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 57

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H.   Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	☒	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	⊢○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			14.8	0				
		TOPSOIL ~50mm	14.8					
		FILL Silty sand, some gravel, black, wet, slumped from mountain face.	14.0			□ 0, X		TP2-1
		SAND (SP) Fine grained sand, weathered, brown, moist	13.6	1		□ 0, X		TP2-2
		Backhoe Shovel Refusal at 1.2 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

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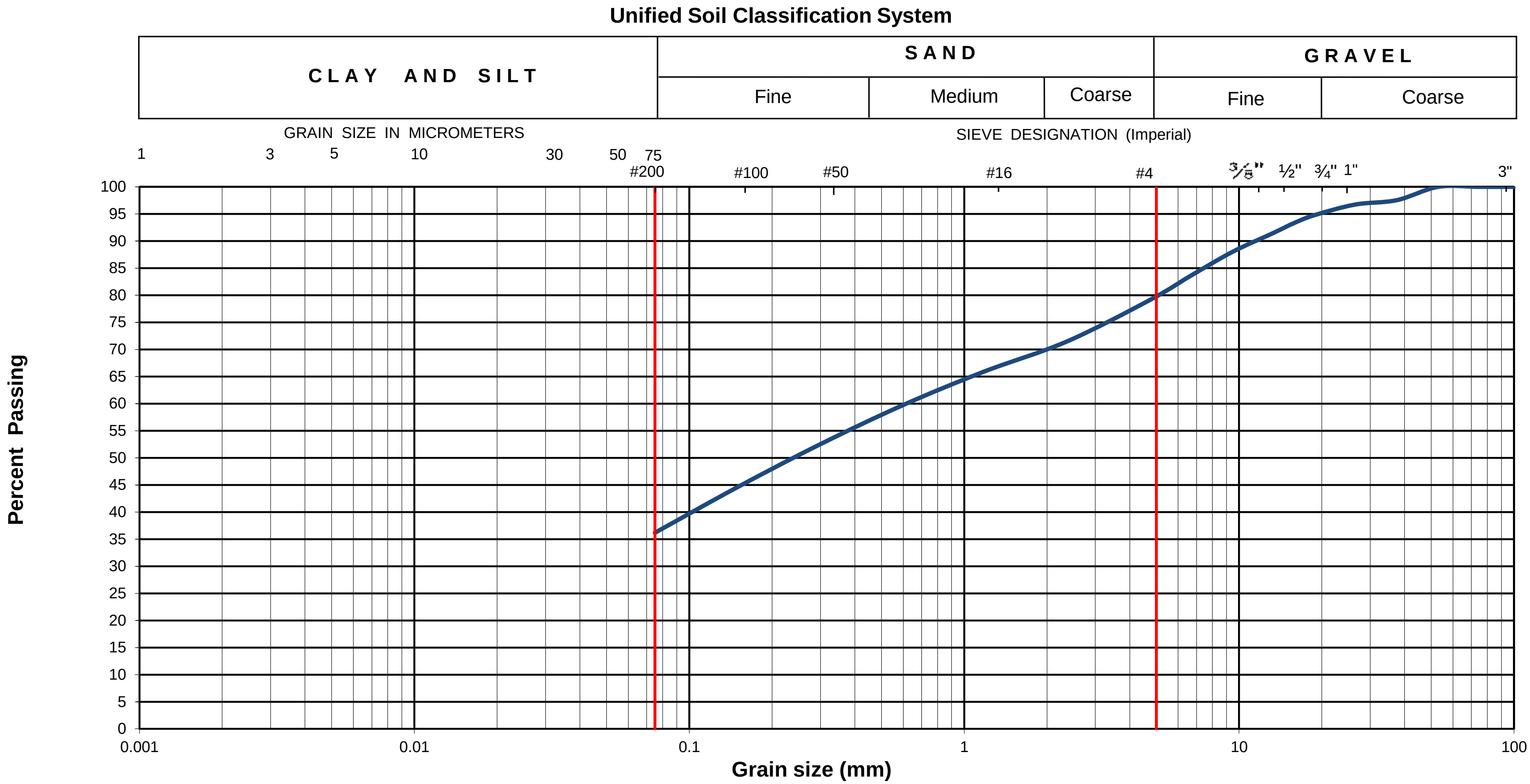
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment				
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 4				
Date Sampled :	October 2, 2021	Borehole No:	TP1	Sample:	n/a	Depth (m) :	0.1-0.9
Sample Composition :		Gravel (%)	21	Sand (%)	43	Silt & Clay (%)	36
Sample Description :	Silty Sand with Gravel (SM)					Figure :	58

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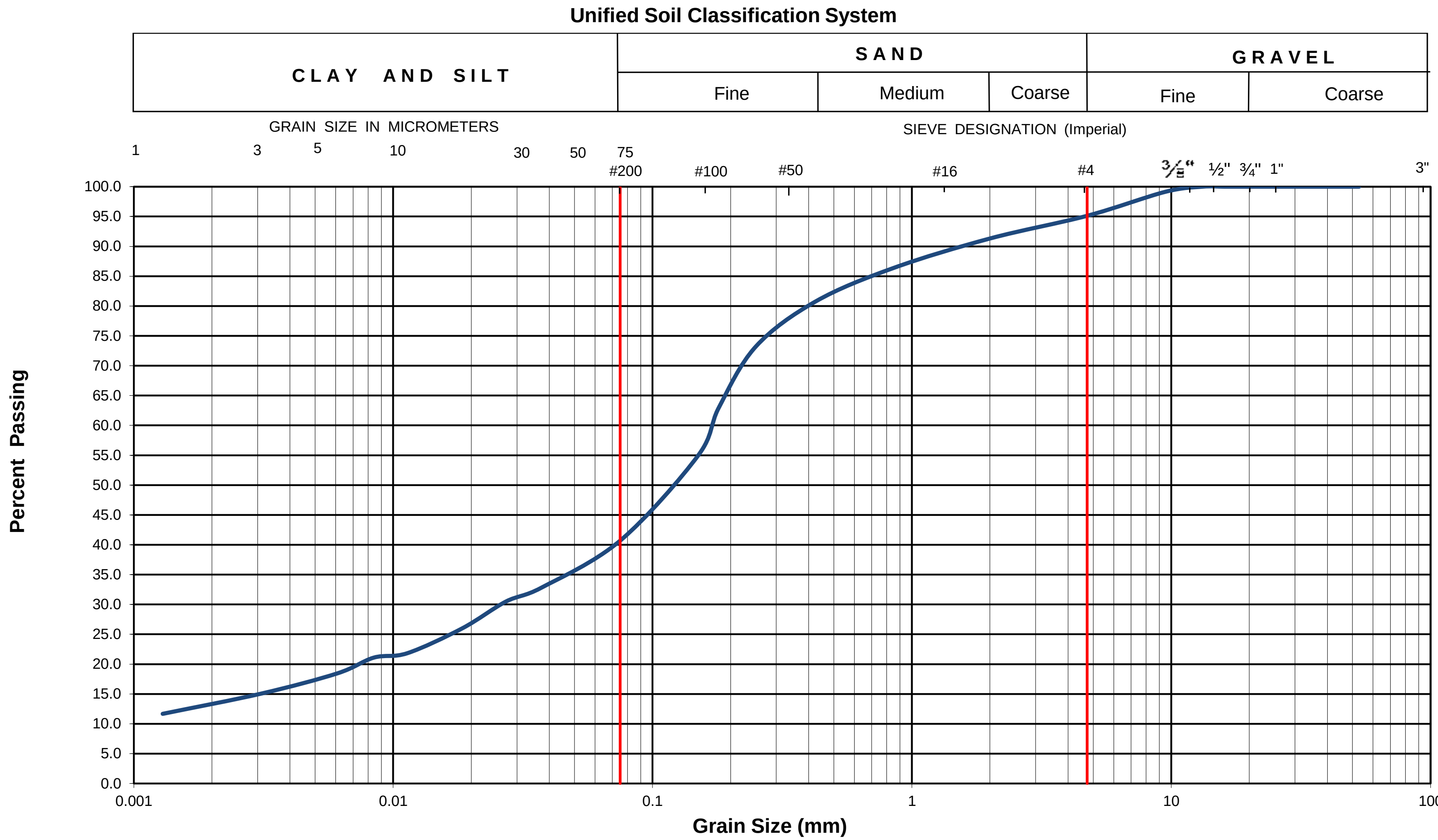
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**					
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH3**	**Sample No.:**	**S2**		**Depth (m) :**	**1-2**
Sample Description :		**% Silt and Clay**	**41**	**% Sand**	**54**	**% Gravel** **5**	**Figure :**	**59**
Sample Description :		**Silty Sand (SM)**						

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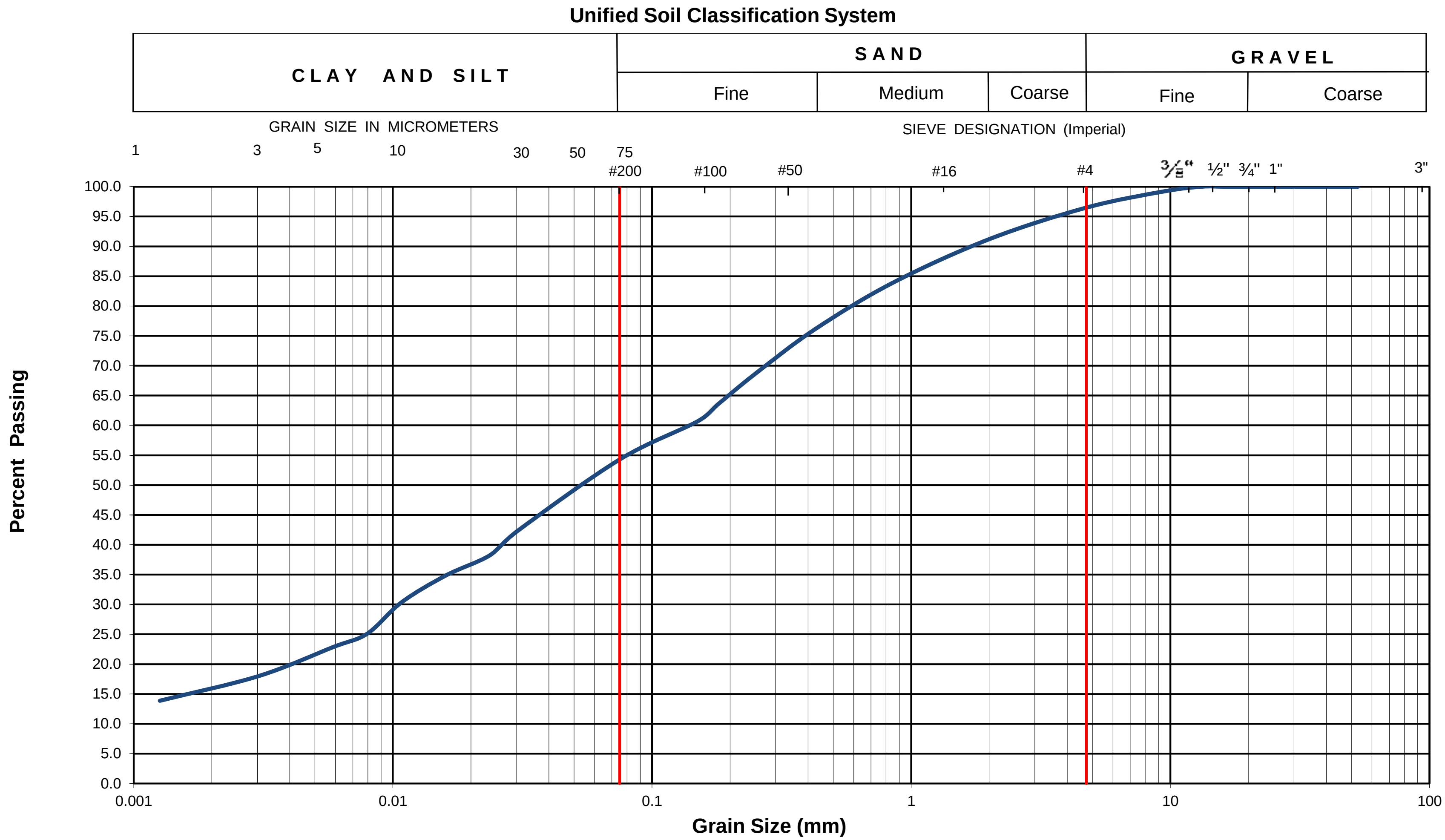
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**					
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH5**	**Sample No.:**	**S2**		**Depth (m) :**	**1-2**
Sample Description :		**% Silt and Clay**	**54**	**% Sand**	**42**	**% Gravel**	**4**	**Figure : 60**
Sample Description :		**Silt and Sand (ML)**						

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Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
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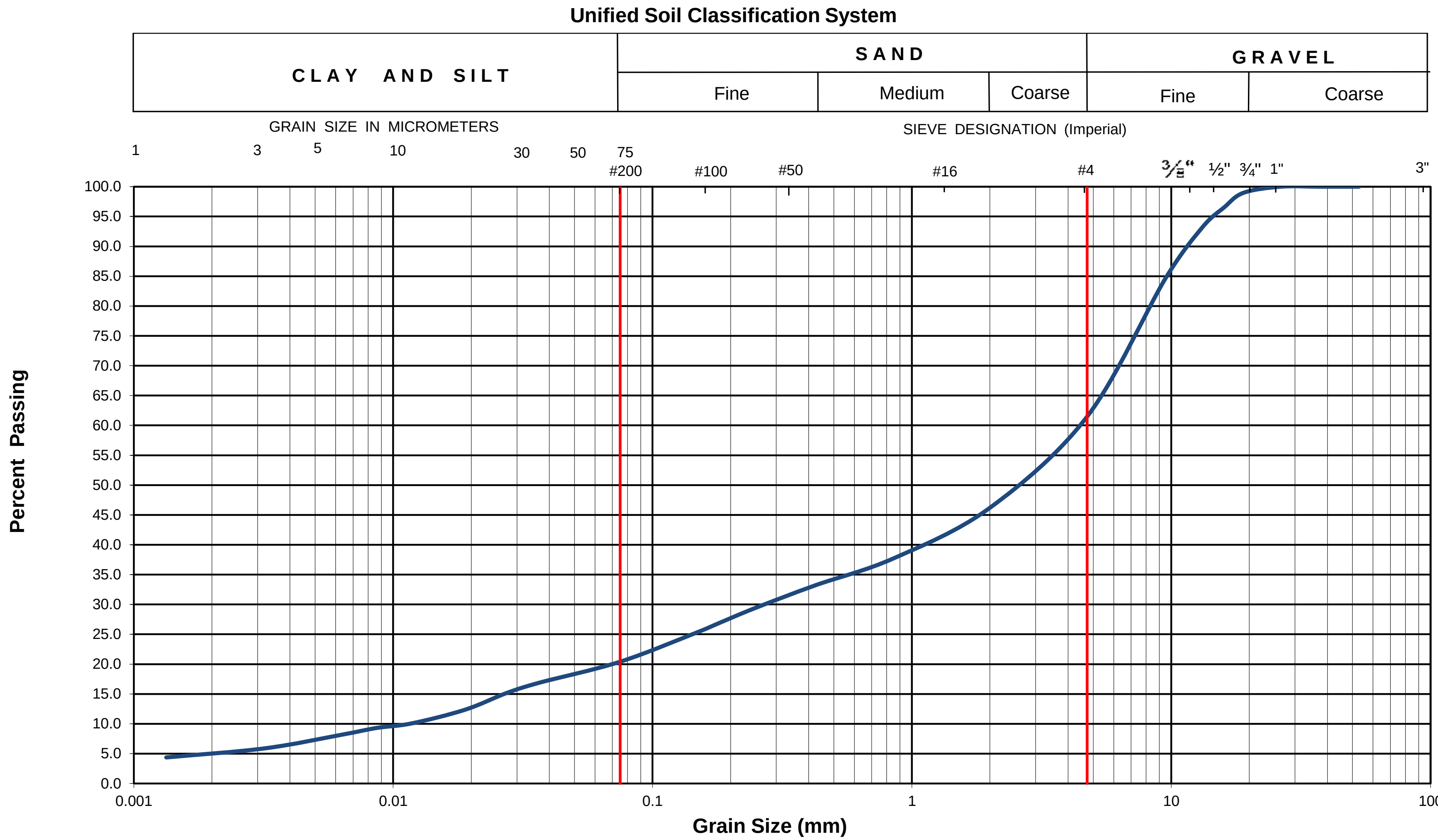

EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 4					
Date Sampled :	October 3, 2021	Borehole No:	BH1	Sample No.:	S2		Depth (m) :	1-2
Sample Description :		% Silt and Clay	20	% Sand	41	% Gravel 39	Figure :	61
Sample Description :	Silty Sand and Gravel (GM)							

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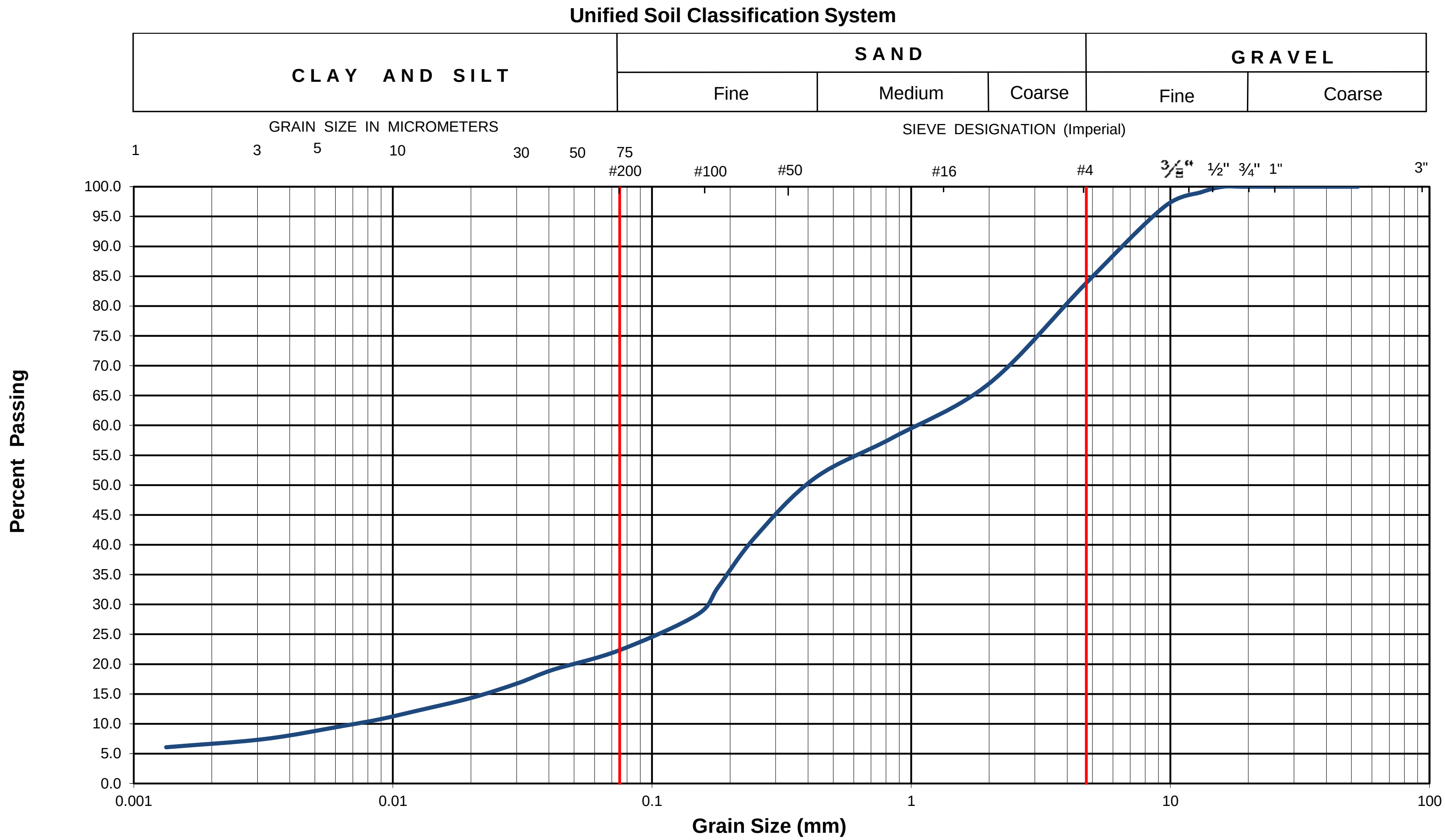
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**					
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH2**	**Sample No.:**	**S3**		**Depth (m) :**	**2-3**
Sample Description :		**% Silt and Clay**	**22**	**% Sand**	**62**	**% Gravel** **16**	**Figure :**	**62**
Sample Description :		**Silty Sand with Gravel (SM)**						

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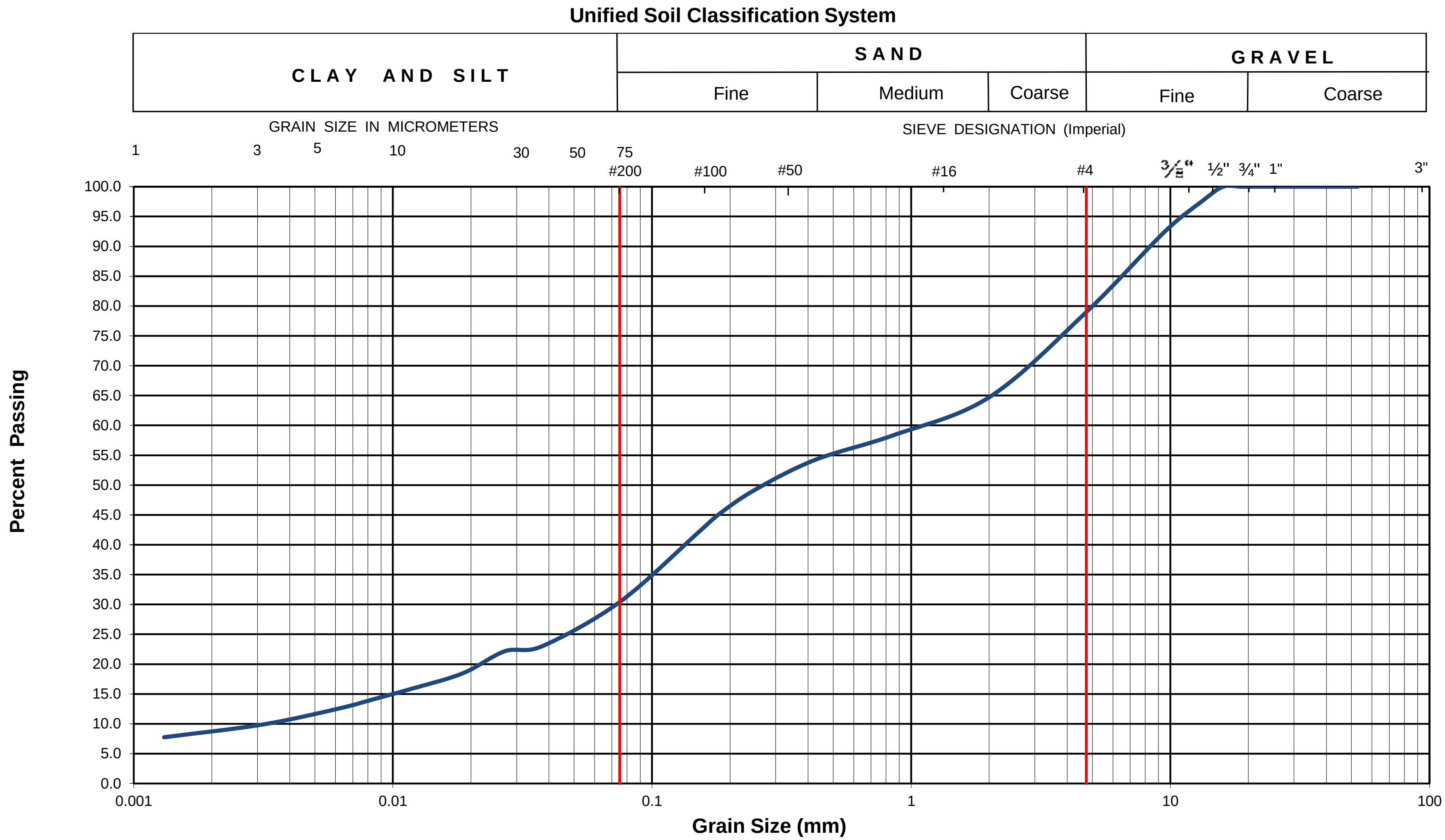
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 4					
Date Sampled :	October 3, 2021	Borehole No:	BH3	Sample No.:	S4		Depth (m) :	3-4
Sample Description :		% Silt and Clay	30	% Sand	49	% Gravel 21	Figure :	63
Sample Description :	Silty Sand (SM)							

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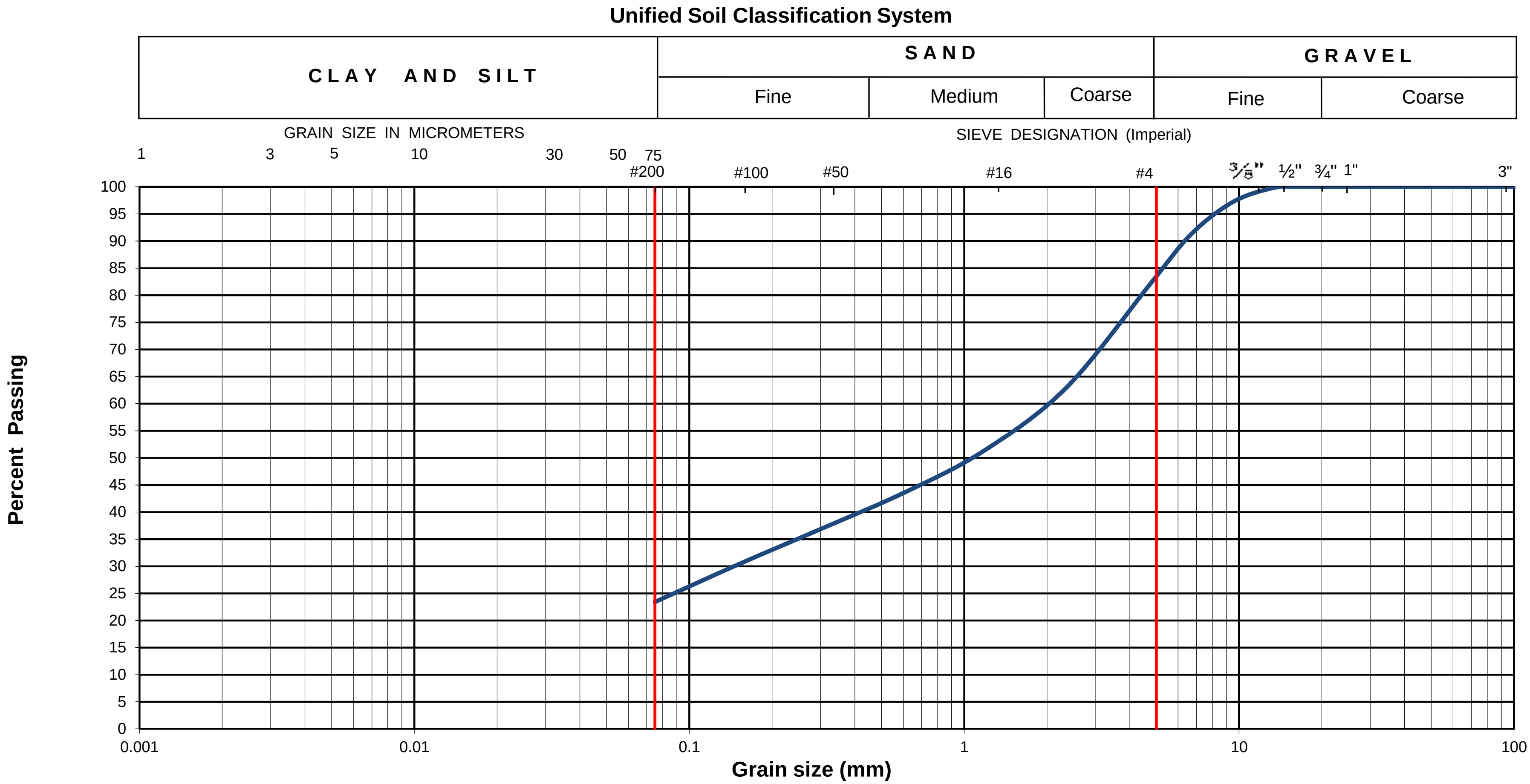
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 4						
Date Sampled :	October 3, 2021	Borehole No:	BH3	Sample:	S10			Depth (m) :	9-10m
Sample Composition :		Gravel (%)	18	Sand (%)	59	Silt & Clay (%)	23	Figure :	64
Sample Description :	Silty Sand with Gravel (SM)								

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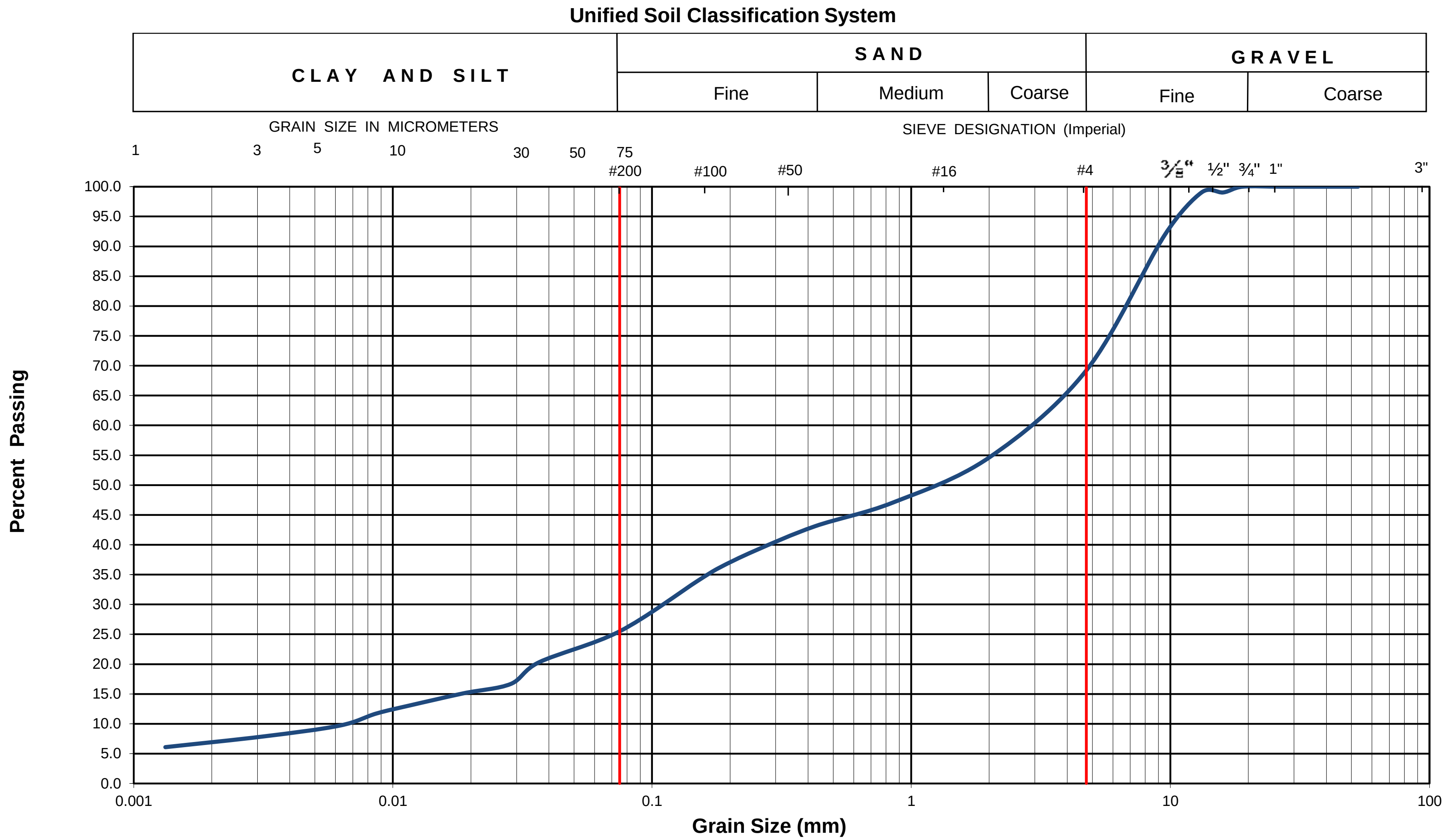
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment					
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 4					
Date Sampled :	October 3, 2021	Borehole No:	BH4	Sample No.:	S5		Depth (m) :	4-5
Sample Description :		% Silt and Clay	26	% Sand	43	% Gravel 31	Figure :	65
Sample Description :		Gravelly Silty Sand (SM)						

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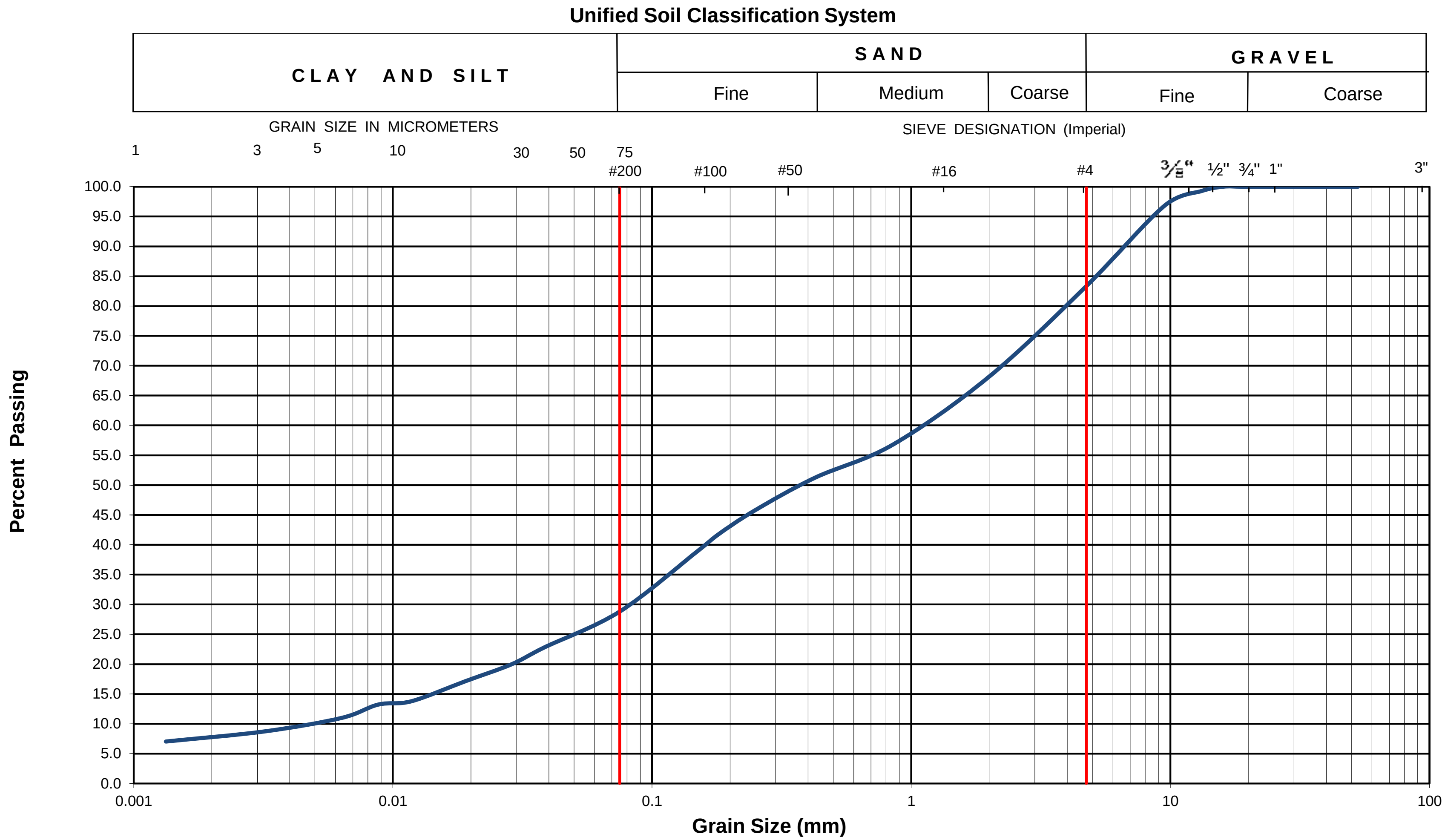
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**					
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH5**	**Sample No.:**	**S5**		**Depth (m) :**	**4-5**
Sample Description :		**% Silt and Clay**	**29**	**% Sand**	**54**	**% Gravel** **17**	**Figure :**	**66**
Sample Description :	**Low Plasticity Silty Sand, some Gravel (SM)**							

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Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
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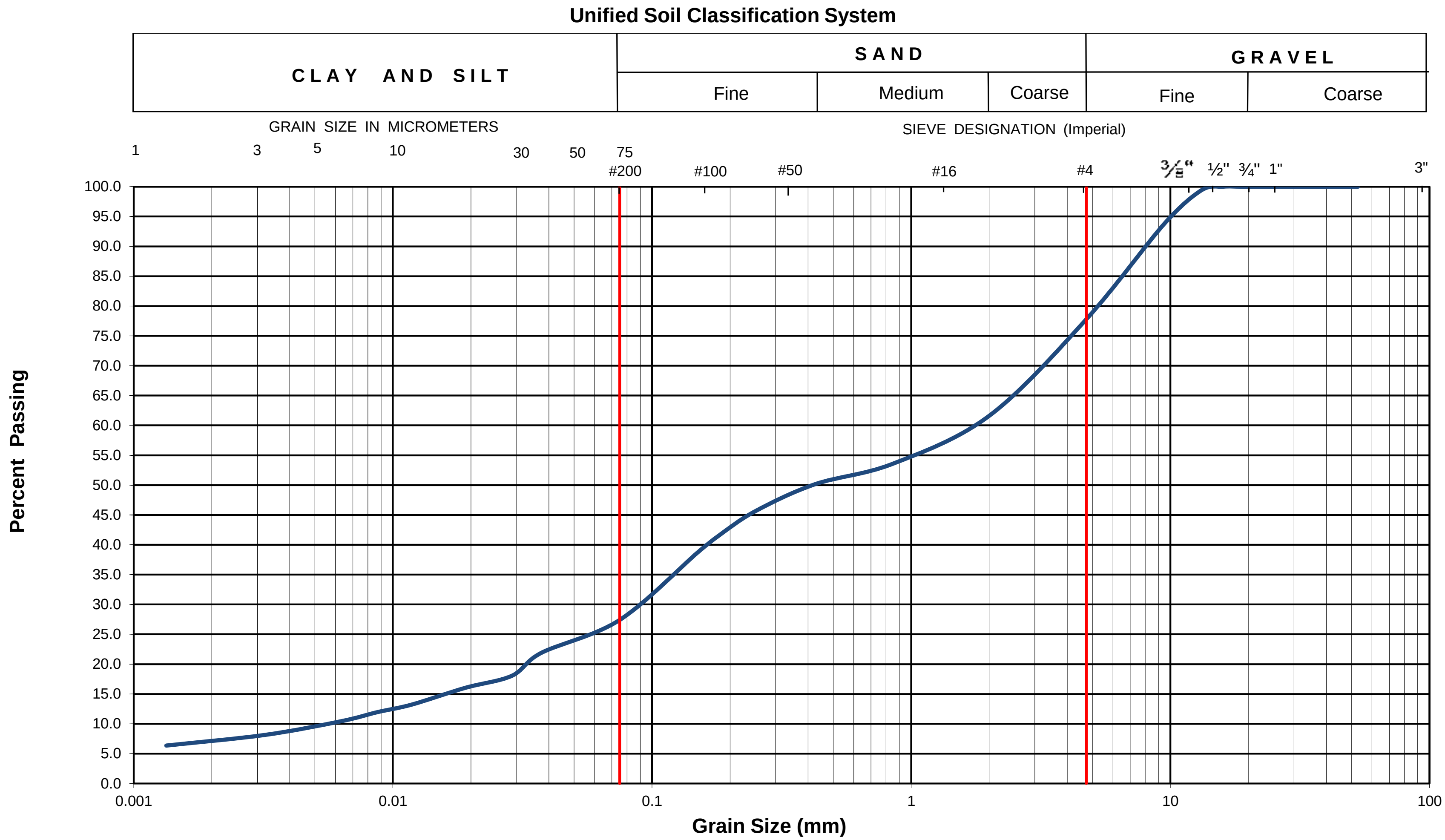

EXP Project No.: OTT-21016638-A0	Project Name : Geotechnical Investigation - High Arctic Water Supply & Treatment						
Client : Government of Nunavut	Project Location : Arctic Bay, Nunavut - Site 4						
Date Sampled : October 3, 2021	Borehole No: BH5		Sample No.: S7			Depth (m) : 6-7	
Sample Description :	% Silt and Clay	27	% Sand	51	% Gravel	22	Figure : 67
Sample Description : Low Plasticity Silty Sand, some Gravel (SM)							

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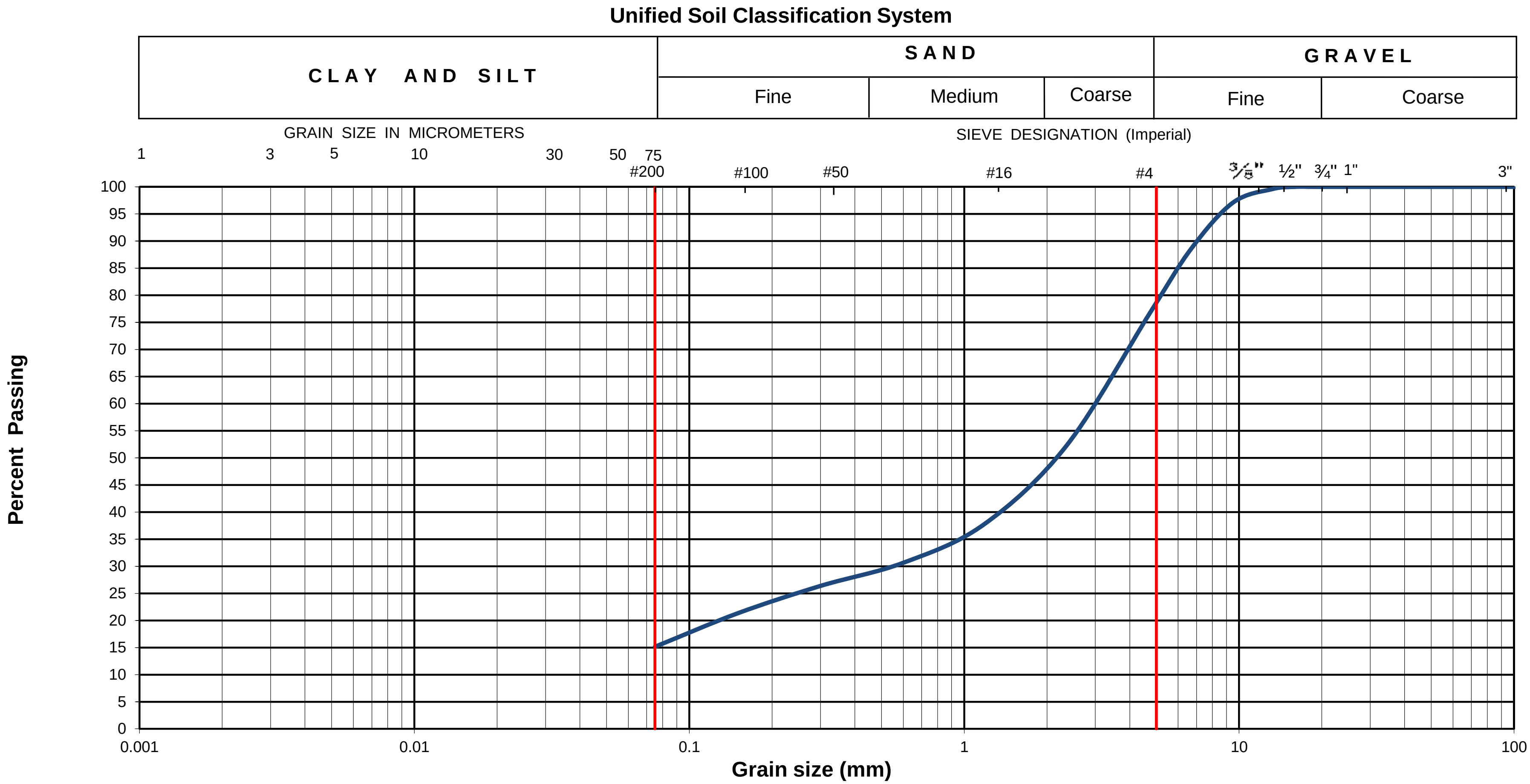
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	OTT-21016638-A0	Project Name :	Geotechnical Investigation - High Arctic Water Supply & Treatment				
Client :	Government of Nunavut	Project Location :	Arctic Bay, Nunavut - Site 4				
Date Sampled :	October 3, 2021	Borehole No:	BH1	Sample:	S5	Depth (m) :	4-5m
Sample Composition :		Gravel (%)	23	Sand (%) 62	Silt & Clay (%) 15	Figure :	68
Sample Description :	Poorly Graded Sand with Gravel (SP)						

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Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
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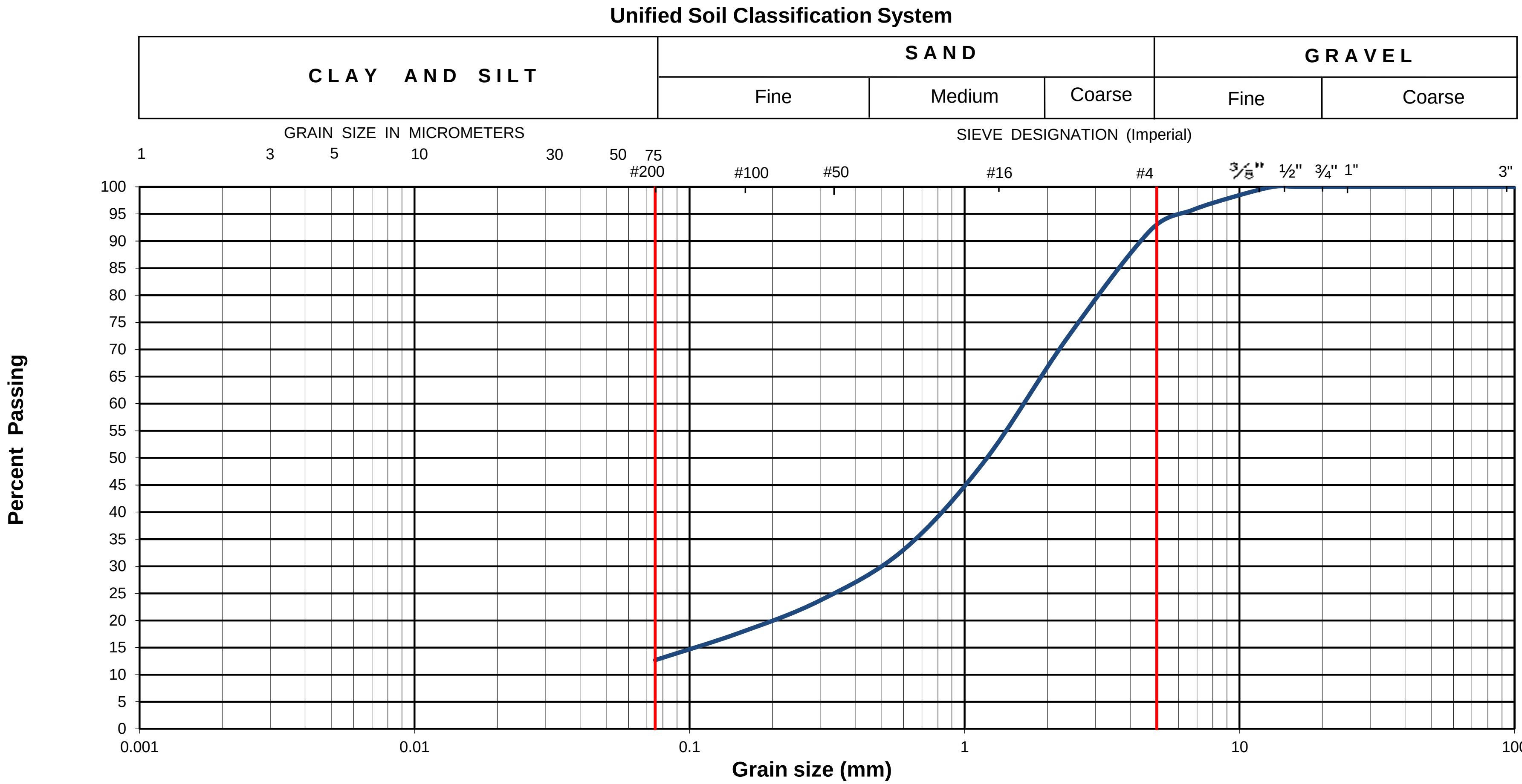

EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**						
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**						
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH1**		**Sample:**	**S8**		**Depth (m) :**	**7-8m**
Sample Composition :		**Gravel (%)**	**8**	**Sand (%)**	**79**	**Silt & Clay (%)**	**13**	**Figure :**	**69**
Sample Description :	**Poorly Graded Sand (SP)**								

Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
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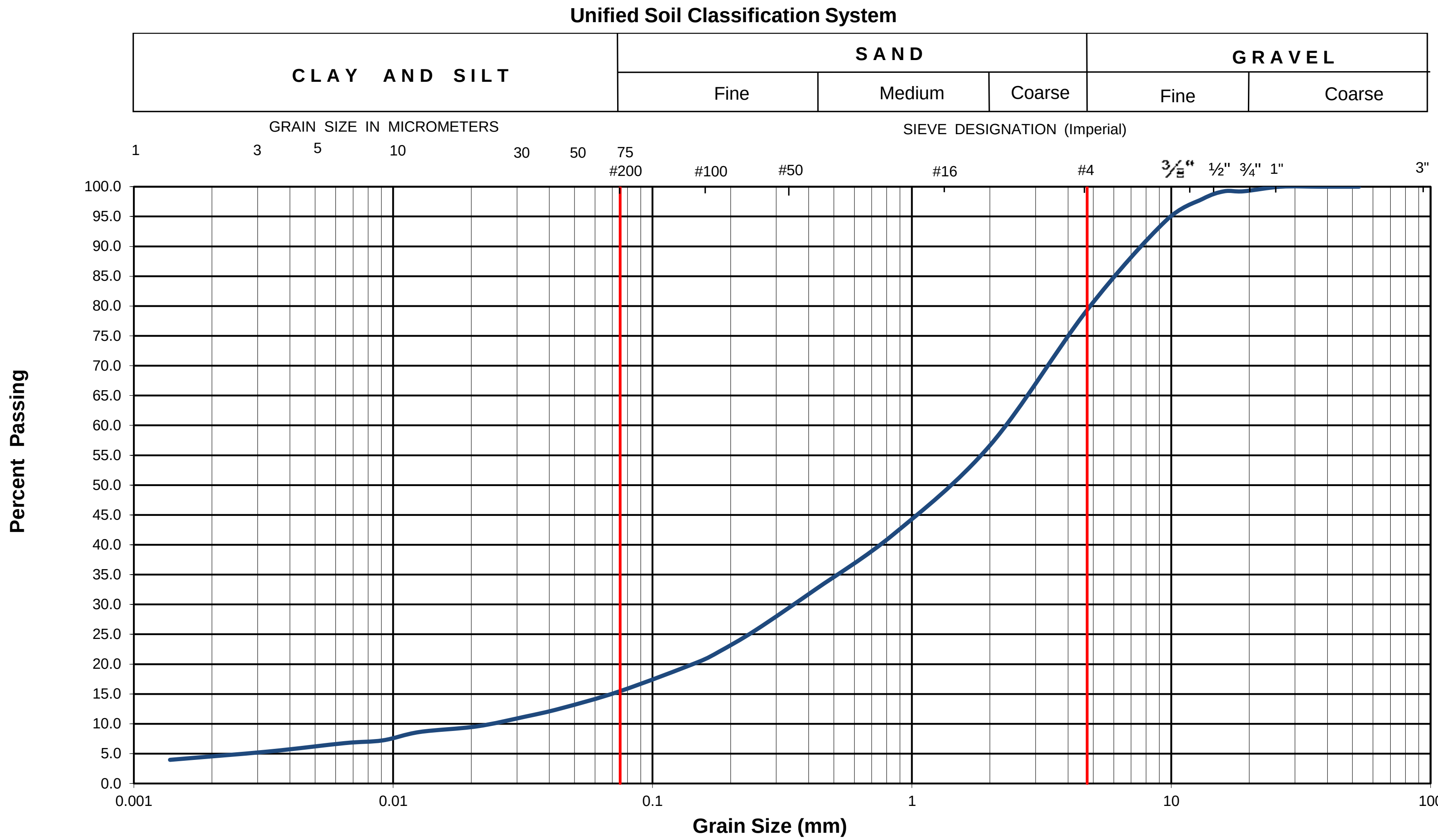

EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**					
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**					
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH2**	**Sample No.:**	**S10**		**Depth (m) :**	**9-10**
Sample Description :		**% Silt and Clay**	**16**	**% Sand**	**63**	**% Gravel 21**	**Figure :**	**70**
Sample Description :		**Poorly Graded Sand with Gravel (SP)**						

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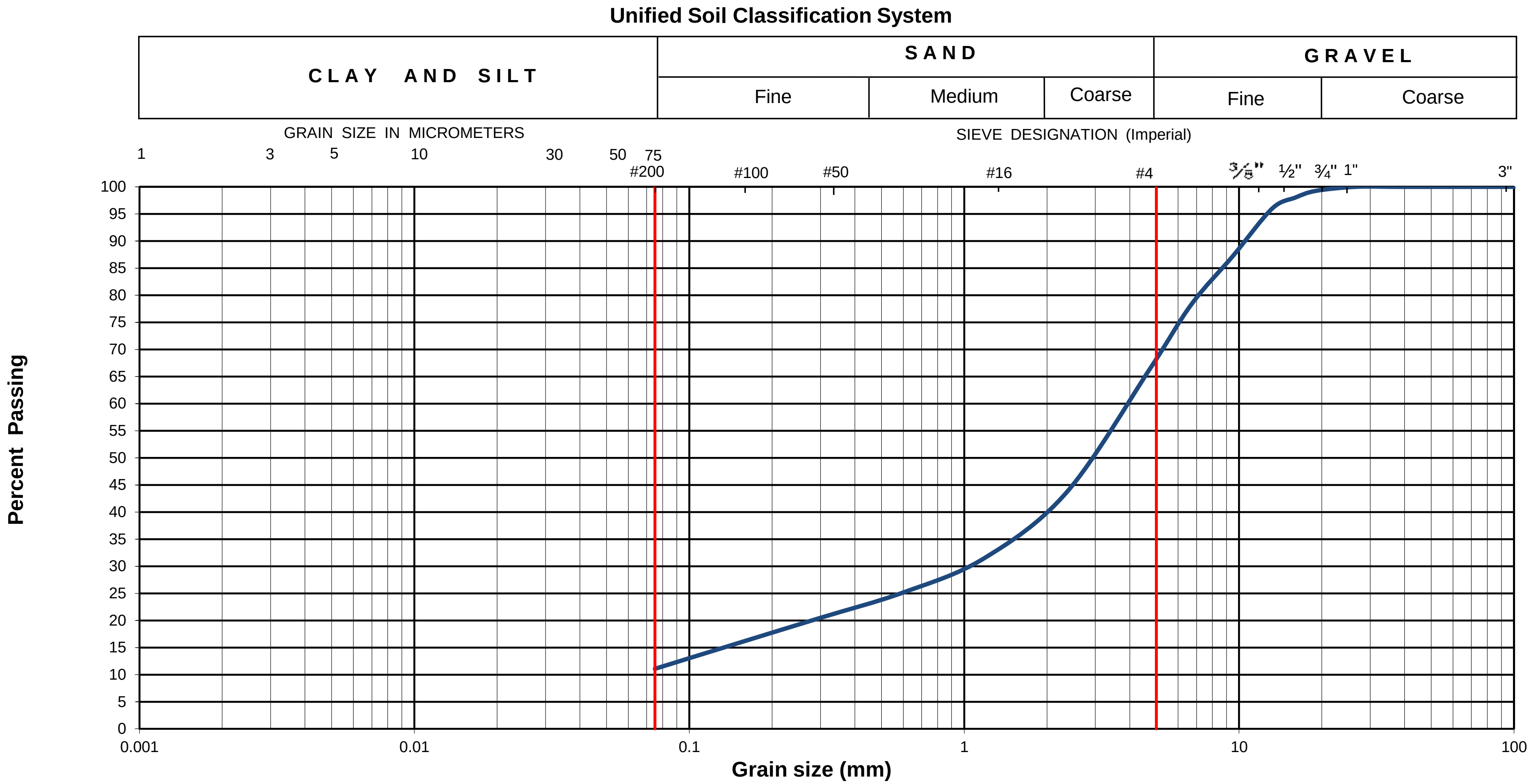
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-21016638-A0**	**Project Name :**	**Geotechnical Investigation - High Arctic Water Supply & Treatment**				
Client :	**Government of Nunavut**	**Project Location :**	**Arctic Bay, Nunavut - Site 4**				
Date Sampled :	**October 3, 2021**	**Borehole No:**	**BH4**	**Sample:**	**S8**	**Depth (m) :**	**7-8m**
Sample Composition :		**Gravel (%)** 34	**Sand (%)** 55	**Silt & Clay (%)** 11		**Figure :**	**71**
Sample Description :	**Gravelly Sand (SP)**						

Appendix A: Results of Geothermal Analyses, Arctic Bay, Site 1

MEMORANDUM

Subject:	Arctic Bay Water Treatment Plant and Storage Tanks Geothermal Analysis Memorandum: Issued for use (Revision 0)	
From:	Jim Oswell and Ron Coutts	Doc. No.:
To:	Surinder Aggarwal	Date: March 15, 2022
cc:	Ismail Taki	Project Number: FRN-21016638-A0

This memorandum outlines the results of geothermal modelling conducted for the proposed water treatment plant (WTP) and associated water storage tanks in Arctic Bay, NU.

Project Details

Figure 1 presents an annotated aerial image of the project site, showing the approximate location of the available boreholes. The majority of the site consists of undisturbed tundra terrain and an existing access road and turn-around, comprising granular fill. The existing WTP is located in the northeast-central part of the proposed site.

Figure 2 presents a sketch of the proposed facilities. It is understood that the WTP will be a single storey structure with approximate plan dimensions of 30 m by 20 m. The building will likely be constructed on an engineered granular pad, which is constructed in-ground such that the building is at the same elevation as the surrounding grade. Potable water and wastewater storage tanks will be located approximately 7.5 m from the building, potentially on a separate engineered granular pad. The potable water tank will be 8 m diameter and 8 m high with a capacity of 400 m^3, and the wastewater tank will be 8 m diameter and 6 m high, with a capacity of 300 m^3.

The WTP building will be maintained at a constant temperature of 22°C. It is assumed in-floor heating will not be provided. The exterior storage tanks will be maintained at a constant temperature of +10°C.

It is understood that the raw water supply to the WTP will be drawn directly from the adjacent lake with no intervening storage.

It was assumed the design life for the WTP structure and storage tanks will be 40 years.

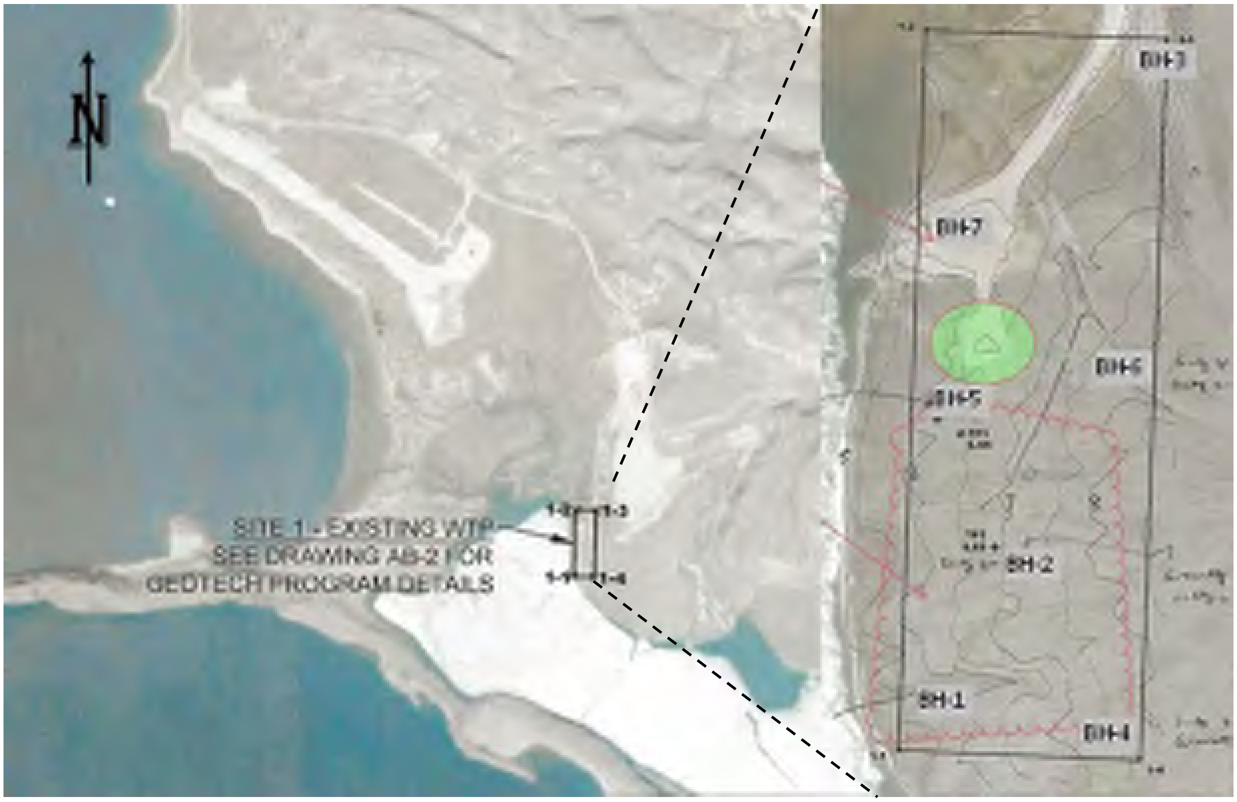


Figure 1 Aerial image of proposed Arctic Bay water treatment plant site.

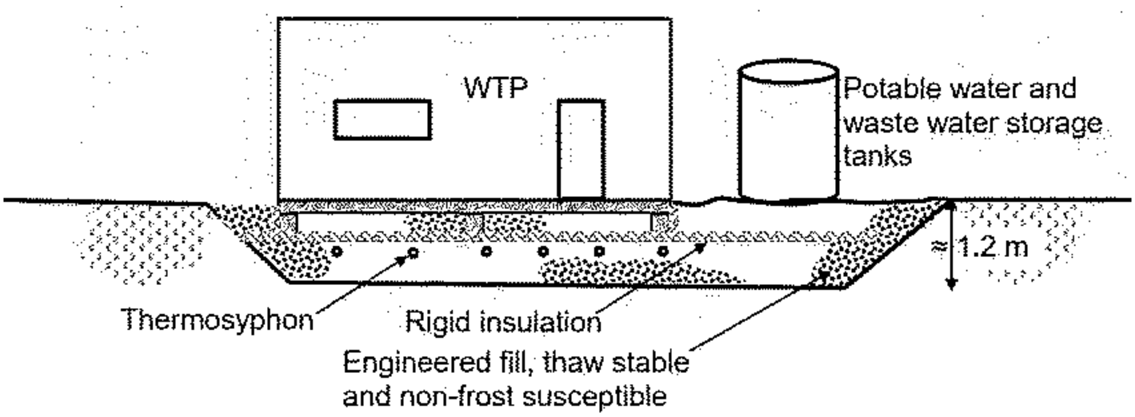


Figure 2 Sketch of water treatment plant and layout of external water storage tanks. (For illustrative purposes only; not to scale).

Climatic Characteristics

Environment Canada does not provide long-term climate normal data for Arctic Bay. There are intermittent monthly or annual meteorological data over several decades for Arctic Bay, but these data are insufficient to establish climate normals data. Hence, climate normals data (1981

– 2010) for Nanisivik was used and is reported in Table 1. Nanisivik is located 35 km west of Arctic Bay. The mean annual air temperature at Nanisivik/Arctic Bay based on these climate normals is -14.8°C.

Climate warming data has been assessed using the available intermittent mean annual air temperature (MAAT) data from the Arctic Bay climate station from 2002 to 2021, and overlain with the Pond Inlet long-term mean annual air temperature data. Figure 3 presents these MAAT data. MAAT data for Nanisivik data is not available after 2011. The annual air warming rate for these data is approximately 0.08°C/year. This warming rate is consistent with data from other Baffin Island communities.

Table 1 Long-term mean monthly climate values for Navisivik/Arctic Bay

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Temp.[1] (°C)	-29.6	-29.9	27.6	-19.8	-10.3	-0.1	5.1	1.7	-5.0	-13.6	-22.5	-26.3
Net rad. (W/m^2)[2]	0.0	10.4	64.8	170	263	274	222	134	60.2	17.4	2.3	0.0
Wind speed (kph)[1,3]	14.0	15.5	16.0	16.9	16.3	16.3	16.9	17.2	15.8	19.1	16.7	14.1
Average snow depth (m)[1]	0.29	0.31	0.32	0.31	0.26	0.13	0.00	0.01	0.06	0.17	0.25	0.27

1 - Canadian Climate Normals, 1981 - 2010 for Nanisivik, NU: http://climate.weather.gc.ca/climate_normals/index_e.html
2 - Canadian Solar Insolation Dataset for Nanisivik, NU:https://ftp.maps.canada.ca/pub/nrcan_rncan/Solar-energy_Energie-solaire/photovoltaic_canada_photovoltaique/municip_MJ.csv
3 – Mean hourly

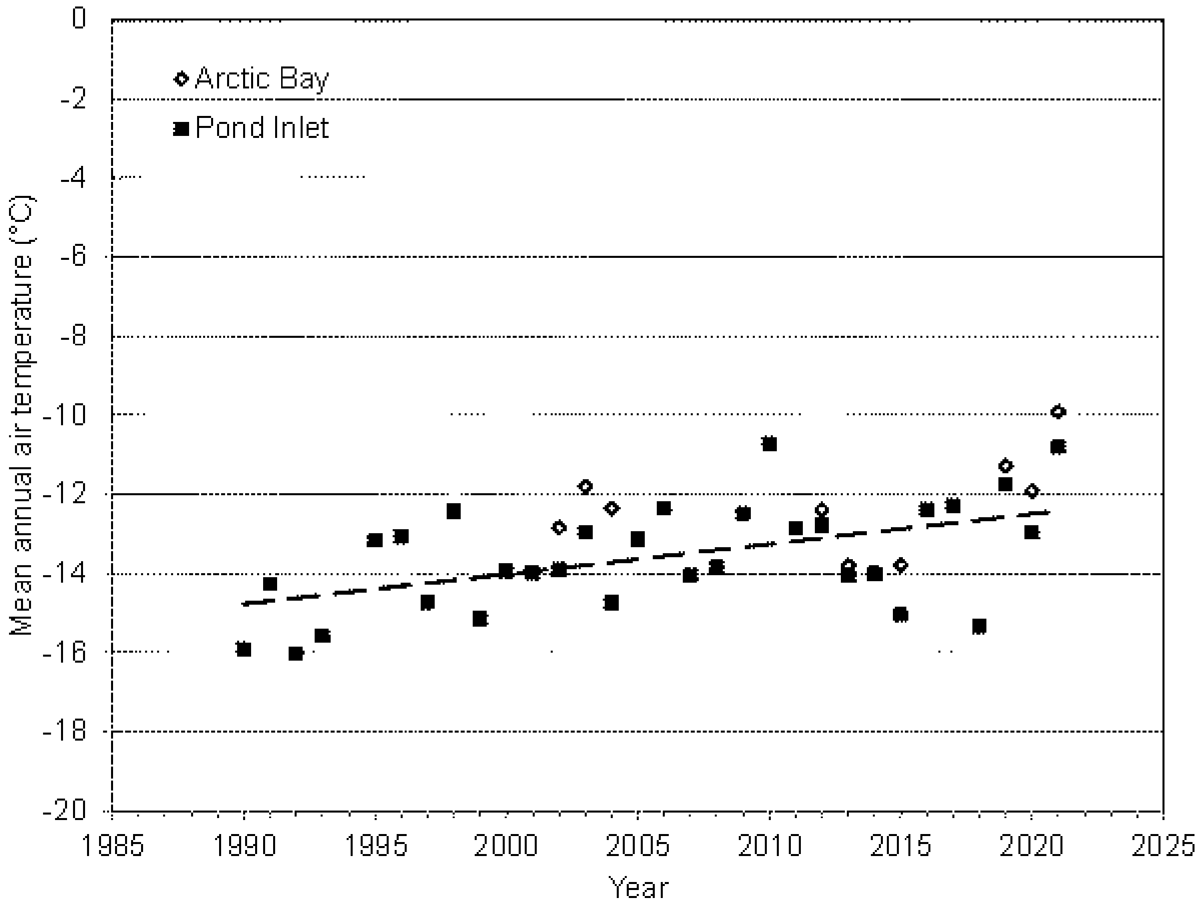


Figure 3 Mean annual air temperature data for Arctic Bay and Pond Inlet, NU. The dashed line represents the linear regression warming rate of 0.08°C/year.

Geotechnical Properties

September 2021, EXP advanced seven boreholes and two shallow test pits within the proposed land unit to be used for Arctic Bay's WTP. The area is within close proximity to the existing WTP facility (at BH-7, on Figure 1). The applicable boreholes are BH01 to BH07 and TP1 and TP2. The proposed area for the new WTP comprises a small portion of land with an existing earth fill structure or disturbed terrain associated with the access road and turn-around for the existing WTP facility. The majority of the project area is on less disturbed tundra. Table 2 presents the inferred undisturbed generalized soil conditions at the project site, however, the organic layer was so thin it was not included in the thermal model as its thermal effect would be insignificant.

It is noted that water content in the mineral soil units exceed 20%, which would be indicative of ice-rich permafrost. The borehole logs also contain references to ice crystals and lenses.

Table 2 Simplified soil stratigraphy for geothermal modelling (based on BH01 to BH07).

Depth interval (m)	Soil unit	Water content range (%)	Applied water content (%)[1]	Comment
0 – 0.05	Organics/topsoil		25	Present on undisturbed terrain. Not applied in geothermal model
0 – 1.2	Sand and gravel		12	Engineered fill pad
0 – 1.2	Sand and gravel		10	Native soil (active layer)
0.05 – 5.0	Gravel and sand (GP) or silty sand (SM)	2 - 25	20	
5.0 – 10+	Gravelly sand (SP)	5 - 35	20	

Note: 1. The applied water content is that to be used in the geothermal model. The value does not necessarily represent an average value. In general, lower water contents are conservative in geothermal models as they result in deeper thaw than for soils with higher water contents.

At borehole BH07 approximately 2 m of granular fill is present. The density and compactness of this fill is unknown. For the geothermal modelling, it was assumed that all existing fill materials will be removed and replaced with engineered fill comprising coarse-grained soils, being thaw stable and non-frost susceptible.

Permafrost Conditions

Arctic Bay lies within the continuous permafrost zone. It is likely that at this community the permafrost extends several hundreds of metres into the ground, although the depth will be spatially moderated by the nearby Arctic Ocean. Ground temperature data was collected by EXP in BH04 during the on-site investigations in September 2021. A full trumpet curve of ground temperatures for Arctic Bay is reported by Ednie and Smith (2015). Figure 4 presents these available ground temperature data. It is observed that the EXP data are warmer than the annual maximum ground temperatures reported by Ednie and Smith (2015). The warmer EXP temperatures are likely due to borehole disturbance as the ground temperatures were recorded only two days after drilling. Ednie and Smith (2015) report a mean annual ground temperature (MAGT) of approximately -10.2°C with a measured active layer of 1.2 m. Ednie and Smith (2010) report a depth of zero seasonal amplitude of about 17.4 m.

The project site is immediately adjacent to the Arctic Ocean. The ground temperatures within the WTP project area may be moderated by the proximity to the shoreline.

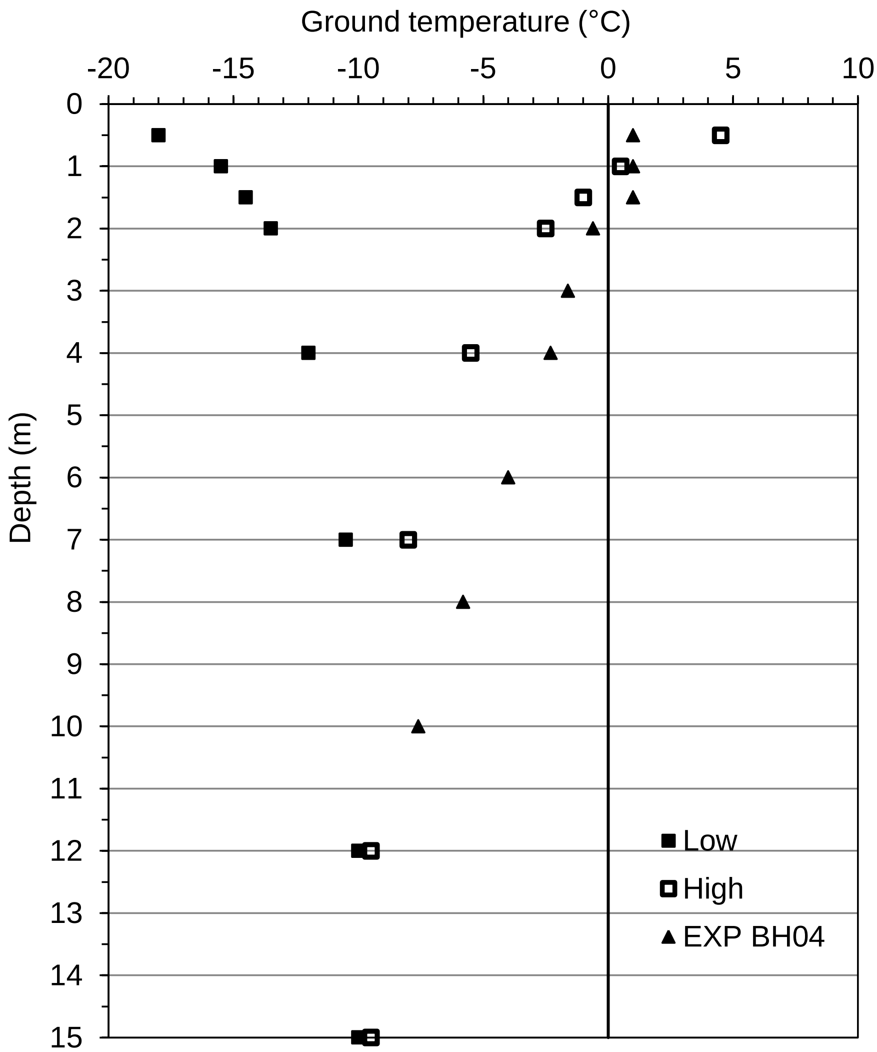


Figure 4. Ground temperature data for 2012 - 2013 from Ednie and Smith (2015).

Hivon and Sego (1993) report that the pore water salinity of soils in the Arctic Bay area range from about 1 PPT to over 30 PPT. For this study, a pore water salinity of 15 PPT was assumed, which represents a freeze point depression (and ice melting temperature) of about -1°C.

Geothermal Modelling Scenarios

It is understood that the WTP structure is an on-grade building with approximate dimensions of 30 m by 20 m. See Figure 2. The construction approach is understood to entail the excavation of native soil within the building footprint to a depth of approximately 1.2 m and then backfilling the excavation with engineered fill that is thaw-stable and non-frost susceptible. If the new structure is to be constructed within an area with existing fill then, for the geothermal modelling and construction, it was assumed that all existing fill under the WTP and storage tank footprints will be removed and the WTP and storage tanks will be constructed on engineered fill placed in or on native ground.

Thermosyphons and rigid insulation will be embedded within the engineered fill. The concrete slab-on-grade was assumed to be 0.15 m thick with thicker sections along the perimeter of the slab and at any column supports. It was assumed that the building interior will be maintained at 22°C.

The desired design outcome from the geothermal modelling analysis and any applied thermal mitigation was to keep seasonal thaw under the structures to within the engineered pad thickness, which is constructed of thaw stable, non-frost susceptible granular materials.

The design isotherm assumed to represent ice melting was -2°C, representing a freezing point depression of 1°C for the assumed pore water salinity, and an additional temperature increment of 1°C for conservatism, considering the uncertainty in the current site-specific ground temperatures.

The geothermal modelling was performed using the commercial computer software TEMP/W developed and marketed by Seequent (formerly GeoSlope International Inc. of Calgary). This program is capable of modelling one-dimensional, two-dimensional, and axisymmetric domains. A proprietary surface energy balance subroutine was used to model ground surface conditions. Because of geometric symmetry, only one-half of the WTP building was included in the model domain. The potable and wastewater storage tanks were modelled using an axisymmetric model domain.

The first step in the geothermal analysis was to construct a one-dimensional model domain to calibrate the baseline ground temperature conditions. This calibration was performed by applying the available surface energy balance climate normals inputs (mean monthly values for air temperature, solar radiation, snow cover, and wind speed) and running the model to periodic steady state to develop a baseline ground temperature response on an annual basis, and the associated minimum and maximum temperature profile with depth (trumpet curve) that is representative of the existing ground temperatures (such as that shown in Figure 4). Thermal model calibration was achieved by adjusting the snow thermal conductivity until a representative site-specific mean annual ground temperature was obtained. A constant geothermal energy flux was applied to the base of the model domain as occurs from the geothermal heat flux. The properly calibrated thermal model reproduces the site-specific mean annual ground temperature (-10.2°C at Arctic Bay) to a satisfactory degree and other temperature profile characteristics, such as the active layer depth.

Selection of thermosyphon characteristics (radiator area and evaporator loop spacing) and rigid insulation thickness benefited from recent geothermal modelling performed for WTP structures in Grise Fiord and Pond Inlet. As a result fewer variations in these variables were considered for this study.

The geothermal modelling addressed the following scenarios:

1. Assess the late summer thaw progression under the WTP floor slab and adjacent potable water and wastewater storage tanks.
2. Assess the annual and long-term temperature conditions under the structures where a 100 mm thick layer of rigid extruded polystyrene insulation is installed under the WTP building and the water storage tanks.
3. Assess thermosyphon operation, considering a specific radiator area and evaporator spacing. The thermosyphons were modelled based on the smallest available radiator area (9.75 m^2) in light of the relatively cold air temperatures at Arctic Bay. Furthermore, use of the smallest available radiator size will provide the ability to incrementally increase the radiator size later if additional heat extraction is ever required. The thermosyphon horizontal evaporator loops in the thermal model were 25 mm diameter and 60 m long with a constant spacing of 1 m.
4. Assess a thermosyphon loop failure scenario by considering the loss of one thermosyphon loop during operations. The design of the thermosyphon system should be such that the system is able to maintain thermal stable conditions under the WTP even in the event of a malfunction of one evaporator loop for up to two consecutive winters. The two year period was used, assuming that remedial repairs of the inoperative thermosyphon would be applied within this timeline.

For these geothermal assessments long-term conditions without and with climate warming were assessed.

Geothermal Modelling Results

<u>Water Treatment Plant</u>

Figure 5 presents a view of the two-dimension model domain for the WTP. The subsurface was divided into multiple layers representing: the engineered fill materials (when applied); upper soils of the active layer; native sand and/or gravel and the underlying saturated sandy gravel or gravelly sand. Figure 6 shows an expanded view of the WTP building and engineered fill pad with the floor slab, rigid insulation and thermosyphons in-place. The rigid insulation (100 mm) was placed under the WTP building and extended 2 m from the exterior walls, and also vertically up the exterior of the edge-thickened floor slab/perimeter footing. The thermosyphons

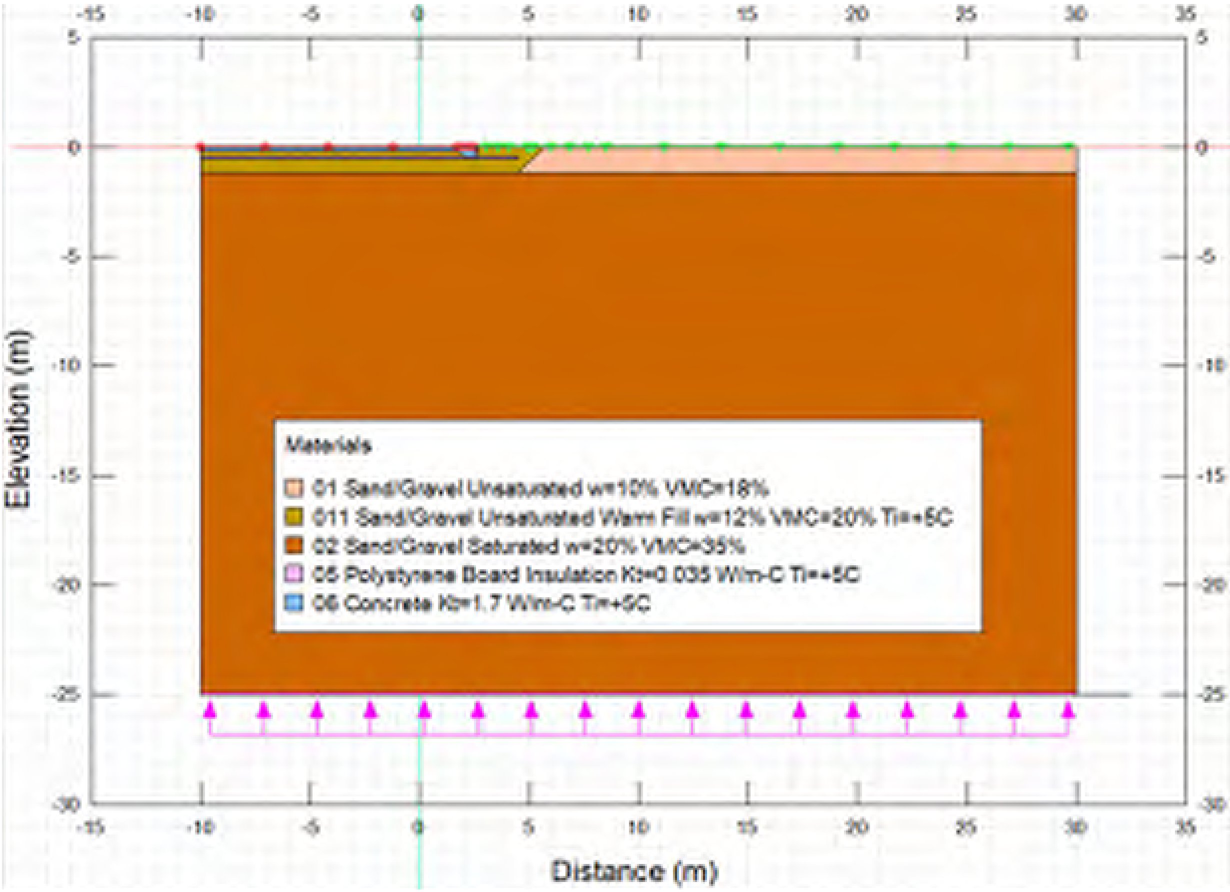


Figure 5 Two-dimensional model domain showing subsurface layers and material properties.

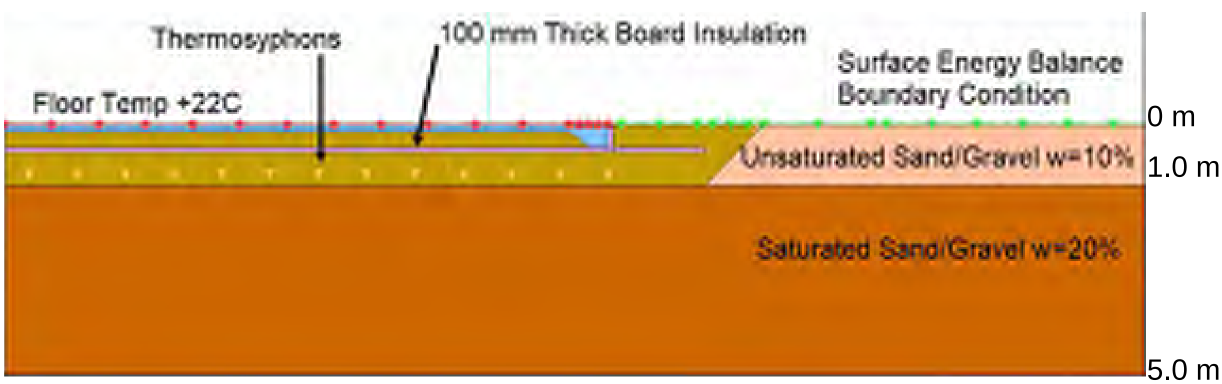


Figure 6 Two-dimensional model domain at WTP.

were placed below the rigid insulation at 1 m spacing with a radiator area of 9.75 m^2, with each evaporator loop having a half-length of 30 m, and an evaporator pipe diameter of 25 mm.

Figure 7 presents the model-calculated ground temperatures for the case with 100 mm rigid insulation and thermosyphons. This model simulation has no climate warming applied and is representative of the warmest ground temperatures and maximum active layer thaw depth in each year following construction. The isotherms (ground temperature contours) are typically shown for September or October when ground temperatures are warmest on an annual basis. Note that thermosyphons do not operate (extract heat) during the period when the air temperature is warmer than the ground temperature. For this model, it was assumed that the building was constructed in summer (instantaneous pad and foundation placement in early August) with a fill placement temperature of +5°C. The -2°C isotherm also remains within the engineered fill pad.

Figure 8 shows the isotherms under the WTP building with 100 mm of insulation and thermosyphons at 1 m spacing after 40 years with the effects of climate warming of 0.08°C/year. In comparison to Figure 7 (with no climate warming), it is seen that the ground temperatures in Figure 8 are a few degrees warmer at any given depth as a result of climate warming for 40 years. Also, the active layer depth outside the building footprint (at the right-hand boundary of the model domain) has deepened. In Figure 8, representing 40 years of climate warming, the -2°C isotherm remains within the engineered frost-stable fill.

The geothermal modelling also considered a thermosyphon loop failure condition where one thermosyphon loop was inoperative for two consecutive winters. It is desirable that the flat loop

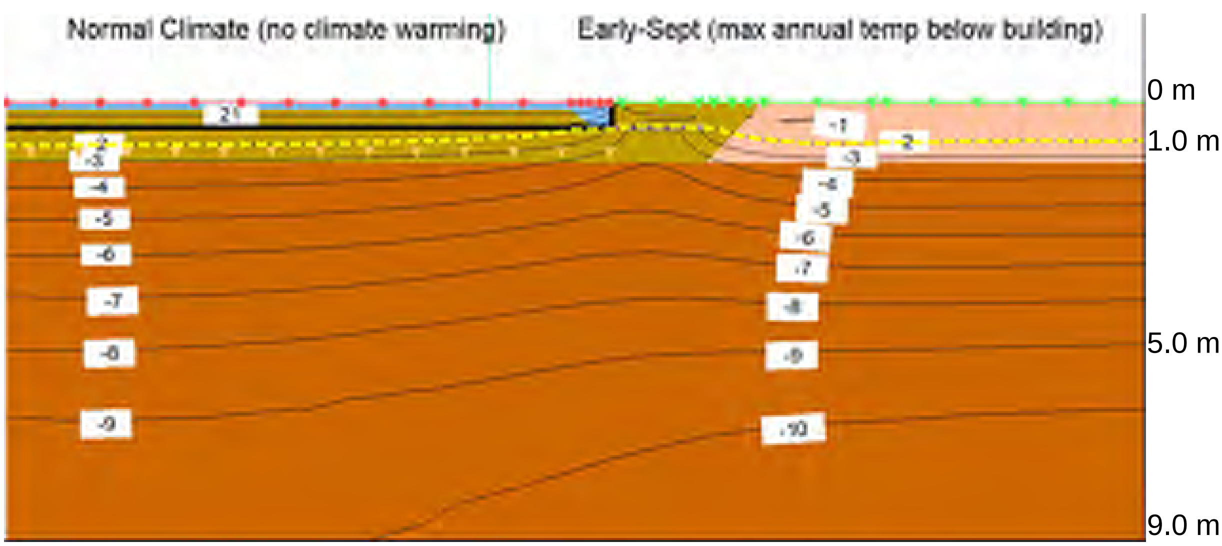


Figure 7 Isotherms under WTP building in late summer, with no climate warming. Thermosyphons at 1 m spacing and 100 mm rigid insulation.

thermosyphons provide sufficient redundancy to maintain frozen ground conditions in the event of a thermosyphon loop failure for a reasonable amount of time to accommodate detection and refurbishment of the failed thermosyphon. Figure 9 shows the effect of a single thermosyphon

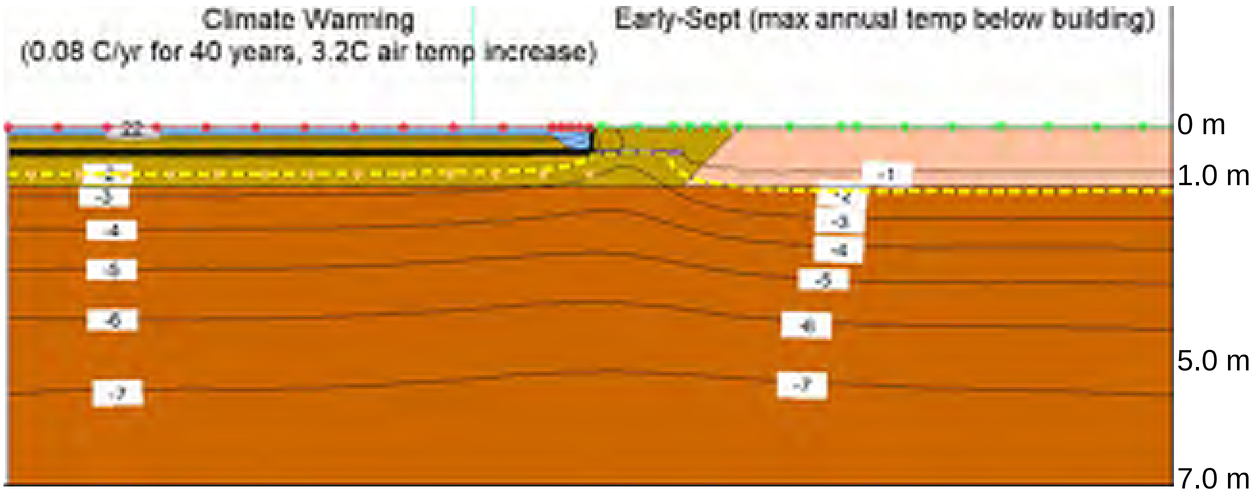


Figure 8 Isotherms under WTP building in late summer, after 40 years with climate warming. Thermosyphons at 1 m spacing and 100 mm rigid insulation.

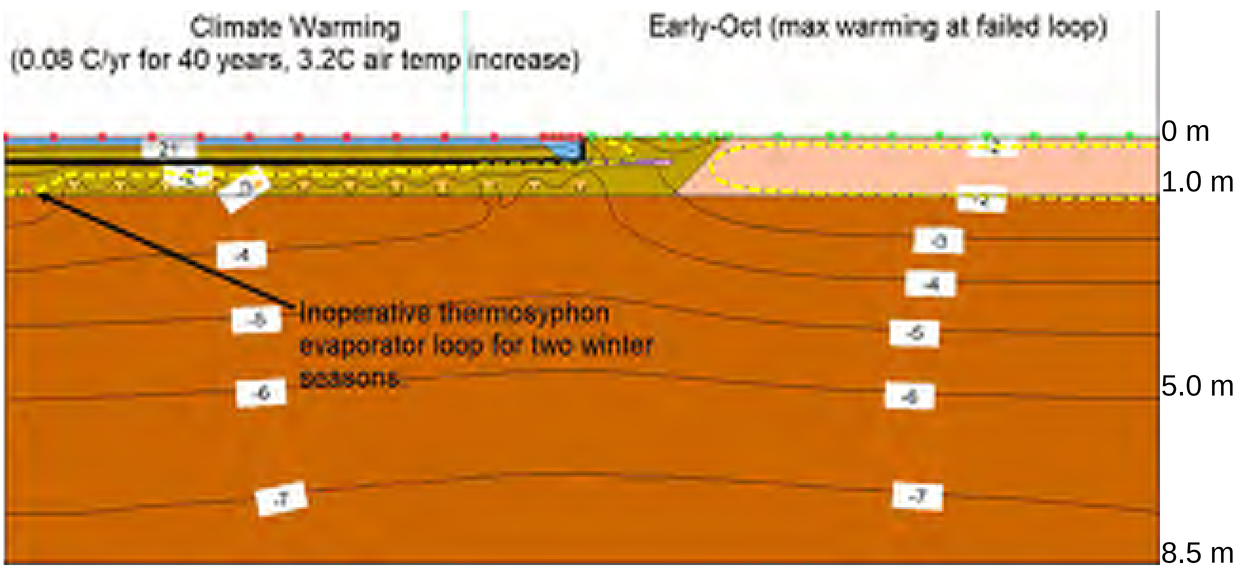


Figure 9 Isotherms under WTP building in early winter, after 40 years with climate warming with inoperative thermosyphon loops in centre of building. Thermosyphons at 1 m spacing and 100 mm rigid insulation.

loop under the centre of the structure (with 100 mm rigid insulation) becoming inoperative for two consecutive winters near the end of the project's life following 40 years of climate warming. Annually, the warmest ground temperatures near the inoperative thermosyphon occur in early October. The -2°C isotherm does not penetrate into the native soils below the frost-stable engineering fill pad. In the long-term, if an inoperative thermosyphon loop is not repaired or otherwise mitigated, a thaw bulb will likely form in the area of the inoperative thermosyphon. The vertical extent of the thaw bulb will be a function of several factors including thermosyphon location, length of time the thermo-syphon is inoperative and what remediation is applied (for example, recharging a leaking thermosyphons or increasing the radiator area of adjacent thermosyphons to extract more heat).

Implications of the modelling results are discussed in a following subsection.

<u>Potable Water and Wastewater Storage Tanks</u>

A model domain similar to the WTP was used to assess the ground temperatures under the exterior potable water and wastewater storage tanks. The model domain was similar to Figure 4 except the left vertical boundary of the domain is an axis of radial symmetry with a storage tank 4 m in radius (8 m diameter). Figure 10 shows the model domain for the storage tanks; no thermosyphons were considered in this case. A rigid insulation thickness of 100 mm was applied. The temperature at the base of the storage tanks was held constant at +10°C year-round.

Figure 11 presents the model-calculated ground temperatures beneath the water tank in mid-August with a 100 mm layer of rigid insulation within the engineered fill pad. No climate warming was applied. This represents conditions of warmest annual ground temperature and accordingly, the maximum annual active layer thaw depth. It is seen that the engineered fill pad does not warm above -6°C under the tank, even in late summer.

Figure 12 shows the effect of climate warming of 0.08°C/year for 40 years on the ground temperatures underlying the water storage tank with 100 mm insulation thickness. Ground temperatures at the base of the the subgrade below the tank remain colder than -2°C, even in the presence of long-term climate warming. In general, the ground temperatures under the water storage tank are nearly 5°C warmer when compared to the non-climate warming case, but still moderately cold, due to the relatively small footprint of the storage tanks combined with the very cold climate.

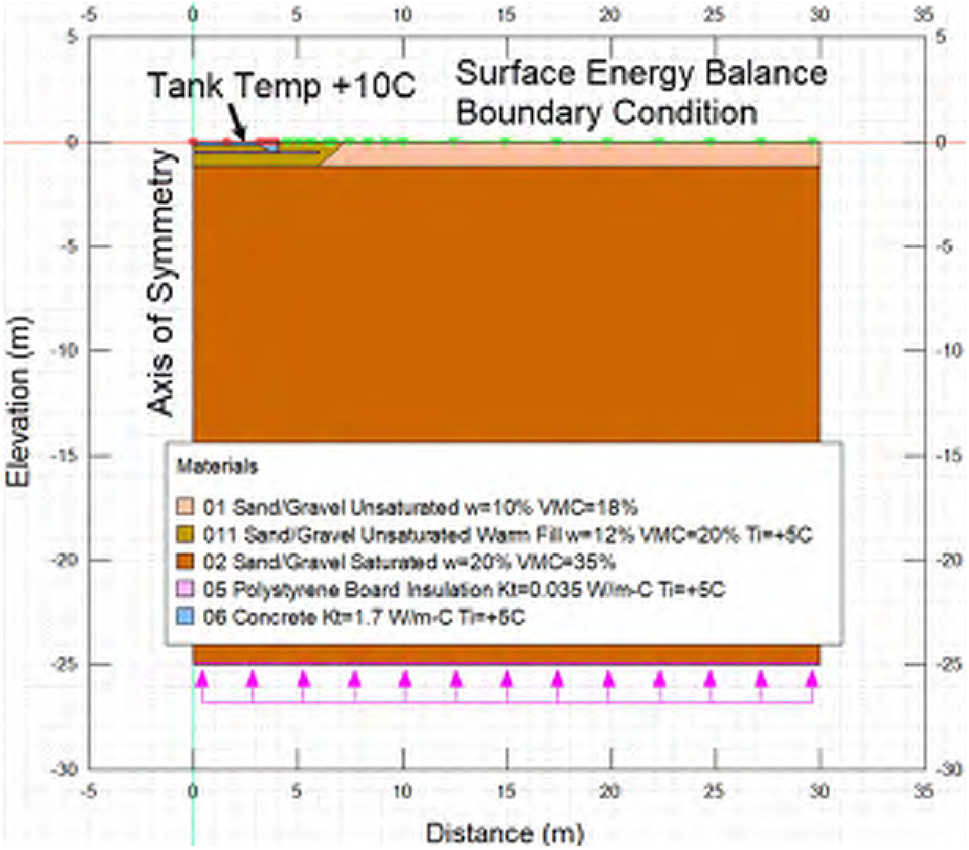


Figure 10 Model domain for exterior treated water and wastewater storage tanks.

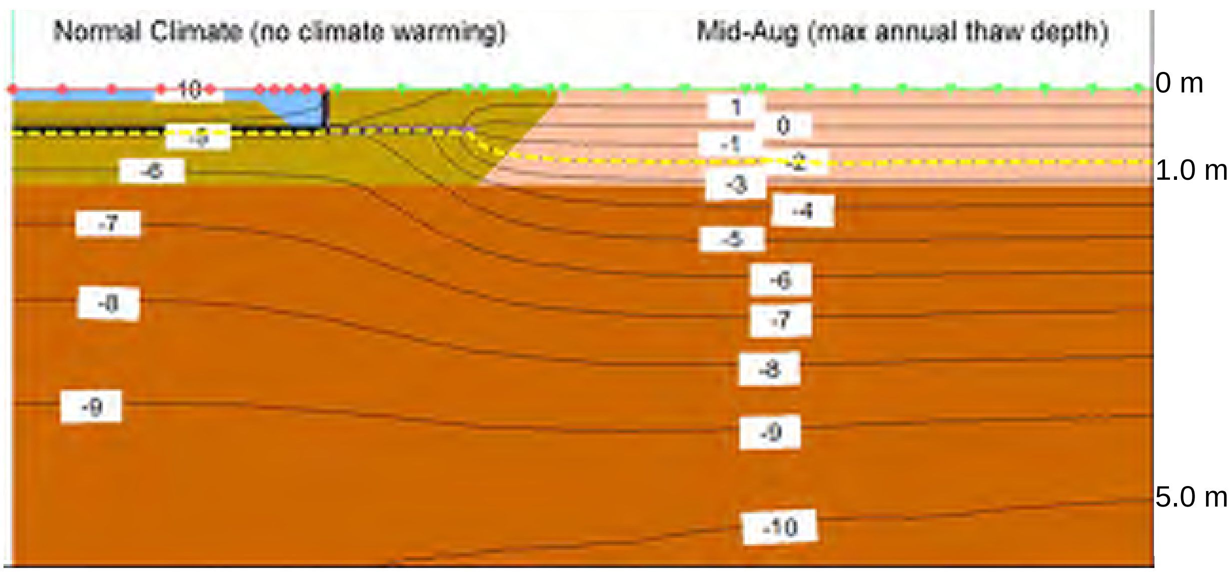


Figure 11 Isotherms under water storage tanks in late summer, with no climate warming. Insulation layer is 100 mm.

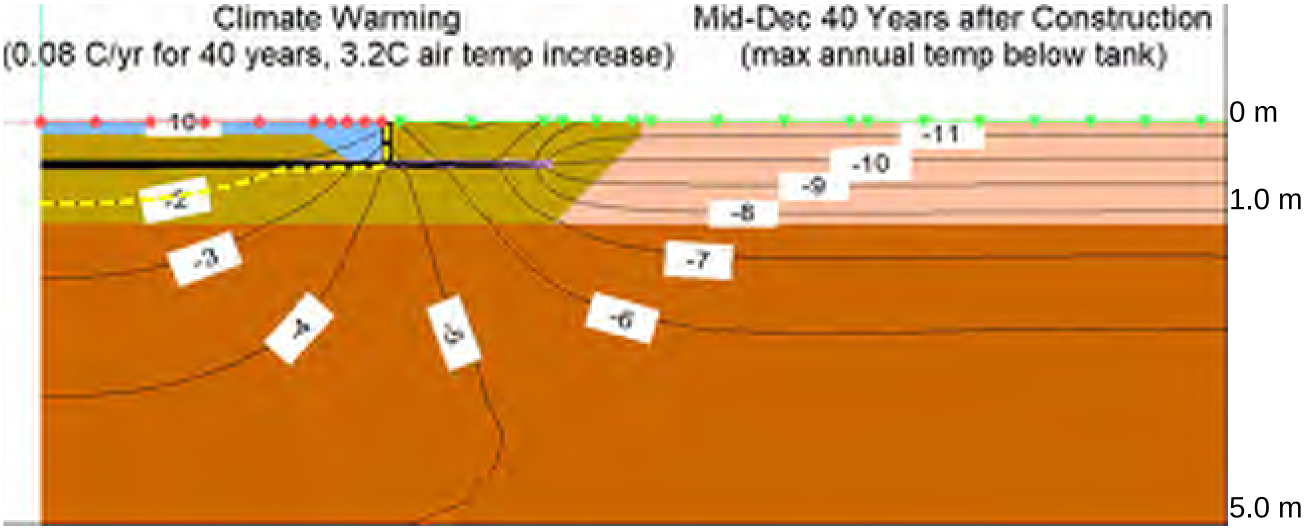


Figure 12 Isotherms under water storage tank in late summer, after 40 years with climate warming. Insulation thickness is 100 mm.

Discussion

The geothermal analysis has shown that a foundation system for the water treatment plant comprising an engineered fill pad with 100 mm of rigid insulation and a horizontal thermosyphon system represents a viable design case. The -2°C isotherm does not progress below the base of the thaw stable engineered fill pad. For the 8 m diameter water storage tanks, minimal thawing progresses below the 100 mm rigid insulation for the applied climate warming case.

Appendix A, appended to the end of this memo provides supplemental information regarding the design, construction, and maintenance of thermosyphons.

Assumptions and Limitations

The following are assumptions and limitations regarding the geothermal analysis reported herein:

- Available information: The geothermal modelling was based on available information regarding ground temperatures and climatic conditions for the Arctic Bay site, together with conceptual design drawings of the building foundation. It was assumed that this information is accurate.
- Soil index and thermal properties: Soil index properties for individual soil units were used to establish representative geothermal properties for those soil units based on relationships between soil index properties and geothermal properties as provided in Andersland and Ladanyi (2004). For soil units where soil index properties were unavailable, assumed index

properties based professional judgement were used to establish the geothermal properties for use in the geothermal model. Based on previous geothermal modelling experience, typical variations from the assumed index properties and the corresponding variation of the geothermal properties are not expected to significantly affect the geothermal model findings regarding long-term thermosyphon performance; however, no modelling sensitivity studies were done in this regard for this project.

- Design life and climate warming rate: It was assumed that the design life of the WTP building and tanks was 40 years. It was assumed that 0.08°C/year is an appropriately conservative climate warming rate, resulting in an increase in the mean annual air temperature (MAAT) of 3.2°C after 40 years. If the building design life is longer and/or the climate warming rate is higher, either or both resulting in a net MAAT increase greater than 3.2°C at the end of the building design life, then the thermosyphons may potentially be challenged to preserve permafrost below the building. With proper monitoring of foundation temperatures (as recommended in CSA, 2021), any such negative temperature impacts would be detected early enough to undertake thermal remedial measures. Remedial measures such as increasing the thermosyphon radiator area via a retrofit, is likely to have the most efficacy for reducing foundation temperatures, and would likely be the most cost effective, should any such mitigative measures ever be necessary.
- Groundwater: The geothermal modelling assumed no convective heat transfer from groundwater movement. It is important that the civil engineering earthworks be designed to inhibit groundwater flow within the engineered fill structure.
- Optimizations: No assessment for possible optimizations was performed. For example, assessment of the heat energy loss from the floor slab as a function of insulation thickness was not performed.
- Geothermal “factor of safety”: In many engineering projects a factor of safety is often applied to account for uncertainty in the various parameters involved in the design or analysis. In geothermal modelling, the best estimate of each of the parameters was used and no parameters were “factored” or adjusted to apply a factor of safety. To address the need for conservatism in design, one approach is to assign a design ground temperature that is colder than the expected freezing temperature. For example, the -1°C isotherm could be selected as the design temperature, which the base of insulation should not exceed. For this project a design ground temperature of -2°C was used after accounting for some expected pore water salinity. The geothermal modelling showed that the ground temperature at the base of the engineered fill pad did not exceed this design value when thermal mitigations (appropriate thickness of insulation and/or horizontal thermosyphons) were applied.

Summary and Recommendations

Based on the geothermal modelling conducted for this project, the following comments and recommendations are provided:

- The study indicates that a combination of 100 mm of rigid insulation and thermosyphons will preserve permafrost conditions within the engineered fill pad beneath the WTP building floor slab. The viable foundation configuration as modelled consisted of 100 mm thick polystyrene board insulation with a thermal conductivity of 0.035 W/m·°C, thermosyphons with a radiator area of 9.75 m^2 and 60 m loop length (0.16 m^2/m radiator area per metre loop length) with a flat loop evaporator pipe spacing of 1.0 m and with the flat loop piping located 450 mm below the bottom of the insulation.
- It is recommended that the engineered fill pad extending horizontally outward from the perimeter of the building or tanks be constructed to avoid surface water infiltration entering under the footing and to avoid the possibility of any water accumulation along the top of the insulation below the floor slab or tanks. All downspouts from the building or tanks should be directed to discharge at least 2 m from the perimeter of the building or tanks or preferably be collected and discharged in a perimeter drainage ditch at the project site. Surface water around the facility should be appropriately managed to reduce the potential for groundwater flow beneath or through the engineered fill pad.
- It is recommended that the thermosyphon flat loop evaporator piping spacing not exceed 1 m and that the thermosyphon radiators are designed such that the radiator area can be increased in the future, if necessary, as determined by temperature performance monitoring of the ground temperatures beneath the concrete floor slabs.
- The supplemental information regarding the design, construction, and maintenance of thermosyphons contained in Appendix A should be considered.

Closure

We trust this information is sufficient for your present needs. If you require additional information please contact the authors.

References

Andersland, O.B. and Ladanyi, B. 2004. Frozen ground engineering, 2nd edition. John Wiley and Sons. Toronto. 363 pgs.

CSA (Canadian Standards Association). 2021. Thermosyphon foundations for buildings in permafrost regions: CSA S500:21. Canadian Standards Association, Rexdale Ontario. 61 pgs.

Ednie, M., Smith, S.L. 2010. Establishment of community-based permafrost monitoring sites, Baffin region, Nunavut. Proceedings, 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference, Calgary AB, September 12-16: 1205-1211.

Ednie, M. and Smith, S.L. 2015. Permafrost temperature data 2008-2014 from community based monitoring sites in Nunavut; Geological Survey of Canada, Open File 7784, 1 .zip file. doi:10.4095/296705.

Appendix A
Recommendations for the use, design, installation and operational monitoring of horizontal loop thermosyphons
Arctic Bay Water Treatment Plant

1.0 Use of Thermosyphons

1.1 Thermosyphons may be used to intercept building heat entering the ground and provide subgrade cooling within an engineered fill pad.

1.2 Thermosyphons should be designed as a two-phase passive refrigeration device charged with a working fluid that transfers heat from the ground to the atmosphere. The device extracts heat from the ground by boiling (evaporation) of the working fluid within the ground and expels the heat to the atmosphere by condensation of the working fluid when it condenses from vapour to liquid. In general, the device operates when the air temperature is colder than the ground temperature.

1.3 The thermosyphon system applied to this project should comprise a flat-loop system consisting of the following system components:

- Thermosyphon: comprising an above-ground radiator, below ground evaporator section, laid in a horizontal loop pattern, and pressurized with an appropriate working fluid.
- Rigid extruded polystyrene: a layer of rigid polystyrene (or approved alternative) insulation placed directly above the thermosyphon flat-loop system. The compressive strength the insulation shall be appropriate for the vertical loads to be placed on it, including, but not limited to vertical stress from overlying granular materials, building floor loads, structural and occupancy loads. The insulation panels shall have overlapping edging to provide a tight fit between panels to reduce vertical air transmission between adjacent panels. Where multiple layers of insulation are placed to achieve the design thickness, vertical joints shall be off-set by at least 150 mm, wherever practicable. The thermal conductivity should be a maximum of 0.035 W/m°C.
- Bedding sand: well-graded sand with a maximum particle size of 4 mm, with less than 8 percent (by weight) smaller than 0.08 mm. Bedding sand should be used to provide a stable and uniform layer on which to install the thermosyphons, cover the thermosyphons and protect the thermosyphons from damage due to the presence of coarse or angular materials in the engineered fill. Bedding sand shall also be used to similarly provide a stable and uniform base and protect the rigid insulation from damage.
- Engineered fill: well-graded, non-saline granular soil with less than 10 percent (by weight) smaller than 0.08 mm, that is non-frost susceptible and thaw stable for use as a fill structure to support the building slab-on-grade and provide a structurally stable section within which the flat-loop thermosyphon system is laid. The engi-

neered fill should be compacted to at least 98 percent of standard Proctor maximum dry density at a water content of 0 to 3 percent over optimum water content.

2.0 Design of Thermosyphon System

2.1 The thermosyphons should be designed in accordance with CSA S500-21 (CSA, 2021). “Thermosyphon Foundations for New Buildings in Permafrost Regions”.

2.2 The thermosyphon system should be design with a service life at least as long as the expected service life of the structure, or 50 years, whichever is longer.

2.3 The thermosyphon design, including spacing of evaporators, size of radiators and performance under upset conditions should be confirmed by numerical thermal modelling.

2.4 The required design thickness and thermal conductivity of the rigid insulation should be verified by geothermal modelling.

2.5 The design of the thermosyphon system should account for the maximum building space heat, in-floor heating, and other sources of heat that may affect subgrade temperatures.

2.6 The design of the thermosyphon system should account for long-term climate warming appropriate for the location. See CSA Plus 4001-19 “Technical Guide: Infrastructure in permafrost: A guideline for climate change adaptation”. As an alternative to climate warming rates determined by global circulation models, a warming rate based on long-term historical data may be used.

2.7 The design should be such that the ground temperature below the insulation layer does exceed an appropriate “design ground temperature” at any time during the year and during the life of the structure. The design ground temperature should be determined in accordance with the project-specific factors, including pore water salinity, ground temperatures, project lifespan, criticality of the structure, confidence in input parameters and other considerations.

2.8 The engineered fill pad should not be less than 1 m total thickness.

2.9 The design and layout of the horizontal loops should be such that if one thermosyphon loop becomes inoperative for several years, the overall thermal and structural stability of the building foundation and floor slab, engineered fill pad and underlying subgrade is not compromised.

2.10 The radiator area should be set to the minimum practicable surface area available from the manufacturer. This limitation is provided to allow for increasing the radiator surface area in the future, if additional heat extraction capacity is required.

2.11 The horizontal thermosyphon loops and overlying rigid insulation should extend a minimum of 2 m beyond the exterior perimeter of the structure, or as dictated by the geothermal modelling.

3.0 Construction/Installation of Thermosyphon System

3.1 The manufacture of the thermosyphon system should comply with ASME Boiler and Pressure Vessel Code (latest version).

3.2 All welding should comply with CSA B51.

3.3 The layout and installation of the horizontal loops should be such that there are no vertical undulations along the length of the evaporator section.

3.4 The maximum length of the horizontal loops (outgoing and return) should not exceed 100 m to 150 m

3.5 The maximum spacing between horizontal loops should not exceed a lateral distance of 1.5 m, or as dictated by the geothermal modelling.

3.6 Where numerous thermosyphons are to be installed, consideration shall be given to splitting the layout of the thermosyphons such that all radiators are not placed in a single group but rather placed in two or more separate groups.

3.7 Where there is a potential for hydrocarbon fluids to leak into the subsurface and reach the rigid insulation (resulting in a deterioration of the insulating material), a suitable high density polyethylene liner should be installed over the entire floor area, immediately below the floor slab.

3.8 It is desirable that radiator sections be installed on the wintertime windward side of the building.

3.9 The radiator sections should be protected from damage by vehicles and vandalism. Concrete barriers, bollards and fencing should be placed to protect the radiators, as necessary.

3.10 Snow should not be permitted to accumulate around the radiator sections.

3.11 The radiators should be supported on an engineered footing/foundation and with structural connections to the building or with independent structural supports.

3.12 At least two multi-bead thermistor cables should be installed in a cross-pattern across the area of the structure shall be installed at the approximate elevation of the thermosyphons, but below the rigid insulation. A maximum spacing of the horizontal beads should be approximately 3 m, depending on the dimensions of the building. If practicable, a small diameter PVC casing may be installed into which the thermistor cable can be inserted later in construction. Where practicable, the leads for the thermistor cable should be carried to the ground surface and terminated in a safe and secure area (such as a secure junction box on the exterior of the structure or at junction box in the mechanical room). It is desirable, if practicable, that the horizontal thermistor casing be extended to a location with access to the horizontal casing is available should repair or replacement of the thermistor cable be required.

3.13 At least two vertical two multi-bead thermistor cables should be installed at two locations within the plan area of the structure. It may be desirable to install a small diameter PVC casing in a drill-hole into which the thermistor cable may be inserted during construction. The vertical thermistor cable should have thermistor beads to measure temperatures immediately below the floor slab, immediately below the insulation layer and at various depths to approximately 10 m below base of floor slab. The leads for the thermistor cable shall be carried to the ground surface and terminated in a safe and secure area (such as a secure junction box on the exterior of the structure or at junction box in the mechanical room). It is desirable, if practicable, that the vertical thermistor casing be extended to the floor slab with access to the vertical casing available should repair or replacement of the thermistor cable be required.

3.14 All instrumentation should be tested and verified to be working prior to placement of the floor slab.

3.15 Precise surveys of the layout of the horizontal loops should be taken to provide accurate locations of the loops as part of record (as-built) drawings of the construction.

3.16 A photographic record of the horizontal loops should be made prior to placement of any fill over the thermistor loops. All photographs should be GPS geo-referenced and date stamped.

3.17 Complete installation records, including all quality control and inspection recordings, testing and quality assurance records should be prepared and provided to the Owner as part of final project turn-over.

4.0 Operational Monitoring and Maintenance

4.1 The thermosyphon manufacturer should prepare an operations monitoring and maintenance plan to be provided to the building operator.

4.2 Ground temperatures in the thermistor cable should be measured and recorded in mid-September each year and the temperature data provided to the engineer-of-record for review and evaluation. Where ground temperature immediately below the insulation layer are found to be approaching the design ground temperature at any time, the thermosyphon manufacturer and the engineer-of-record shall be notified immediately.

4.3 When the air temperature is -15°C or lower a thermal imaging camera should be used to photograph the radiators. Where the infrared image shows a “cool” radiator, the manufacturer should be contacted and repairs undertaken. This action shall be performed at least once per year.

4.4 A infrared digital thermometer may be used to check the performance of the radiators. In winter, the radiator should have a surface temperature warmer than the air temperature. Where the infrared digital thermometer shows a “cool” radiator, the manufacturer should be contacted and repairs undertaken. This action shall be performed at least twice per year, with one month between readings.

Appendix B: Results of Chemical Tests for Arctic Bay, Sites 1, 3 and 4

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2650 QUEENSVIEW DRIVE, UNIT 100
OTTAWA, ON K2B8H6
(613) 688-1899

ATTENTION TO: SURINDER AGGARWAL

PROJECT: FRN-21016638-AO

AGAT WORK ORDER: 21Z835686

SOIL ANALYSIS REVIEWED BY: Nivine Basily, Inorganics Report Writer

DATE REPORTED: Dec 03, 2021

PAGES (INCLUDING COVER): 5

VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (905) 712-5100

*Notes

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Certificate of Analysis

AGAT WORK ORDER: 21Z835686
PROJECT: FRN-21016638-AO

CLIENT NAME: EXP SERVICES INC
ATTENTION TO: SURINDER AGGARWAL
SAMPLING SITE:Arctic Bag, Nunavut Site 1
SAMPLED BY:EXP

Inorganic Chemistry (Soil)

DATE RECEIVED: 2021-11-26
DATE REPORTED: 2021-12-03

			SAMPLE DESCRIPTION:	BH1 S2 1.2m	BH2 S6 5.6	BH3 S3 2.3m	BH4 S8 7.8m	BH5 S2 1.2m	BH6 S2 1.2m	BH7 S3 2.3m
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2021-10-20	2021-10-20	2021-10-20	2021-10-20	2021-10-20	2021-10-20	2021-10-20
Parameter	Unit	G / S	RDL	3262223	3262224	3262225	3262226	3262227	3262228	3262229
Chloride (2:1)	µg/g		2	6	12	554	7	2	193	145
Sulphate (2:1)	µg/g		2	6	7	642	63	6	15	14
pH (2:1)	pH Units		NA	7.54	7.58	7.19	7.71	7.23	7.05	7.09
Electrical Conductivity (2:1)	mS/cm		0.005	0.038	0.052	1.65	0.115	0.025	0.344	0.264
Resistivity (2:1) (Calculated)	ohm.cm		1	26300	19200	606	8700	40000	2910	3790

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

3262223-3262229 pH, Chloride and Sulphate were determined on the extract obtained from the 2:1 leaching procedure (2 parts DI water: 1 part soil). Resistivity is a calculated parameter.

Analysis performed at AGAT Toronto (unless marked by *)

Certified By:

Results relate only to the items tested. Results apply to samples as received.

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Quality Assurance

CLIENT NAME: EXP SERVICES INC
PROJECT: FRN-21016638-AO
SAMPLING SITE:Arctic Bag, Nunavut Site 1

AGAT WORK ORDER: 21Z835686
ATTENTION TO: SURINDER AGGARWAL
SAMPLED BY:EXP

Soil Analysis

RPT Date: Dec 03, 2021			DUPLICATE				REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD	Method Blank	Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Inorganic Chemistry (Soil)															
Chloride (2:1)	3262223	3262223	6	6	NA	< 2	91%	70%	130%	103%	80%	120%	104%	70%	130%
Sulphate (2:1)	3262223	3262223	6	6	NA	< 2	97%	70%	130%	99%	80%	120%	103%	70%	130%
pH (2:1)	3283973		8.09	8.12	0.4%	NA	102%	80%	120%						
Electrical Conductivity (2:1)	3262223	3262223	0.038	0.040	5.1%	< 0.005	101%	80%	120%						

Comments: NA signifies Not Applicable.
pH duplicates QA acceptance criteria was met relative as stated in Table 5-15 of Analytical Protocol document.

Duplicate NA: results are under 5X the RDL and will not be calculated.

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Results relate only to the items tested. Results apply to samples as received.

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Method Summary

CLIENT NAME: EXP SERVICES INC
AGAT WORK ORDER: 21Z835686
PROJECT: FRN-21016638-AO
ATTENTION TO: SURINDER AGGARWAL
SAMPLING SITE:Arctic Bag, Nunavut Site 1
SAMPLED BY:EXP

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
Chloride (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
Sulphate (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
pH (2:1)	INOR 93-6031	modified from EPA 9045D and MCKEAGUE 3.11	PH METER
Electrical Conductivity (2:1)	INOR-93-6036	modified from MSA PART 3, CH 14 and SM 2510 B	EC METER
Resistivity (2:1) (Calculated)	INOR-93-6036	McKeague 4.12, SM 2510 B,SSA #5 Part 3	CALCULATION

Results relate only to the items tested. Results apply to samples as received.

AGAT Laboratories

1 Large Ice Pack

5835 Coopers Avenue
Mississauga, Ontario L4Z 1Y2
Ph: 905.712.5100 Fax: 905.712.5122
webearth.agatlabs.com

Laboratory Use Only

Work Order #: 21Z835686

Cooler Quantity: bag

Arrival Temperatures: 19.7 | 19.5 | 19.7
3.9 | 4.0 | 4.1

Custody Seal Intact: ☐Yes ☐No ☐N/A

Notes:

Chain of Custody Record

If this is a Drinking Water sample, please use Drinking Water Chain of Custody Form (potable water consumed by humans)

Report Information:

Company: EXP
Contact: Surinder Aggarwal
Address: 2650 Queensview Drive Suite 100
Ottawa ON K2B 8H6
Phone: 613-688-1899 Fax:
Reports to be sent to:
1. Email: Surinder.Aggarwal@exp.com
2. Email: Ryan.Diguiseppe@exp.com

Regulatory Requirements:

(Please check all applicable boxes)

☐ Regulation 153/04 — Table ____ (Indicate One): ☐Ind/Com ☐Res/Park ☐Agriculture
Soil Texture (Check One): ☐Coarse ☐Fine

☐ Excess Soils R406 — Table ____ (Indicate One)
☐ Regulation 558
☐ CCME

☐ Sewer Use: ☐Sanitary ☐Storm — Region ____
☐ Prov. Water Quality Objectives (PWQO)
☐ Other ____ (Indicate One)

Is this submission for a Record of Site Condition? ☐ Yes ☐ No

Report Guideline on *Certificate of Analysis* ☐ Yes ☐ No

Turnaround Time (TAT) Required:

Regular TAT (Most Analysis) ☑ 5 to 7 Business Days

Rush TAT (Rush Surcharges Apply)

☐ 3 Business Days ☐ 2 Business Days ☐ Next Business Day

OR Date Required (Rush Surcharges May Apply):

Please provide prior notification for rush TAT
*TAT is exclusive of weekends and statutory holidays

For 'Same Day' analysis, please contact your AGAT CPM

Project Information:

Project: FRN-21016638-A0
Site Location: Arctic Bay, Nunavut Site 1
Sampled By: EXP
AGAT ID #: PO:

Please note: If quotation number is not provided, client will be billed full price for analysis.

Invoice Information:

Bill To Same: Yes ☑ No ☐

Company:
Contact:
Address:
Email:

Sample Matrix Legend

B	Biota
GW	Ground Water
O	Oil
P	Paint
S	Soil
SD	Sediment
SW	Surface Water

Sample Identification	Date Sampled	Time Sampled	# of Containers	Sample Matrix	Comments/ Special Instructions	Field Filtered - Metals, Hg, CrVI, DOC (Y/N)	Metals & Inorganics	Metals - ☐ CrVI, ☐ Hg, ☐ HWSB	BTEX, F1-F4 PHCs	Analyze F4G if required ☐ Yes ☐ No	PAHs	Total PCBs ☐ Aroclor	VOC	Landfill Disposal Characterization TCLP: TCLP: ☐ M&I ☐ VOCs ☐ ABNs ☐ B(a)P ☐ PCBs	Excess Soils SPLP Rainwater Leach SPLP: ☐ Metals ☐ VOCs ☐ SVOCs	Excess Soils Characterization Package pH, ICPMS Metals, BTEX, F1-F4	Salt - EC/SAR	pH	Sulphate	Chloride	Electro Conduc / Resis.					Potentially Hazardous or High Concentration (Y/N)
BH 1 s2 1-2m	Oct 2021	AM PM	1															✓	✓	✓	✓					
BH 2 s6 5-6m		AM PM	1																							
BH 3 s3 2-3m		AM PM																								
BH 4 s8 7-8m		AM PM																								
BH 5 s2 1-2m		AM PM																								
BH 6 s2 1-2m		AM PM																								
BH 7 s3 2-3m	↓	AM PM	↓															✓	✓	✓	✓					
		AM PM																								
		AM PM																								
		AM PM																								
		AM PM																								

Samples Relinquished By (Print Name and Sign)	Date	Time	Samples Received By (Print Name and Sign)	Date	Time
Ryan DiGiuseppe	Nov 25/21	5:00pm	C Griffiths	Nov 26/21	08h00
C Griffith	Nov 26/21	16h00	Anthony Davidson		

'21 NOV 27 11:09AM

Page ____ of ____

Nº: T 114899

Pink Copy - Client | Yellow Copy - AGAT | White Copy - AGAT

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MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
http://www.agatlabs.com

CLIENT NAME: EXP SERVICES INC
2650 QUEENSVIEW DRIVE, UNIT 100
OTTAWA, ON K2B8H6
(613) 688-1899

ATTENTION TO: SURINDER AGGARWAL

PROJECT: FRN-21016638-AO

AGAT WORK ORDER: 21Z841144

SOIL ANALYSIS REVIEWED BY: Amanjot Bhela, Inorganic Lab Manager

DATE REPORTED: Dec 16, 2021

PAGES (INCLUDING COVER): 5

VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (905) 712-5100

*Notes

Disclaimer:

- *All work conducted herein has been done using accepted standard protocols, and generally accepted practices and methods. AGAT test methods may incorporate modifications from the specified reference methods to improve performance.*
- *All samples will be disposed of within 30 days after receipt unless a Long Term Storage Agreement is signed and returned. Some specialty analysis may be exempt, please contact your Client Project Manager for details.*
- *AGAT's liability in connection with any delay, performance or non-performance of these services is only to the Client and does not extend to any other third party. Unless expressly agreed otherwise in writing, AGAT's liability is limited to the actual cost of the specific analysis or analyses included in the services.*
- *This Certificate shall not be reproduced except in full, without the written approval of the laboratory.*
- *The test results reported herewith relate only to the samples as received by the laboratory.*
- *Application of guidelines is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to, warranties of merchantability, fitness for a particular purpose, or non-infringement. AGAT assumes no responsibility for any errors or omissions in the guidelines contained in this document.*
- *All reportable information as specified by ISO/IEC 17025:2017 is available from AGAT Laboratories upon request.*

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Western Enviro-Agricultural Laboratory Association (WEALA)
Environmental Services Association of Alberta (ESAA)

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AGAT Laboratories
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CANADA L4Z 1Y2
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FAX (905)712-5122
http://www.agatlabs.com

Certificate of Analysis

AGAT WORK ORDER: 21Z841144
PROJECT: FRN-21016638-AO

CLIENT NAME: EXP SERVICES INC
ATTENTION TO: SURINDER AGGARWAL
SAMPLING SITE:Arctic Bay, Nunavut - Site 3
SAMPLED BY:EXP

Inorganic Chemistry (Soil)

DATE RECEIVED: 2021-12-07
DATE REPORTED: 2021-12-16

			SAMPLE DESCRIPTION:	BH1 S2 1.2m	BH2 S3 2.3m	BH3 S3 2.3m	BH4 S5 4.5m	BH5 S2 1.2m
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2021-10-01	2021-10-01	2021-10-01	2021-10-01	2021-10-01
Parameter	Unit	G / S	RDL	3312893	3312909	3312910	3312911	3312912
pH, 2:1 CaCl2 Extraction	pH Units		NA	6.82	6.85	7.06	7.18	6.54
Electrical Conductivity (2:1)	mS/cm		0.005		0.388	0.364	2.55	0.197
Chloride (2:1)	µg/g		2	69	179	121	1320	76
Sulphate (2:1)	µg/g		2	21	61	116	657	18
Resistivity (2:1) (Calculated)	ohm.cm		1	5350	2580	2750	392	5080

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

3312893-3312912 EC, Chloride and sulphate was determined on the DI water extract obtained from the 2:1 leaching procedure (2 parts DI water:1 part soil). pH was determined on the 0.01M CaCl2 extract obtained from 2:1 leaching procedure (2 parts extraction fluid:1 part wet soil).

Analysis performed at AGAT Toronto (unless marked by *)

Certified By:

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Quality Assurance

CLIENT NAME: EXP SERVICES INC
PROJECT: FRN-21016638-AO
SAMPLING SITE:Arctic Bay, Nunavut - Site 3

AGAT WORK ORDER: 21Z841144
ATTENTION TO: SURINDER AGGARWAL
SAMPLED BY:EXP

Soil Analysis

RPT Date: Dec 16, 2021			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Inorganic Chemistry (Soil)															
Electrical Conductivity (2:1)	3337822		0.162	0.166	2.4%	< 0.005	106%	80%	120%	NA			NA		
pH, 2:1 CaCl2 Extraction	3312912	3312912	6.54	6.89	5.2%	NA	100%	80%	120%	NA			NA		
Chloride (2:1)	3312865		209	211	1.0%	< 2	98%	70%	130%	105%	80%	120%	107%	70%	130%
Sulphate (2:1)	3312865		653	659	0.9%	< 2	100%	70%	130%	104%	80%	120%	NA	70%	130%

Comments: NA Signifies Not Applicable
Matrix spike NA: Spike level < native concentration. Matrix spike acceptance limits do not apply and are not calculated.

Inorganic Chemistry (Soil)															
pH, 2:1 CaCl2 Extraction	3337822		6.62	6.78	2.4%		100%	80%	120%	NA			NA		

Certified By:

AGAT Laboratories is accredited to ISO/IEC 17025 by the Canadian Association for Laboratory Accreditation Inc. (CALA) and/or Standards Council of Canada (SCC) for specific tests listed on the scope of accreditation. AGAT Laboratories (Mississauga) is also accredited by the Canadian Association for Laboratory Accreditation Inc. (CALA) for specific drinking water tests. Accreditations are location and parameter specific. A complete listing of parameters for each location is available from www.cala.ca and/or www.scc.ca. The tests in this report may not necessarily be included in the scope of accreditation. RPDs calculated using raw data. The RPD may not be reflective of duplicate values shown, due to rounding of final results.

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MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
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FAX (905)712-5122
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Method Summary

CLIENT NAME: EXP SERVICES INC
AGAT WORK ORDER: 21Z841144
PROJECT: FRN-21016638-AO
ATTENTION TO: SURINDER AGGARWAL
SAMPLING SITE:Arctic Bay, Nunavut - Site 3
SAMPLED BY:EXP

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
Electrical Conductivity (2:1)	INOR-93-6036	modified from MSA PART 3, CH 14 and SM 2510 B	EC METER
pH, 2:1 CaCl2 Extraction	INOR-93-6031	modified from EPA 9045D and MCKEAGUE 3.11	PH METER
Chloride (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
Sulphate (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
Resistivity (2:1) (Calculated)	INOR-93-6036	McKeague 4.12, SM 2510 B,SSA #5 Part 3	EC METER

Results relate only to the items tested. Results apply to samples as received.

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Ph: 905.712.5100 Fax: 905.712.5122
webearth.agatlabs.com

Laboratory Use Only

Work Order #: 21Z841144

Cooler Quantity: one bag

Arrival Temperatures: 20.2 | 20.1 | 20.0 ; 2.5 | 2.8 | 3.1

Custody Seal Intact: ☐ Yes ☐ No ☐ N/A

Notes: ice packs

Chain of Custody Record

If this is a Drinking Water sample, please use Drinking Water Chain of Custody Form (potable water consumed by humans)

Report Information:

Company: EXP
Contact: Surinder Aggarwal
Address: 2650 Queensview Drive Suite 100
Ottawa ON K2B 8H6
Phone: 613-688-1899 Fax:
Reports to be sent to:
1. Email: Surinder.Aggarwal@exp.com
2. Email: Ryan.Digiuseppe@exp.com

Regulatory Requirements:

(Please check all applicable boxes)

☐ Regulation 153/04
Table ____ Indicate One
☐ Ind/Com
☐ Res/Park
☐ Agriculture

Soil Texture (Check One)
☐ Coarse
☐ Fine

☐ Excess Soils R406
Table ____ Indicate One

☐ Regulation 558

☐ CCME

☐ Sewer Use
☐ Sanitary ☐ Storm
____ Region

☐ Prov. Water Quality Objectives (PWQO)

☐ Other
____ Indicate One

Is this submission for a **Record of Site Condition?** ☐ Yes ☐ No

Report Guideline on *Certificate of Analysis* ☐ Yes ☐ No

Turnaround Time (TAT) Required:

Regular TAT (Most Analysis) ☒ 5 to 7 Business Days

Rush TAT (Rush Surcharges Apply)

☐ 3 Business Days ☐ 2 Business Days ☐ Next Business Day

OR Date Required (Rush Surcharges May Apply):

Please provide prior notification for rush TAT
**TAT is exclusive of weekends and statutory holidays*

For 'Same Day' analysis, please contact your AGAT CPM

Project Information:

Project: FRN-21016636-A0
Site Location: Arctic Bay, Nunavut - Site 3
Sampled By: EXP
AGAT ID #: PO:

Please note: If quotation number is not provided, client will be billed full price for analysis.

Invoice Information:

Bill To Same: Yes ☒ No ☐

Company:
Contact:
Address:
Email:

Sample Matrix Legend

B	Biota
GW	Ground Water
O	Oil
P	Paint
S	Soil
SD	Sediment
SW	Surface Water

Sample Identification	Date Sampled	Time Sampled	# of Containers	Sample Matrix	Comments/ Special Instructions	Field Filtered - Metals, Hg, CrVI, DOC (Y/N)	O. Reg 153: Metals & Inorganics	O. Reg 153: Metals - ☐ CrVI, ☐ Hg, ☐ HWSB	O. Reg 153: BTEX, F1-F4 PHCs; Analyze F4G if required ☐ Yes ☐ No	PAHs	Total PCBs ☐ Aroclor	VOC	O. Reg 558: Landfill Disposal Characterization TCLP; TCLP: ☐ M&I ☐ VOCs ☐ ABNs ☐ B(a)P ☐ PCBs	O. Reg 406: Excess Soils SPLP Rainwater Leach; SPLP: ☐ Metals ☐ VOCs ☐ SVOCs	O. Reg 406: Excess Soils Characterization Package; pH, ICPMS Metals, BTEX, F1-F4	Salt - EC/SAR	pH	Sulphate	Chloride	Elec Conduc / Resistivity				Potentially Hazardous or High Concentration (Y/N)
BH 1 s2 1-2m	Oct 1/21	AM PM	1														✓	✓	✓	✓				
BH 2 s3 2-3m	Oct 1	AM PM																						
BH 3 s3 2-3m	Oct 1	AM PM																						
BH 4 s5 4-5m	Oct 1	AM PM																						
BH 5 s2 1-2m	Oct 1	AM PM															✓	✓	✓	✓				
		AM PM																						
		AM PM																						
		AM PM																						
		AM PM																						
		AM PM																						
		AM PM																						

Samples Relinquished By (Print Name and Sign)	Date	Time	Samples Received By (Print Name and Sign)	Date	Time
Ryan DiGiuseppe	Dec 6/21	5:00pm	C. Griffith	Dec.07/21	08h05
CG to Puro	Dec.07/21	16h00	Dave Eastman	12/8/21	8:34 am

Page 1 of 1

Nº: T114902

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CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
http://www.agatlabs.com

CLIENT NAME: EXP SERVICES INC
2650 QUEENSVIEW DRIVE, UNIT 100
OTTAWA, ON K2B8H6
(613) 688-1899
ATTENTION TO: SURINDER AGGARWAL
PROJECT: FRN-21016638-AO
AGAT WORK ORDER: 21Z841141
SOIL ANALYSIS REVIEWED BY: Amanjot Bhela, Inorganic Lab Manager
DATE REPORTED: Dec 29, 2021
PAGES (INCLUDING COVER): 5
VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (905) 712-5100

*Notes

Disclaimer:

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Mississauga, Ontario L4Z 1Y2
Ph: 905.712.5100 Fax: 905.712.5122
webearth.agatlabs.com

Laboratory Use Only

Work Order #: 21Z841141

Cooler Quantity: one bag
Arrival Temperatures: 20.1 | 20.0 | 19.9 ; 2.5 | 2.8 | 3.1

Custody Seal Intact: ☐Yes ☐No ☐N/A
Notes: ice packs

Chain of Custody Record

If this is a Drinking Water sample, please use Drinking Water Chain of Custody Form (potable water consumed by humans)

Report Information:

Company: EXP
Contact: Surinder Aggarwal
Address: 2650 Queensview drive Suite 100
Ottawa ON K2B 8H6
Phone: 613-688-1899 Fax:
Reports to be sent to:
1. Email: Surinder.Aggarwal@Exp.com
2. Email: Ryan.DiGiuseppe@exp.com

Project Information:

Project: FRU-21016638-A0
Site Location: Arctic Bay, Nunavut - Site 4
Sampled By: EXP
AGAT ID #: PO:

Please note: If quotation number is not provided, client will be billed full price for analysis.

Invoice Information:

Bill To Same: Yes ☒ No ☐

Company:
Contact:
Address:
Email:

Regulatory Requirements:

(Please check all applicable boxes)

☐ Regulation 153/04 — Table (Indicate One): ☐Ind/Com ☐Res/Park ☐Agriculture; Soil Texture (check One): ☐Coarse ☐Fine

☐ Excess Soils R406 — Table (Indicate One)

☐ Regulation 558

☐ CCME

☐ Sewer Use ☐Sanitary ☐Storm — Region

☐ Prov. Water Quality Objectives (PWQO)

☐ Other (Indicate One)

Is this submission for a Record of Site Condition? ☐ Yes ☐ No

Report Guideline on Certificate of Analysis ☐ Yes ☐ No

Turnaround Time (TAT) Required:

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Rush TAT (Rush Surcharges Apply)

☐ 3 Business Days ☐ 2 Business Days ☐ Next Business Day

OR Date Required (Rush Surcharges May Apply):

Please provide prior notification for rush TAT
*TAT is exclusive of weekends and statutory holidays

For 'Same Day' analysis, please contact your AGAT CPM

Sample Matrix Legend

- **B** Biota
- **GW** Ground Water
- **O** Oil
- **P** Paint
- **S** Soil
- **SD** Sediment
- **SW** Surface Water

Sample Identification	Date Sampled	Time Sampled	# of Containers	Sample Matrix	Comments/ Special Instructions	Field Filtered - Metals, Hg, CVI, DOC (Y/N)	Metals & Inorganics (O. Reg 153)	Metals - ☐CVI ☐Hg ☐HWSB	BTEX, F1-F4 PHCs	Analyze F4G if required ☐Yes ☐No	PAHs	Total PCBs ☐Aroclor	VOC	Landfill Disposal Characterization TCLP: TCLP: ☐M&I ☐VOCs ☐ABNs ☐B(a)P ☐PCBs (O. Reg 558)	Excess Soils SPLP Rainwater Leach SPLP: ☐Metals ☐VOCs ☐SVOCs (O. Reg 406)	Excess Soils Characterization Package pH, ICPMS Metals, BTEX, F1-F4	Salt - EC/SAR	pH	Sulphate	Chloride	Elec Conduc / Resistivity			Potentially Hazardous or High Concentration (Y/N)
BH 1 S2 1.2m	Oct 3/21	AM PM	1															✓	✓	✓	✓			
BH 2 S3 2.3m	↓	AM PM	↓															↓	↓	↓	↓			
BH 3 S2 1.2m		AM PM																						
BH 4 S5 4.5m		AM PM																						
BH 5 S2 1.2m		AM PM																✓	✓	✓	✓			
TP 1 0-3'	Oct 2/21	AM PM																						
		AM PM																						
		AM PM																						
		AM PM																						
		AM PM																						
		AM PM																						

Samples Relinquished By (Print Name and Sign): Ryan DiGiuseppe	Date: Dec 6/21	Time: 5:00pm	Samples Received By (Print Name and Sign): C. Griffith	Date: Dec 07/21	Time: 08h05	Page 1 of 1
Samples Relinquished By (Print Name and Sign): C. Griffith	Date: Dec 07/21	Time: 16h00	Samples Received By (Print Name and Sign): Hana Eastman	Date: 12/8/21	Time: 8:36 am	
Samples Relinquished By (Print Name and Sign):	Date:	Time:	Samples Received By (Print Name and Sign):	Date:	Time:	№: T 114901

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Document ID: DIV-78-1511.020

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MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
http://www.agatlabs.com

Method Summary

CLIENT NAME: EXP SERVICES INC
PROJECT: FRN-21016638-AO
SAMPLING SITE:Arctic Bay, Nunavut - Site 4
AGAT WORK ORDER: 21Z841141
ATTENTION TO: SURINDER AGGARWAL
SAMPLED BY:EXP

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
pH, 2:1 CaCl2 Extraction	INOR-93-6031	modified from EPA 9045D and MCKEAGUE 3.11	PH METER
Chloride (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
Sulphate (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
Resistivity (2:1) (Calculated)	INOR-93-6036	McKeague 4.12, SM 2510 B,SSA #5 Part 3	EC METER

Results relate only to the items tested. Results apply to samples as received.

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AGAT Laboratories

Quality Assurance

CLIENT NAME: EXP SERVICES INC
PROJECT: FRN-21016638-AO
SAMPLING SITE:Arctic Bay, Nunavut - Site 4

AGAT WORK ORDER: 21Z841141
ATTENTION TO: SURINDER AGGARWAL
SAMPLED BY:EXP

Soil Analysis

RPT Date: Dec 29, 2021			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits Lower	Acceptable Limits Upper	Recovery	Acceptable Limits Lower	Acceptable Limits Upper	Recovery	Acceptable Limits Lower	Acceptable Limits Upper
Inorganic Chemistry (Soil)															
pH, 2:1 CaCl2 Extraction	3312912		6.54	6.89	5.2%	NA	100%	80%	120%						
Chloride (2:1)	3312865	3312865	209	211	1.0%	< 2	98%	70%	130%	105%	80%	120%	107%	70%	130%
Sulphate (2:1)	3312865	3312865	653	659	0.9%	< 2	100%	70%	130%	104%	80%	120%	NA	70%	130%

Comments: NA Signifies Not Applicable.
Duplicate NA: results are less than 5X the RDL and RPD will not be calculated.
Matrix spike: Spike level < native concentration. Matrix spike acceptance limits do not apply.

Certified By:

AGAT Laboratories is accredited to ISO/IEC 17025 by the Canadian Association for Laboratory Accreditation Inc. (CALA) and/or Standards Council of Canada (SCC) for specific tests listed on the scope of accreditation. AGAT Laboratories (Mississauga) is also accredited by the Canadian Association for Laboratory Accreditation Inc. (CALA) for specific drinking water tests. Accreditations are location and parameter specific. A complete listing of parameters for each location is available from www.cala.ca and/or www.scc.ca. The tests in this report may not necessarily be included in the scope of accreditation. RPDs calculated using raw data. The RPD may not be reflective of duplicate values shown, due to rounding of final results.

Results relate only to the items tested. Results apply to samples as received.

AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 21Z841141
PROJECT: FRN-21016638-AO

5835 COOPERS AVENUE
MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
http://www.agatlabs.com

CLIENT NAME: EXP SERVICES INC
SAMPLING SITE:Arctic Bay, Nunavut - Site 4

ATTENTION TO: SURINDER AGGARWAL
SAMPLED BY:EXP

Inorganic Chemistry (Soil)

DATE RECEIVED: 2021-12-07 **DATE REPORTED: 2021-12-29**

Parameter	Unit	G / S	RDL	BH1 S2 1.2m	BH2 S3 2.3m	BH3 S2 1.2m	BH4 S5 4.5m	BH5 S5 1.2m	TD1 0.3'
SAMPLE TYPE:				Soil	Soil	Soil	Soil	Soil	Soil
DATE SAMPLED:				2021-10-03	2021-10-03	2021-10-03	2021-10-03	2021-10-03	2021-10-02
				3312865	3312866	3312867	3312868	3312869	3312870
pH, 2:1 CaCl2 Extraction	pH Units		NA	7.30	7.21	7.25	7.33	7.27	7.23
Chloride (2:1)	µg/g		2	209	415	491	1120	896	30
Sulphate (2:1)	µg/g		2	653	1620	380	1660	633	384
Resistivity (2:1) (Calculated)	ohm.cm		1	943	488	794	345	521	1810

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

3312865-3312870 pH was determined on the 0.01M CaCl2 extract obtained from 2:1 leaching procedure (2 parts extraction fluid:1 part wet soil).

Analysis performed at AGAT Toronto (unless marked by *)

Certified By: Amanjot Bhela

Results relate only to the items tested. Results apply to samples as received.

Appendix E – Phase I & II Environmental Site Assessment

1. **Phase I & II ESA Report (EXP) – Site 1, Arctic Bay (December 22, 2021)**
2. **Phase I & II ESA Report (EXP) – Site 3, Arctic Bay (December 22, 2021)**
3. **Phase I & II ESA Report (EXP) – Site 4, Arctic Bay (December 22, 2021)**

Business Case for New Water Treatment Facilities & Associated Infrastructure
Phase I & II Environmental Site Assessment, Proposed Site 1, Arctic Bay, Nunavut

Client:
Government of Nunavut

Type of Document:
Final

Project Name:
Phase I & II Environmental Site Assessment

Project Number:

FRE-21016638-A0

Prepared By:
Carl Hentschel, P.Eng., PMP, Environmental Engineer

Reviewed By:
Mark McCalla, P. Geo. (ON), Senior Geoscientist

EXP Services Inc.
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Date Submitted:
2021-12-22

Legal Notification

This report was prepared by EXP Services Inc. for the account of the **Government of Nunavut**.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. EXP Services Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this project.

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Executive Summary

EXP Services Inc. (EXP) was retained by the Government of Nunavut to complete a Phase I Environmental Site Assessment (ESA) and Limited Phase II ESA for the undeveloped property in Arctic Bay, Nunavut, hereinafter referred to as the 'subject site'. This site is also known as “Site 1” for the purpose of the overall project.

The purpose of this Phase I ESA is to determine if past or present site activities have resulted in actual or potential contamination at the subject site.

The purpose of the limited Phase II ESA was to collect surface soil samples at Site 1 as part of a screening level investigation. These would be sent for laboratory analysis of the most likely contaminants of concern (COC), as determined by the Phase I ESA findings. In the absence of any findings, the analysis would default to the most common COC which is petroleum hydrocarbons.

It is understood that the report will be used as part of a business case for the development of a new community water treatment facility.

The Phase I ESA was completed in general accordance with CSA Standard Z768-01 (R2016). Subject to this standard of care, EXP makes no express or implied warranties regarding its services to any third-party, and no third-party beneficiaries re intended. Limitation of liability, scope of report and third-party reliance are outlined in Section 9 of this report.

The subject site is located along the shore of a shallow unnamed freshwater lake and approximately 1 km southeast of the airport and 500 m south of the hamlet’s sand quarry in Arctic Bay, Nunavut. The subject site has an area of approximately 0.1 hectares. At the time of the investigation, the subject site was undeveloped land. The regional groundwater flow direction is anticipated to be southwesterly towards the Arctic Ocean (i.e., Arctic Bay) found roughly 0.5 km to the west.

A review of historical aerial photographs and other records for the subject site found no evidence that it had never been developed. This concurred with information gathered during an on-site interview.

There were no water bodies on the subject site. The closest body of water is an unnamed freshwater lake bordering the south side of the subject site. Based on the existing geological mapping information, overburden stratigraphy generally consisted of silty gravelly sand to sandy gravel overburden with some soil and/or granite bedrock outcropping throughout.

The findings of the Phase II ESA are the following:

- Seven (7) boreholes were advanced on the subject site, from which four (4) soil samples were selected environmental laboratory analysis;
- The surface soil consisted of a brown, moist, sand, gravel, and cobble till; and,
- No petroleum hydrocarbons or BTEX parameters above the federal soil quality standards were detected in any of the soil samples submitted for analysis.

Based on the findings of the Phase I ESA and Phase II ESA completed at the subject site (i.e., Site 1), EXP did not identify any areas of potential environmental concern. No further environmental assessment work is recommended.

This executive summary is a brief synopsis of the report and should not be read in lieu of reading the report in its entirety.

1.0 Introduction

EXP Services Inc. (EXP) was retained by the Government of Nunavut to complete a Phase I Environmental Site Assessment (ESA) and Limited Phase II ESA for the undeveloped property in Arctic Bay, Nunavut, hereinafter referred to as the 'subject site'. This site is also known as “Site 1” for the purpose of the overall project.

1.1 Objective

The purpose of this Phase I ESA is to determine if past or present site activities have resulted in actual or potential contamination at subject site.

The Phase I ESA was completed in general accordance with CSA Standard Z768-01 (R2016). Subject to this standard of care, EXP makes no express or implied warranties regarding its services to any third-party, and no third-party beneficiaries re intended. Limitation of liability, scope of report and third-party reliance are outlined in Section 9 of this report.

The purpose of the limited Phase II ESA was to collect surface soil samples at Site 1 as part of a screening level investigation. These would be sent for laboratory analysis of the most likely contaminants of concern (COC), as determined by the Phase I ESA findings. In the absence of any findings, the analysis would default to the most common COC which is petroleum hydrocarbons.

It is understood that the report will be used as part of a business case for the development of a new community water treatment facility.

1.2 Site Description

The subject site is located along the shore of a shallow unnamed freshwater lake, and approximately 1 km southeast of the airport and 500 m south of the hamlet’s sand quarry in Arctic Bay, Nunavut. The subject site has an area of approximately 0.1 hectares. At the time of the investigation, the subject site was undeveloped land. The regional groundwater flow direction is anticipated to be westerly towards the Arctic Ocean (i.e., Arctic Bay) found roughly 0.5 km to the west.

2.0 Scope of Phase I ESA Investigation

The scope of work for the Phase I ESA consisted of the following activities:

- Reviewing the historical occupancy of the subject site through the use of available archived and relevant municipal materials, and aerial photographs;
- Reviewing municipal and territorial records to determine whether activities that have occurred within the Phase I study area pose a potential environmental concern to the subject site;
- Obtaining an EcoLog Environmental Risk Information Services Ltd. (ERIS) report for the subject site and surrounding properties within a 250-metre radius of the subject site;
- Reviewing available geological maps for the vicinity of the subject site;
- Conducting a reconnaissance of the subject site and surrounding properties within a 150-metre radius of the subject site in order to identify the presence of actual and/or potential environmental contaminants or concerns of significance;
- Conducting interviews with designated representative(s) as a resource for current and historical information;
- Reviewing the current use of the subject site and any land use practices that may have impacted its environmental condition; and,
- Preparing a report to document the findings.

In completing the scope of work, EXP did not conduct any intrusive investigations, including sampling, analyses, or monitoring. EXP has confirmed neither the completeness nor the accuracy of any of the records that were obtained or of any of the statements made by others.

EXP personnel who conducted assessment work for this project included Stefan Bilan, CET, Carl Hentschel, P.Eng., PMP, and Mark McCalla, P.Geo. An outline of their qualifications is provided in Section 9.0.

3.0 Phase I ESA Records Review

3.1 Phase I ESA Study Area Determination

For the purpose of this assignment, the Phase I Study Area consists of neighbouring properties within a distance of approximately 250 metres from the Site boundaries. The Phase I Study Area is bounded by an unnamed lake to the south, undeveloped land to the north, and east, and a weather station and water collection point to the west.

3.2 First Developed Use Determination

Based on a review of records, the subject site has never been developed.

3.3 Fire Insurance Plans

A search of The Catalogue of Canadian Fire Insurance Plans 1875 – 1975 (Catalogue) was conducted to determine if fire insurance plans (FIPs) for the site existed. No FIPs exist for the Phase I study area.

3.4 Chain of Title

A chain of title was not required for the subject site.

3.5 Environmental Reports

No environmental reports were provided for review.

3.6 Environmental Source Information

Information pertaining to the subject site was obtained by reviewing documents that are available to the public through local and territorial sources. EXP did not identify the need to contact any federal agencies.

3.6.1 Hazardous Materials Spill Database

On October 26, 2021, the Government of the Northwest Territories *Hazardous Materials Spill Database* website was searched for postings in the vicinity of the subject site. This database also includes properties in Nunavut and is used by both territories inclusively.

No records were found that posed an environmental concern to the subject site.

3.6.2 PCB Storage Sites

Documents entitled *National Inventory of PCBs in Use and PCB Wastes in Storage in Canada*, *2003 Annual Report* prepared by Environment Canada were reviewed. No records pertaining to PCB storage sites were identified within the Phase I study area.

3.7 EcoLog ERIS Database Search

A search of territorial and federal databases for records pertaining to the subject site and properties within the Phase I study area was conducted by EcoLog ERIS. EXP has confirmed neither the completeness nor the accuracy of the records that were provided. A summary of the more significant findings is provided below. A copy of the EcoLog ERIS report is provided in Appendix B.

No database listings were found for the subject site or properties in the vicinity of the subject site.

3.8 Physical Setting Sources

3.8.1 Aerial Photographs

No aerial photographs which captured the Site location were available.

3.8.2 Topography, Hydrology, Geology

The following information sources were reviewed to determine the nature of the subsurface materials at the site:

- Geological Survey of Canada (2006), Generalized Bedrock Geology of Canada.
- Geological Survey of Canada (2006) Geology of Nunavut.

According to the above maps the grey and pink granite bedrock can be classified as granulite-facies granitoids of the Paleoproterozoic era. The site soil is comprised of silty gravelly sand to sandy gravel overburden with some topsoil and/or bedrock outcropping throughout.

Topographically, the subject site is located on the edge a lake. Based on this and the proximity of the arctic ocean, the local direction of groundwater flow is inferred to be south. However due to the presence of permafrost, shallow groundwater is only able to migrate during the warm season when the active layer thaws.

3.8.3 Fill Materials

It is not anticipated that significant amounts of fill material are present at the subject site.

3.9 Site Operating Records

No site operating records were available for review.

3.10 Summary of Records Review

Based on a review of the available records, no areas of potential environmental concern were identified.

4.0 Phase I ESA Interviews

Interviews were conducted by EXP with the individuals identified to be the most knowledgeable about both the current and historical subject site uses. The purpose of interviews is to obtain information to assist in identifying areas of potential environmental concern and identify details of potentially contaminating activities or potential contaminant pathways, in, on or below the subject site.

The Hamlet of Arctic Bay was contacted on October 2, 2021. They provided the following information during that investigation:

- The subject site has never had a land use.
- There has never been stored on or a reported spill at the subject site.

Responses to other questions were made during site reconnaissance and are discussed in section 5.0.

5.0 Phase I ESA Site Reconnaissance

5.1 General Requirements

On October 2, 2021, Mr. Stefan Bilan of EXP conducted the site visit in accordance with EXP's internal health and safety protocols. The purpose of the site visit was to assess the current conditions of the subject site.

The general environmental management and housekeeping practices at the subject site were reviewed as part of this assessment insofar as they could impact the environmental condition of the property; however, a detailed review of regulatory compliance issues was beyond the scope of EXP's investigation.

Adjacent properties were observed from within the grounds of the subject site, as well as publicly accessible areas. Photographs documenting the site visit are included in Appendix A.

5.2 Specific Observations at the Subject Site

5.2.1 Buildings and Structures

The were no site buildings on the subject site.

5.2.2 Site Utilities and Services

The subject site is not serviced by any infrastructure.

5.3 Storage Tanks

5.3.1 Underground Storage Tanks

No UST were observed on the subject site and there was no evidence of historical UST.

5.3.2 Above Ground Storage Tanks

No AST were observed on the subject site and there was no evidence of historical UST.

5.4 Chemical Storage Handling and Floor Condition

No chemicals were observed on the subject site and there was no evidence of historical UST observed on the subject site.

5.5 Areas of Stained Soil, Pavement or Stressed Vegetation

The subject site was snow covered at the time of the site visit, therefore no evidence of possible significant staining of soil or stressed vegetation could be observed.

5.6 Fill and Debris

The subject site is at approximately the same elevation as the surrounding properties and as such substantial quantities of fill are not anticipated to be present at the subject site.

Regionally, the topography appears to slope down towards the south and west.

5.7 Air Emissions

No air emissions are associated with the property, other than those from the building heating system. There are no concerns.

5.8 Odours

No strong odours were present during the site visit.

5.9 Noise

No excessive noise was heard during the site visit.

5.10 Other Observations

There were no pits or lagoons, no railways or spurs, and no unidentified substances observed on the subject site.

5.11 Special Attention Items, Hazardous Building Materials and Designated Substances

5.11.1 Asbestos

As there is no structure on the subject site, asbestos is not considered a concern.

5.11.2 Ozone Depleting Substances (ODSs)

As there is no refrigeration equipment on the subject site, ODSs are not considered a concern.

5.11.3 Lead

As there is no structure on the subject site, lead is not considered a concern.

5.11.4 Mercury

As there is no equipment on the subject site, mercury is not considered a concern.

5.11.5 Polychlorinated Biphenyls (PCB)

As there is no equipment on the subject site, PCBs are not considered a concern.

5.11.6 Urea Formaldehyde Foam Insulation

There are no UFFI issues as the site is vacant.

5.11.7 Radon

Radon is not expected to be a problem for the site.

5.11.8 Mould

As there is no structure on the subject site, mould is not considered a concern.

5.11.9 Other Substances

No other special attention substances (such as acrylonitrile or isocyanates) were suspected to be present at the subject site at the time of site reconnaissance.

5.12 Processing and Manufacturing Operations

No processing or manufacturing operations were observed at the subject site.

5.13 Hazardous Materials Use and Storage

No hazardous materials are used or stored at the subject site.

5.14 Vehicle and Equipment Maintenance Areas

No vehicle and equipment maintenance activities were observed or reported.

5.15 Drains and Sumps

No drains or sumps were observed during the site visit.

5.16 Oil/Water Separators

No oil-water separators were observed at the subject site.

5.17 Sewage and Wastewater Disposal

No sewage and wastewater are generated at the subject site.

5.18 Solid Waste Generation, Storage & Disposal

Currently no solid wastes are generated at the subject site.

5.19 Liquid Waste Generation, Storage & Disposal

No liquid wastes are generated at the subject site.

5.20 Unidentified Substances

No unidentified substances were observed on the subject site at the time of the site visit. No dumping or any other deleterious materials were identified.

5.21 Hydraulic Lift Equipment

No hydraulic equipment was observed at the subject site.

5.22 Mechanical Equipment

No mechanical equipment of concern was present on the subject site.

5.23 Abandoned and Existing Wells

There is no evidence that there are any domestic water wells on the subject site.

5.24 Roads, Parking Facilities and Right of Ways

There is a no roadway access presently on the subject site.

5.25 Adjacent and Surrounding Properties

A visual inspection of the adjacent properties and properties within 150 m of the subject site was conducted from publicly accessible areas to identify the occupants and document the uses and sources of potential environmental concerns that may impact the subject site.

The following land uses border the subject site:

- North: Undeveloped lands followed by quarry pits;
- East: Undeveloped lands;
- West: Existing water treatment plant (small building) and built roadway, along with a remote weather station. This is followed by undeveloped wetlands. After a visual inspection around both installations for signs of leaks or spills, neither the water treatment plant nor the weather station is considered potentially contaminating activities; and,
- South: Unnamed freshwater lake.

5.26 Summary and Written Description of Investigation

Based on the site reconnaissance, no APECs were identified.

6.0 Phase I ESA Conclusions

Based on the findings of the Phase I ESA completed at the subject site, EXP did not identify any areas of potential environmental concern.

7.0 Phase II ESA Investigation

7.1 Methodology

On Oct 2, 2021, Mr. Stefan Bilan of EXP oversaw the drilling of seven (7) boreholes on the subject site by Canadrill. The boreholes were advanced using an air hammer drilling rig, and samples were collected from cuttings at roughly 1 m intervals. All but one borehole were terminated at 10 m below surface grade (bsg), with the remaining hole being abandoned at 6 m bsg due to a side cave-in collapse. Sampling for environmental purposes was conducted on the sample collected within the top 2 m bsg interval. Soil samples were selected for laboratory analysis based on visual, olfactory evidence of impacts (if observed) as well as field screened for combustible organic vapours. In the absence of any areas of potential environmental concern identified in the Phase I ESA, the soil samples were submitted for the most common contaminants of concern which are petroleum hydrocarbons and benzene, toluene, ethylbenzene, xylenes (BTEX). The following representative soil samples were submitted for laboratory analysis.

Table 7.1: Summary of Soil Samples Submitted for Laboratory Analyses

Borehole & Soil Sample Identification	Depth (m bsg)	Rationale for Submission	Analysis
BH1-2	1 – 2	Representative soil sample	PHC, BTEX
BH4-2	1 – 2	Representative soil sample	PHC, BTEX
BH6-1	0 - 1	Representative soil sample	PHC, BTEX
BH7-1	0 - 1	Representative soil sample	PHC, BTEX

Note:
PHC – petroleum hydrocarbons fractions F1 to F4
BTEX – benzene, toluene, ethylbenzene, xylenes
mbsg- metres below surface grade

Soil samples identified for possible laboratory analysis were collected from the dedicated sampling tube and placed directly into pre-cleaned, laboratory-supplied glass sample jars/vials. Samples to be analysed for PHC fraction F1 and BTEX were collected using a soil core sampler and placed into vials containing methanol as a preservative. The jars and vials were sealed with Teflon-lined lids to minimize head-space and reduce the potential for induced volatilization during storage/transport prior to analysis. All samples were then placed in a cooler containing icepacks for sample preservation purposes. The vials were inverted prior to being placed in a cooler to ensure that no head-space was present in the samples.

The representative samples were transported to Paracel Laboratories Limited (Paracel) in Ottawa, under Chain of Custody protocol for chemical analysis.

7.2 Applicable Site Condition Standards

Analytical results obtained for Site soil samples were assessed against the Canadian Council of Ministers of the Environment's (CCME) *Canada Wide Standard for Petroleum Hydrocarbons in Soil*, as set out by the Government of Nunavut's *Environmental Guideline for Management of Contaminated Sites, 1999 (revised 2014)*. This effects based criteria is protective of human health and the environment for different groundwater conditions (potable and non-potable), land use scenarios (residential, parkland, institutional, commercial, industrial, community and agricultural/other), soil texture (coarse or medium/fine) and restoration depth (full or stratified).

For assessment purposes, EXP selected the CCME's Agriculture/Wildland Site Condition Standards (SCS) for a coarse textured soil. The selection of this category was based on the subject site being open tundra, without any neighbouring built-up properties, and with a coarse soil.

5.2 Phase II ESA Findings

5.2.1 Native Material

Soils encountered consisted of moist brown sand, gravel, and cobble till. No odours or staining were observed in the soil samples.

5.2.2 Analytical Results

The soil analytical results are summarized below and the Certificates of Analysis are enclosed in Appendix C.

Table 7.2: Results of Laboratory Analyses for Soil Samples

Parameter	CCME Criteria [1]	BH1-2	BH4-2	BH6-1	BH7-1
Combustible Organic Vapours	n/a	0% LEL	0% LEL	0% LEL	0% LEL
Benzene	0.0095	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.082	<0.05	<0.05	<0.05	<0.05
Toluene	0.37	<0.05	<0.05	<0.05	<0.05
Total Xylenes	11	<0.05	<0.05	<0.05	<0.05
Petroleum Fraction 1	30	<0.7	<0.7	<0.7	<0.7
Petroleum Fraction 2	150	<4	<4	<4	<4
Petroleum Fraction 3	300	182	221	<8	<8
Petroleum Fraction4	2800	45	51	<6	<6

Note:

1: CCME Canada Wide Standard - Agriculture/Wildland – Coarse Grained Soil
All results in ug/g

The concentrations of PHC and BTEX measured in all four analysed soil samples met the CCME SCS for all BTEX and petroleum hydrocarbon parameters apart from benzene. As the soil was very coarse in nature and hold times had been exceeded due to transportation delays, the laboratory was unable to achieve a method detection limit below the criteria even as no benzene impact was detected.

8.0 Phase II ESA Conclusions and Recommendations

The findings of the Phase II ESA are the following:

- Seven (7) boreholes were advanced on the subject site, from which four (4) soil samples were selected environmental laboratory analysis;
- The surface soil consisted of a brown, moist, sand, gravel, and cobble till;
- No petroleum hydrocarbons or BTEX parameters above the federal soil quality standards were detected in any of the soil samples submitted for analysis; and,
- Based on these findings EXP recommends no further environmental work be undertaken.

9.0 Qualifications of Assessors

The site visit and reporting were conducted by Carl Hentschel, P.Eng. (ON/NU/NWT), PMP. Mr. Hentschel has 20 years of experience in the environmental consulting field working primarily in Ontario, Quebec and the northern territories. He has managed and/or completed numerous Phase I Environmental Site Assessments (ESA); Phase II ESAs, soil and groundwater remediation projects, designated substance surveys, building demolition management, environmental effects evaluations (EEE), air quality assessments, bid specification preparation, and is an experienced technical report writer and reviewer.

The report was reviewed by Mark McCalla, P.Geo.. Mr. McCalla is a senior Environmental Scientist with EXP who has over 30 years of experience in the environmental consulting field. His technical undertakings have including work in the following fields: Phase I and II Environmental Site Assessments; Site Specific Risk Assessments; Petroleum and chlorinated hydrocarbon contaminated sites; Soil and groundwater remediation technologies; Hydrogeological, Terrain Analysis and Aggregate Assessments; Preparation of Ontario Ministry of Environment Certificate of Approvals and Records of Site Condition. Mr. McCalla is a Qualified Person for completing Phase I and II Environmental Site Assessments as per O.Reg. 153/04.

EXP Services Inc. is a full-service consulting and engineering firm and provides a full range of environmental services through the Environmental Services Group. EXP's Environmental Services Group has developed a strong working relationship with clients in both the private and public sectors and has developed a positive relationship with the various regulatory agencies. Personnel in the numerous branch offices form part of a large network of full-time dedicated environmental professionals in the EXP organization.

10.0 References

- Canadian Standards Association, *Phase One Environmental Site Assessment Z768-01 (R2016)*, November 2001.
- Dubreuil, L. and C. Woods, *Catalogue of Canadian Fire Insurance Plans, 1875 – 1975,* 2002.
- Environment Canada, *National Inventory of PCBs in Use and PCB Wastes in Storage in Canada, 2003 Annual Report*, 2004.
- Natural Resources Canada, The Atlas of Canada, *Toporama website* (atlas.gc.ca/toporama/en/)
- Government of the Northwest Territories, *Hazardous Materials Spill Database* (https://www.enr.gov.nt.ca/en/spills)

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

Basis of Report

This report ("Report") is based on site conditions known or inferred by the investigation undertaken as of the date of the Report. Should changes occur which potentially impact the condition of the site the recommendations of EXP may require re-evaluation. Where special concerns exist, or the Government of Nunavut ("the Client") has special considerations or requirements, these should be disclosed to EXP to allow for additional or special investigations to be undertaken not otherwise within the scope of investigation conducted for the purpose of the Report.

Reliance on Information Provided

The evaluation and conclusions contained in the Report are based on conditions in evidence at the time of site inspections and information provided to EXP by the Client and others. The Report has been prepared for the specific site, development, building, design or building assessment objectives and purpose as communicated by the Client. EXP has relied in good faith upon such representations, information and instructions and accepts no responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of any misstatements, omissions, misrepresentation or fraudulent acts of persons providing information. Unless specifically stated otherwise, the applicability and reliability of the findings, recommendations, suggestions or opinions expressed in the Report are only valid to the extent that there has been no material alteration to or variation from any of the information provided to exp. If new information about the environmental conditions at the Site is found, the information should be provided to EXP so that it can be reviewed and revisions to the conclusions and/or recommendations can be made, if warranted.

Standard of Care

The Report has been prepared in a manner consistent with the degree of care and skill exercised by engineering consultants currently practicing under similar circumstances and locale. No other warranty, expressed or implied, is made. Unless specifically stated otherwise, the Report does not contain environmental consulting advice.

Complete Report

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment form part of the Report. This material includes, but is not limited to, the terms of reference given to EXP by the Client, communications between EXP and the Client, other reports, proposals or documents prepared by EXP for the Client in connection with the site described in the Report. In order to properly understand the suggestions, recommendations and opinions expressed in the Report, reference must be made to the Report in its entirety. EXP is not responsible for use by any party of portions of the Report.

Use of Report

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. No other party may use or rely upon the Report in whole or in part without the written consent of EXP. Any use of the Report, or any portion of the Report, by a third party are the sole responsibility of such third party. EXP is not responsible for damages suffered by any third party resulting from unauthorised use of the Report.

Report Format

Where EXP has submitted both electronic file and a hard copy of the Report, or any document forming part of the Report, only the signed and sealed hard copy shall be the original documents for record and working purposes. In the event of a dispute or discrepancy, the hard copy shall govern. Electronic files transmitted by EXP utilize specific software and hardware systems. EXP makes no representation about the compatibility of these files with the Client's current or future software and hardware systems. Regardless of format, the documents described herein are EXP's instruments of professional service and shall not be altered without the written consent of EXP.

12.0 Signatures

We trust this report meets your current needs. If you have any questions pertaining to the investigation undertaken by EXP, please do not hesitate to contact the undersigned.

Carl Hentschel, P. Eng., PMP
Senior Engineer
Earth and Environment

Mark McCalla, P.Geo.(ON)
Senior Geoscientist
Earth and Environment

Figures

APPROXIMATE GEOTECHNICAL SITE EXTENTS - POINT TABLE (UTM ZONE 16)

SITE	POINT	EASTING	NORTHING
1	1-1	564866.368	8100568.480
1	1-2	564877.326	8100868.020
1	1-3	564977.259	8100864.365
1	1-4	564966.291	8100564.565
3	3-1	561869.994	8105140.846
3	3-2	561877.221	8105040.688
3	3-3	561777.580	8105033.796
3	3-4	561770.262	8105133.528
4	4-1	560738.257	8105656.109
4	4-2	560808.431	8105584.866
4	4-3	560737.188	8105514.691
4	4-4	560666.699	8105586.254

EXP Services Inc.
t: +1.506.452.9000 | f: +1.506.459.3954
1133 Regent Street, Suite 300
Fredericton, NB, E3B 3Z2
CANADA
www.exp.com

exp.

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:25000 — 0 500 1000 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
PHASE I & II ESA
OVERALL PLAN**

Project No. FRN-21016638-A0

Dwg. No. **AB1-1**

Rev. No. 0

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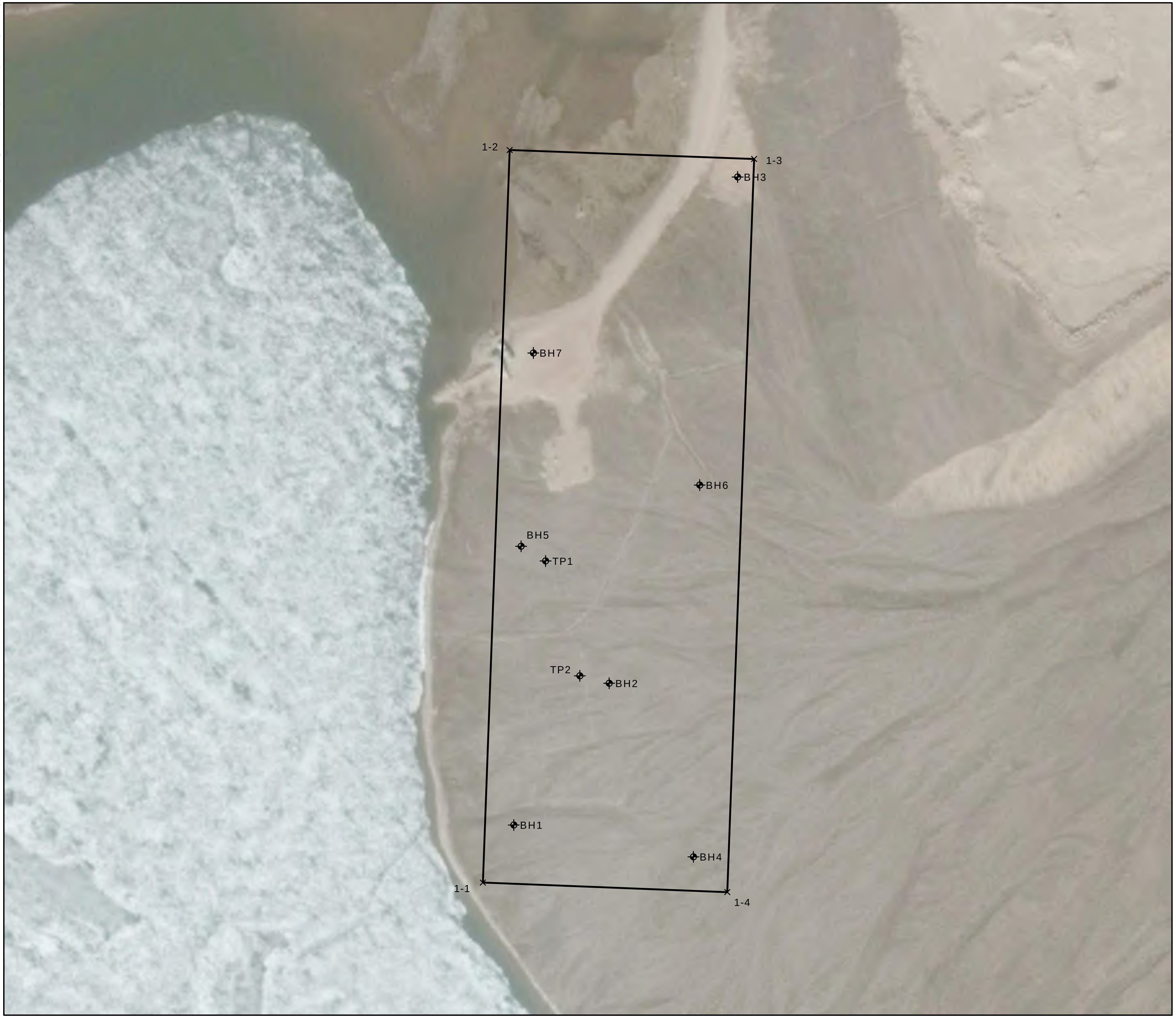
IAN BILLIALD

12/21/2021 12:03 PM



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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:1500 0 30 60 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
PHASE I & II ESA
SITE 1

Project No.
FRN-21016638-A0

Dwg. No.
AB1-2

Rev. No.
0

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IAN BILLIALD

12/21/2021 12:05 PM

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IAN BILLIALD

12/21/2021 12:05 PM

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:5000 — 0, 100, 200 m

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY PHASE I ESA STUDY AREA - SITE 1

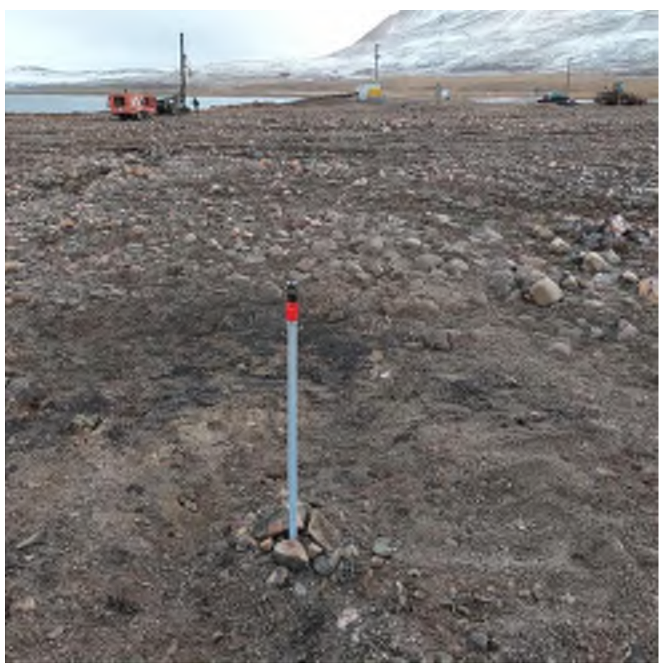
Project No. FRN-21016638-A0

Dwg. No. **AB1-3**

Rev. No. 0

Appendix A – Site Photographs

Photograph No. 1
View adjacent weather station to the northwest.



Photograph No. 2
View from site looking northwest.

Photograph No. 3
View from site looking east.

Appendix B – ERIS Database Report

DATABASE REPORT

Project Property: *Phase I ESA*
Site 1
Arctic Bay NU
Project No: *FRN-21016638-A0 Phase 800 Task 30*
Report Type: *Standard Report NT,NU*
Order No: *21092700229*
Requested by: *exp Services Inc.*
Date Completed: *September 30, 2021*

Environmental Risk Information Services
A division of Glacier Media Inc.
1.866.517.5204 | info@erisinfo.com | erisinfo.com

Table of Contents

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Executive Summary

Property Information:

Project Property:		*Phase I ESA* *Site 1 Arctic Bay NU*
Project No:		*FRN-21016638-A0 Phase 800 Task 30*
Coordinates:		
	Latitude:	*72.9928175*
	Longitude:	*-85.0089034*
	UTM Northing:	*8,100,758.60*
	UTM Easting:	*564,992.63*
	UTM Zone:	*16X*
Elevation:		*69 FT* *20.90 M*

Order Information:

Order No:	*21092700229*
Date Requested:	*September 27, 2021*
Requested by:	*exp Services Inc.*
Report Type:	*Standard Report NT,NU*

Historical/Products:

Executive Summary: Report Summary

Database	Name	Searched	Project Property	Within 0.25 km	Total
AUWR	***Automobile Wrecking & Supplies***	*Y*	*0*	*0*	*0*
CDRY	***Dry Cleaning Facilities***	*Y*	*0*	*0*	*0*
CFST	***Crown Land Fuel Storage Tanks***	*Y*	*0*	*0*	*0*
CHM	***Chemical Register***	*Y*	*0*	*0*	*0*
CNG	***Compressed Natural Gas Stations***	*Y*	*0*	*0*	*0*
EHS	***ERIS Historical Searches***	*Y*	*0*	*0*	*0*
FCON	***Federal Convictions***	*Y*	*0*	*0*	*0*
FCS	***Contaminated Sites on Federal Land***	*Y*	*0*	*0*	*0*
FRST	***Federal Identification Registry for Storage Tank Systems (FIRSTS)***	*Y*	*0*	*0*	*0*
GHG	***Greenhouse Gas Emissions from Large Facilities***	*Y*	*0*	*0*	*0*
IAFT	***Indian & Northern Affairs Fuel Tanks***	*Y*	*0*	*0*	*0*
MINE	***Canadian Mine Locations***	*Y*	*0*	*0*	*0*
MNR	***Mineral Occurrences***	*Y*	*0*	*0*	*0*
NATE	***National Analysis of Trends in Emergencies System (NATES)***	*Y*	*0*	*0*	*0*
NDSP	***National Defense & Canadian Forces Spills***	*Y*	*0*	*0*	*0*
NDWD	***National Defence & Canadian Forces Waste Disposal Sites***	*Y*	*0*	*0*	*0*
NEBI	***National Energy Board Pipeline Incidents***	*Y*	*0*	*0*	*0*
NEBT	***National Energy Board Wells***	*Y*	*0*	*0*	*0*
NEES	***National Environmental Emergencies System (NEES)***	*Y*	*0*	*0*	*0*
NPCB	***National PCB Inventory***	*Y*	*0*	*0*	*0*
NPRI	***National Pollutant Release Inventory***	*Y*	*0*	*0*	*0*
OGWE	***Oil and Gas Wells***	*Y*	*0*	*0*	*0*
RST	***Retail Fuel Storage Tanks***	*Y*	*0*	*0*	*0*
SCT	***Scott's Manufacturing Directory***	*Y*	*0*	*0*	*0*
SPL	***Spills***	*Y*	*0*	*0*	*0*
		Total:	*0*	*0*	*0*

Executive Summary: Site Report Summary - Project Property

Map Key	*DB*	*Company/Site Name*	*Address*	*Dir/Dist (m)*	*Elev diff (m)*	*Page Number*

No records found in the selected databases for the project property.

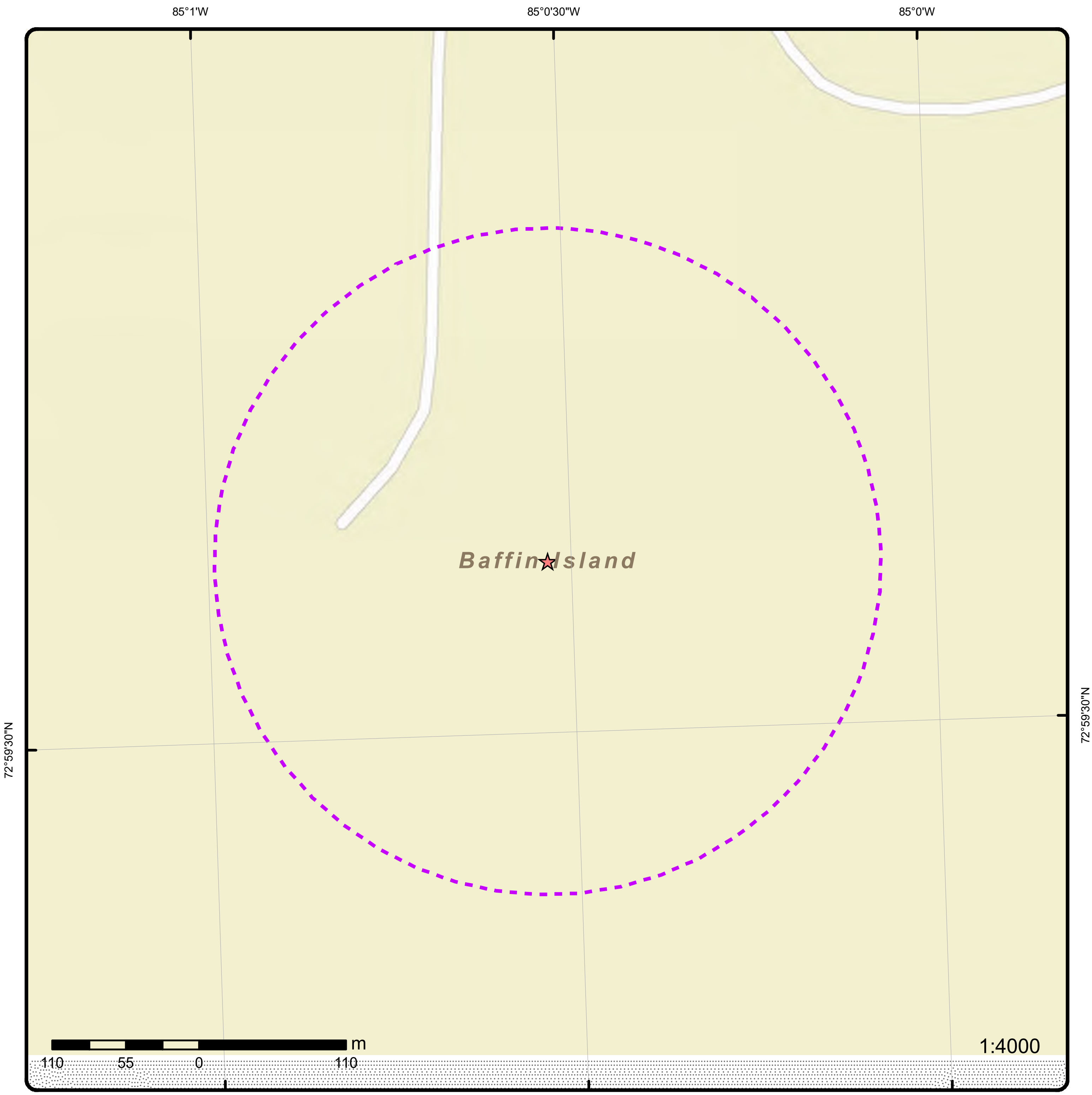
Executive Summary: Site Report Summary - Surrounding Properties

Map Key	*DB*	*Company/Site Name*	*Address*	*Dir/Dist (m)*	*Elev Diff (m)*	*Page Number*

No records found in the selected databases for the surrounding properties.

Executive Summary: Summary By Data Source

No records found in the selected databases for the project property or surrounding properties.



Map: 0.25 Kilometer Radius

Order Number: 21092700229

Address: Site 1, Arctic Bay, NU

Project Property	Freeways; Highways	Beach	Shopping & Sports Area
Buffer Outline	Traffic Circle; Ramp	Airport	University/College
Eris Sites with Higher Elevation	Major Arterial; Minor Arterial	Industrial Area	Cemetery; Golf Course
Eris Sites with Same Elevation	Local Road	Military Base	Parkt (National)
Eris Sites with Lower Elevation	Service Road; Traffic Circle; Ramp	Aircraft Roads	Park (City/County)
Eris Sites with Unknown Elevation	Rail	Native Reservation	
		Hospital	

Source: © 2021 ESRI StreetMap Premium.

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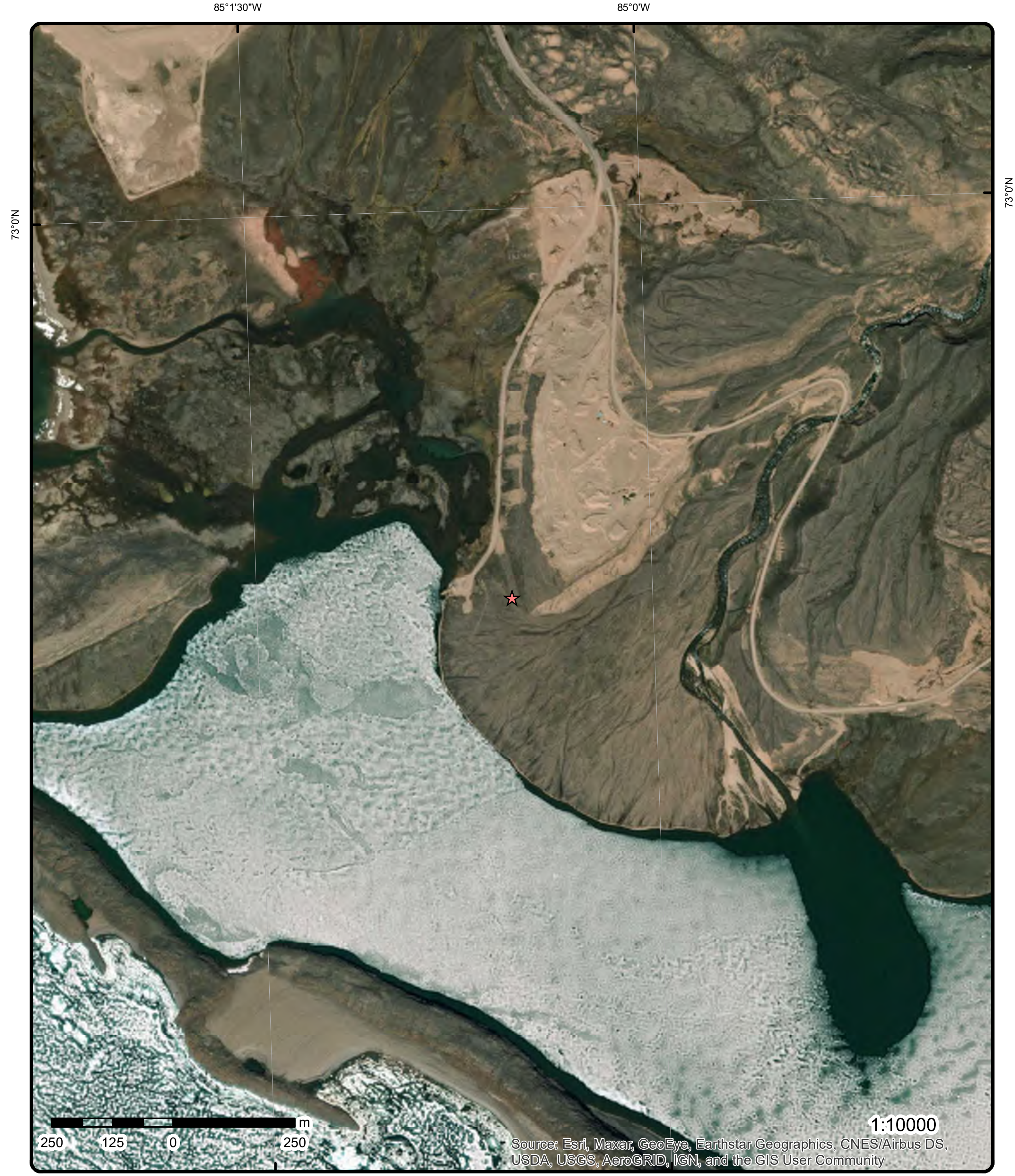

Aerial   Year: 2019

Order Number: 21092700229

Address: Site 1, Arctic Bay, NU

Source: ESRI World Imagery

© ERIS Information Limited Partnership

Topographic Map

Order Number: 21092700229

Address: Site 1, NU

Source: ESRI World Topographic Map

© ERIS Information Limited Partnership

Detail Report

Map Key	Number of Records	Direction/ Distance (m)	Elev/Diff (m)	Site	DB

No records found in the selected databases for the project property or surrounding properties.

Unplottable Summary

Total: 0 Unplottable sites

DB	Company Name/Site Name	Address	City	Postal

Unplottable Report

No unplottable records were found that may be relevant for the search criteria.

Appendix: Database Descriptions

*Environmental Risk Information Services (ERIS) can search the following databases. The extent of historical information varies with each database and current information is determined by what is publicly available to ERIS at the time of update. **Note:** Databases denoted with " * " indicates that the database will no longer be updated. See the individual database description for more information.*

Automobile Wrecking & Supplies: Private AUWR

This database provides an inventory of known locations that are involved in the scrap metal, automobile wrecking/recycling, and automobile parts & supplies industry. Information is provided on the company name, location and business type.

Government Publication Date: 1999-Dec 31, 2020

Dry Cleaning Facilities: Federal CDRY

List of dry cleaning facilities made available by Environment and Climate Change Canada. Environment and Climate Change Canada's Tetrachloroethylene (Use in Dry Cleaning and Reporting Requirements) Regulations (SOR/2003-79) are intended to reduce releases of tetrachloroethylene to the environment from dry cleaning facilities.

Government Publication Date: Jan 2004-Dec 2018

Crown Land Fuel Storage Tanks: Territorial CFST

The Department of Indian and Northern Affairs Canada mandates that all fuel storage tanks on Crown Land be recorded, when an individual applies for a land use permit or surface lease. Please note that there are numerous records in the database where the "Commencement Date" is previous to 1997. However, since INAC only began registering tank locations in 1997, any tanks installed previous to that may or may not be in the database, due to lack of regulations. Note the following descriptions: Commencement Date is the original file date, Fuel Application Date is the date an application was submitted for a tank, and the Fuel Confirmation Date is the date the department accepted the application and confirmed the information submitted.

Government Publication Date: Oct 1997-Nov 2019

Chemical Register: Private CHM

This database includes a listing of locations of facilities within the Province or Territory that either manufacture and/or distributes chemicals.

Government Publication Date: 1999-Dec 31, 2020

Compressed Natural Gas Stations: Private CNG

Canada has a network of public access compressed natural gas (CNG) refuelling stations. These stations dispense natural gas in compressed form at 3,000 pounds per square inch (psi), the pressure which is allowed within the current Canadian codes and standards. The majority of natural gas refuelling is located at existing retail gasoline that have a separate refuelling island for natural gas. This list of stations is made available by the Canadian Natural Gas Vehicle Alliance.

Government Publication Date: Dec 2012 -Aug 2021

ERIS Historical Searches: Private EHS

ERIS has compiled a database of all environmental risk reports completed since March 1999. Available fields for this database include: site location, date of report, type of report, and search radius. As per all other databases, the ERIS database can be referenced on both the map and "Statistical Profile" page.

Government Publication Date: 1999-Jun 30, 2021

Federal Convictions: Federal FCON

Environment Canada maintains a database referred to as the "Environmental Registry" that details prosecutions under the Canadian Environmental Protection Act (CEPA) and the Fisheries Act (FA). Information is provided on the company name, location, charge date, offence and penalty.

Government Publication Date: 1988-Jun 2007*

Contaminated Sites on Federal Land: Federal FCS

The Federal Contaminated Sites Inventory includes information on known federal contaminated sites under the custodianship of departments, agencies and consolidated Crown corporations as well as those that are being or have been investigated to determine whether they have contamination arising from past use that could pose a risk to human health or the environment. The inventory also includes non-federal contaminated sites for which the Government of Canada has accepted some or all financial responsibility. It does not include sites where contamination has been caused by, and which are under the control of, enterprise Crown corporations, private individuals, firms or other levels of government. Includes fire training sites and sites at which Per- and Polyfluoroalkyl Substances (PFAS) are a concern.

Government Publication Date: Jun 2000-Aug 2021

Federal Identification Registry for Storage Tank Systems (FIRSTS): Federal FRST

A list of federally regulated Storage tanks from the Federal Identification Registry for Storage Tank Systems (FIRSTS). FIRSTS is Environment and Climate Change Canada's database of storage tank systems subject to the Storage Tank for Petroleum Products and Allied Petroleum Products Regulations. The main objective of the Regulations is to prevent soil and groundwater contamination from storage tank systems located on federal and aboriginal lands. Storage tank systems that do not have a valid identification number displayed in a readily visible location on or near the storage tank system may be refused product delivery.

Government Publication Date: May 31, 2018

Greenhouse Gas Emissions from Large Facilities: Federal GHG

List of greenhouse gas emissions from large facilities made available by Environment Canada. Greenhouse gas emissions in kilotonnes of carbon dioxide equivalents (kt CO2 eq).

Government Publication Date: 2013-Dec 2019

Indian & Northern Affairs Fuel Tanks: Federal IAFT

The Department of Indian & Northern Affairs Canada (INAC) maintains an inventory of aboveground & underground fuel storage tanks located on both federal and crown land. Our inventory provides information on the reserve name, location, facility type, site/facility name, tank type, material & ID number, tank contents & capacity, and date of tank installation.

Government Publication Date: 1950-Aug 2003*

Canadian Mine Locations: Private MINE

This information is collected from the Canadian & American Mines Handbook. The Mines database is a national database that provides over 290 listings on mines (listed as public companies) dealing primarily with precious metals and hard rocks. Listed are mines that are currently in operation, closed, suspended, or are still being developed (advanced projects). Their locations are provided as geographic coordinates (x, y and/or longitude, latitude). As of 2002, data pertaining to Canadian smelters and refineries has been appended to this database.

Government Publication Date: 1998-2009*

Mineral Occurrences: Territorial MNR

The C.S. Lord Northern Geoscience Centre maintains a database of mineral showings (commodity occurrences) for both the Northwest Territories and Nunavut. The database provides Showing ID, latitude, longitude, Showing Name, commodity type, current development stage, and general comments on lithology, mineralization and geological settings.

Government Publication Date: 1900-Sep 2018

National Analysis of Trends in Emergencies System (NATES): Federal NATE

In 1974 Environment Canada established the National Analysis of Trends in Emergencies System (NATES) database, for the voluntary reporting of significant spill incidents. The data was to be used to assist in directing the work of the emergencies program. NATES ran from 1974 to 1994. Extensive information is available within this database including company names, place where the spill occurred, date of spill, cause, reason and source of spill, damage incurred, and amount, concentration, and volume of materials released.

Government Publication Date: 1974-1994*

National Defense & Canadian Forces Spills: Federal NDSP

The Department of National Defense and the Canadian Forces maintains an inventory of spills to land and water. All spill sites have been classified under the "Transportation of Dangerous Goods Act - 1992". Our inventory provides information on the facility name, location, spill ID #, spill date, type of spill, as well as the quantity of substance spilled & recovered.

Government Publication Date: Mar 1999-Apr 2018

National Defence & Canadian Forces Waste Disposal Sites: Federal NDWD

The Department of National Defence and the Canadian Forces maintains an inventory of waste disposal sites located on DND lands. Where available, our inventory provides information on the base name, location, type of waste received, area of site, depth of site, year site opened/closed and status.

Government Publication Date: 2001-Apr 2007*

National Energy Board Pipeline Incidents: Federal NEBI

Locations of pipeline incidents from 2008 to present, made available by the Canada Energy Regulator (CER) - previously the National Energy Board (NEB). Includes incidents reported under the Onshore Pipeline Regulations and the Processing Plant Regulations related to pipelines under federal jurisdiction, does not include incident data related to pipelines under provincial or territorial jurisdiction.

Government Publication Date: 2008-Jun 30, 2021

National Energy Board Wells: Federal NEBT

The NEBW database contains information on onshore & offshore oil and gas wells that are outside provincial jurisdiction(s) and are thereby regulated by the National Energy Board. Data is provided regarding the operator, well name, well ID No./UWI, status, classification, well depth, spud and release date.

Government Publication Date: 1920-Feb 2003*

National Environmental Emergencies System (NEES): Federal NEES

In 2000, the Emergencies program implemented NEES, a reporting system for spills of hazardous substances. For the most part, this system only captured data from the Atlantic Provinces, some from Quebec and Ontario and a portion from British Columbia. Data for Alberta, Saskatchewan, Manitoba and the Territories was not captured. However, NEES is also a repository for previous Environment Canada spill datasets. NEES is composed of the historic datasets ' or Trends ' which dates from approximately 1974 to present. NEES Trends is a compilation of historic databases, which were merged and includes data from NATES (National Analysis of Trends in Emergencies System), ARTS (Atlantic Regional Trends System), and NEES. In 2001, the Emergencies Program determined that variations in reporting regimes and requirements between federal and provincial agencies made national spill reporting and trend analysis difficult to achieve. As a consequence, the department has focused efforts on capturing data on spills of substances which fall under its legislative authority only (CEPA and FA). As such, the NEES database will be decommissioned in December 2004.

Government Publication Date: 1974-2003*

National PCB Inventory: Federal NPCB

Environment Canada's National PCB inventory includes information on in-use PCB containing equipment in Canada including federal, provincial and private facilities. Federal out-of-service PCB containing equipment and PCB waste owned by the federal government or by federally regulated industries such as airlines, railway companies, broadcasting companies, telephone and telecommunications companies, pipeline companies, etc. are also listed. Although it is not Environment Canada's mandate to collect data on non-federal PCB waste, the National PCB inventory includes some information on provincial and private PCB waste and storage sites. Some addresses provided may be Head Office addresses and are not necessarily the location of where the waste is being used or stored.

Government Publication Date: 1988-2008*

National Pollutant Release Inventory: Federal NPRI

Environment Canada has defined the National Pollutant Release Inventory ("NPRI") as a federal government initiative designed to collect comprehensive national data regarding releases to air, water, or land, and waste transfers for recycling for more than 300 listed substances.

Government Publication Date: 1993-May 2017

Oil and Gas Wells: Private OGWE

The Nickle's Energy Group (publisher of the Daily Oil Bulletin) collects information on drilling activity including operator and well statistics. The well information database includes name, location, class, status and depth. The main Nickle's database is updated on a daily basis, however, this database is updated on a monthly basis. More information is available at www.nickles.com.

Government Publication Date: 1988-Feb 28, 2021

Retail Fuel Storage Tanks: Private RST

This database includes an inventory of retail fuel outlet locations (including marinas) that have on their property gasoline, oil, waste oil, natural gas and / or propane storage tanks.

Government Publication Date: 1999-Dec 31, 2020

Scott's Manufacturing Directory: Private SCT

Scott's Directories is a data bank containing information on over 200,000 manufacturers across Canada. Even though Scott's listings are voluntary, it is the most comprehensive database of Canadian manufacturers available. Information concerning a company's address, plant size, and main products are included in this database.

Government Publication Date: 1992-Mar 2011*

Spills: Territorial SPL

The Department of Environment and Natural Resource (ENR) in Yellowknife maintains an inventory of spill locations through the "Hazardous Materials Spills Database". Information is provided on the spill number, date, location, spill description, quantity & commodity spilled and all applicable parties involved. Data previously maintained and made available by the Department of Resources, Wildlife & Economic Development (RWED).

Government Publication Date: Aug 31, 2021

Definitions

Database Descriptions: This section provides a detailed explanation for each database including: source, information available, time coverage, and acronyms used. They are listed in alphabetic order.

Detail Report: This is the section of the report which provides the most detail for each individual record. Records are summarized by location, starting with the project property followed by records in closest proximity.

Distance: The distance value is the distance between plotted points, not necessarily the distance between the sites' boundaries. All values are an approximation.

Direction: The direction value is the compass direction of the site in respect to the project property and/or center point of the report.

Elevation: The elevation value is taken from the location at which the records for the site address have been plotted. All values are an approximation. Source: Google Elevation API.

Executive Summary: This portion of the report is divided into 3 sections:

'Report Summary'- Displays a chart indicating how many records fall on the project property and, within the report search radii.

'Site Report Summary'-Project Property'- This section lists all the records which fall on the project property. For more details, see the 'Detail Report' section.

'Site Report Summary-Surrounding Properties'- This section summarizes all records on adjacent properties, listing them in order of proximity from the project property. For more details, see the 'Detail Report' section.

Map Key: The map key number is assigned according to closest proximity from the project property. Map Key numbers always start at #1. The project property will always have a map key of '1' if records are available. If there is a number in brackets beside the main number, this will indicate the number of records on that specific property. If there is no number in brackets, there is only one record for that property.

The symbol and colour used indicates 'elevation': the red inverted triangle will dictate 'ERIS Sites with Lower Elevation', the yellow triangle will dictate 'ERIS Sites with Higher Elevation' and the orange square will dictate 'ERIS Sites with Same Elevation.'

Unplottables: These are records that could not be mapped due to various reasons, including limited geographic information. These records may or may not be in your study area, and are included as reference.

Appendix C – Certificates of Analysis

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1-800-749-1947
www.paracellabs.com

Certificate of Analysis

exp Services Inc. (Ottawa)

100-2650 Queensview Dr.
Ottawa, ON K2B 8K2
Attn: Chris Kimmerly

Client PO:
Project: FRD0021016633840040
Custody: 133772/73/74

Report Date: 25-Oct-2021
Order Date: 22-Oct-2021

Order #: 2143577

This Certificate of Analysis contains analytical data applicable to the following samples as submitted:

Paracel ID	Client ID
2143577-03	Site 1 BH4-2 AB
2143577-05	Site 1 BH1-2 AB
2143577-07	Site 1 BH6-1 AB
2143577-09	Site 1 BH7-1 AB
2143577-13	Site 3 BH3-1 AB
2143577-14	Site 3 BH4-1 AB
2143577-16	Site 3 BH1-1 AB
2143577-17	Site 3 BH2-1 AB
2143577-20	Site 4 BH1-1 AB
2143577-21	Site 4 BH2-1 AB
2143577-23	Site 4 BH4-1 AB
2143577-24	Site 4 BH3-1 AB

Approved By:

Dale Robertson, BSc
Laboratory Director

Any use of these results implies your agreement that our total liabilty in connection with this work, however arising, shall be limited to the amount paid by you for this work, and that our employees or agents shall not under any circumstances be liable to you in connection with this work.

Analysis Summary Table

Analysis	Method Reference/Description	Extraction Date	Analysis Date
BTEX by P&T GC-MS	EPA 8260 - P&T GC-MS	22-Oct-21	25-Oct-21
PHC F1	CWS Tier 1 - P&T GC-FID	22-Oct-21	25-Oct-21
PHCs F2 to F4	CWS Tier 1 - GC-FID, extraction	22-Oct-21	23-Oct-21
Solids, %	Gravimetric, calculation	22-Oct-21	23-Oct-21

PARACEL LABORATORIES LTD.

Order #: 2143577

Certificate of Analysis

Client: exp Services Inc. (Ottawa)

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

	Client ID:	Site 1 BH4-2 AB	Site 1 BH1-2 AB	Site 1 BH6-1 AB	Site 1 BH7-1 AB
	Sample Date:	29-Sep-21 17:05	29-Sep-21 13:45	30-Sep-21 14:15	30-Sep-21 16:35
	Sample ID:	2143577-03	2143577-05	2143577-07	2143577-09
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	98.5	99.0	96.9	98.5
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	97.2%	96.9%	101%	98.0%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	221 [1]	182 [1]	<8 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	51 [1]	45 [1]	<6 [1]	<6 [1]

	Client ID:	Site 3 BH3-1 AB	Site 3 BH4-1 AB	Site 3 BH1-1 AB	Site 3 BH2-1 AB
	Sample Date:	01-Oct-21 16:15	01-Oct-21 17:15	01-Oct-21 10:15	01-Oct-21 14:15
	Sample ID:	2143577-13	2143577-14	2143577-16	2143577-17
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	89.6	88.0	90.8	84.2
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	115%	109%	110%	134%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	<8 [1]	77 [1]	26 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	<6 [1]	25 [1]	<6 [1]	<6 [1]

Certificate of Analysis

Client: exp Services Inc. (Ottawa)

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

Client ID:		Site 4 BH1-1 AB	Site 4 BH2-1 AB	Site 4 BH4-1 AB	Site 4 BH3-1 AB
Sample Date:		03-Oct-21 08:30	03-Oct-21 10:30	03-Oct-21 13:15	03-Oct-21 14:15
Sample ID:		2143577-20	2143577-21	2143577-23	2143577-24
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	86.7	85.3	86.3	87.9
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	116%	110%	126%	132%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	<8 [1]	<8 [1]	<8 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	<6 [1]	<6 [1]	<6 [1]	<6 [1]

Certificate of Analysis

Client: **exp Services Inc. (Ottawa)**

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

Method Quality Control: Blank

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	ND	7	mg/kg						
F2 PHCs (C10-C16)	ND	4	mg/kg						
F3 PHCs (C16-C34)	ND	8	mg/kg						
F4 PHCs (C34-C50)	ND	6	mg/kg						
Volatiles									
Benzene	ND	0.02	mg/kg						
Ethylbenzene	ND	0.05	mg/kg						
Toluene	ND	0.05	mg/kg						
m,p-Xylenes	ND	0.05	mg/kg						
o-Xylene	ND	0.05	mg/kg						
Xylenes, total	ND	0.05	mg/kg						
Surrogate: Toluene-d8	*7.62*		*mg/kg*		*95.3*	*50-140*			

Method Quality Control: Duplicate

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	349	7	mg/kg dry	247			34.2	40	
F2 PHCs (C10-C16)	ND	4	mg/kg dry	ND			NC	30	
F3 PHCs (C16-C34)	ND	8	mg/kg dry	ND			NC	30	
F4 PHCs (C34-C50)	ND	6	mg/kg dry	ND			NC	30	
Physical Characteristics									
% Solids	69.2	0.1	% by Wt.	69.8			0.9	25	
Volatiles									
Benzene	ND	0.02	mg/kg dry	ND			NC	50	
Ethylbenzene	1.46	0.05	mg/kg dry	0.983			38.8	50	
Toluene	ND	0.05	mg/kg dry	ND			NC	50	
m,p-Xylenes	1.13	0.05	mg/kg dry	0.764			39.1	50	
o-Xylene	ND	0.05	mg/kg dry	ND			NC	50	
Surrogate: Toluene-d8	*8.61*		*mg/kg dry*		*97.7*	*50-140*			

Method Quality Control: Spike

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	190	7	mg/kg	ND	95.2	80-120			
F2 PHCs (C10-C16)	98	4	mg/kg	ND	97.5	60-140			
F3 PHCs (C16-C34)	246	8	mg/kg	ND	99.4	60-140			
F4 PHCs (C34-C50)	160	6	mg/kg	ND	102	60-140			
Volatiles									
Benzene	2.86	0.02	mg/kg	ND	71.4	60-130			
Ethylbenzene	3.18	0.05	mg/kg	ND	79.6	60-130			
Toluene	3.05	0.05	mg/kg	ND	76.2	60-130			
m,p-Xylenes	6.34	0.05	mg/kg	ND	79.3	60-130			
o-Xylene	3.15	0.05	mg/kg	ND	78.8	60-130			
Surrogate: Toluene-d8	*7.50*		*mg/kg*		*93.7*	*50-140*			

Qualifier Notes:

Login Qualifiers :

Container and COC sample IDs don't match - ID on Jar lid reads: "SIte 4 BH2-1". ID on Jar label reads: "Site 4 BH4-1".

Applies to samples: Site 4 BH2-1 AB

Sample - One or more parameter received past hold time - PHC F2-F4, CCME

Applies to samples: Site 1 BH4-2 AB, Site 1 BH1-2 AB, Site 1 BH6-1 AB, Site 1 BH7-1 AB, Site 3 BH3-1 AB, Site 3 BH4-1 AB, Site 3 BH1-1 AB, Site 3 BH2-1 AB, Site 4 BH1-1 AB, Site 4 BH2-1 AB, Site 4 BH4-1 AB, Site 4 BH3-1 AB

Sample Qualifiers :

1 : Holding time had been exceeded upon receipt of the sample at the laboratory.

Sample Data Revisions

None

Work Order Revisions / Comments:

MeOH Vial: Full of soil.

Other Report Notes:

n/a: not applicable
ND: Not Detected
MDL: Method Detection Limit
Source Result: Data used as source for matrix and duplicate samples
%REC: Percent recovery.
RPD: Relative percent difference.
NC: Not Calculated

Soil results are reported on a dry weight basis when the units are denoted with 'dry'.
Where %Solids is reported, moisture loss includes the loss of volatile hydrocarbons.

CCME PHC additional information:

- The method for the analysis of PHCs complies with the Reference Method for the CWS PHC and is validated for use in the laboratory. All prescribed quality criteria identified in the method has been met.
- F1 range corrected for BTEX.
- F2 to F3 ranges corrected for appropriate PAHs where available.
- The gravimetric heavy hydrocarbons (F4G) are not to be added to C6 to C50 hydrocarbons.
- In the case where F4 and F4G are both reported, the greater of the two results is to be used for comparison to CWS PHC criteria.
- When reported, data for F4G has been processed using a silica gel cleanup.

PARACEL LABORATORIES LTD.

Paracel ID: 2143577

Paracel Order Number (Lab Use Only)	Chain Of Custody (Lab Use Only)
2143577	№ 133772

Client Name: EXP Services Inc.	Project Ref: FRD00210166 38-400-40		Page 1 of 3
Contact Name: Chris Kimmerly / Ismail Taki	Quote #:		Turnaround Time
Address: 2650 Queensview Drive, Ottawa. Suite 100	PO #:		☑ 1 day ☐ 3 day
	E-mail: chris.kimmerly@exp.com		☐ 2 day ☐ Regular
Telephone:			Date Required:

☐ REG 153/04 ☐ REG 406/19 — Other Regulation

☐ Table 1 ☐ Res/Park ☐ Med/Fine ☐ REG 558 ☐ PWQO

☐ Table 2 ☐ Ind/Comm ☐ Coarse ☐ CCME ☐ MISA

☐ Table 3 ☐ Agri/Other ☐ SU - Sani ☐ SU - Storm

☐ Table ___ Mun: ___

For RSC: ☐ Yes ☐ No ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

#	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Date	Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)					
1	Site 1 TP1 AB	S		2	Sep 29/21	4pm												
2	BH4-1 AB	S		2		5pm												
3	BH4-2 AB	S		2		5:05pm	X											
4	BH1-1 AB	S		2		3:30pm												
5	BH1-2 AB	S		2		3:45pm	X											
6	BH2-2 AB	S		2	Sep 30/21	8:35am	X											
7	BH6-1 AB	S		2		2:15pm	X											
8	BH3-1 AB	S		2		3:30pm												
9	BH7-1 AB	S		2		4:35pm	X											
10	BH2-1 AB	S		2		8:32am												

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct 1/21

Method of Delivery: PARACEL COURIER

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: [signature]	Verified By: [signature]
Relinquished By (Print): Stefan Bitan	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12:20	Date/Time: Oct 22 21 1:56
Date/Time: Oct 4/2021	Temperature: °C Amb	Temperature: 6.3 °C	pH Verified: ☐ By:

Chain of Custody (Env) xlsx — Revision 4.0

Paracel ID: 2143577

PARACEL LABORATORIES LTD.

www.paracellabs.com

Paracel Order Number (Lab Use Only): 2143577

Chain Of Custody (Lab Use Only) № 133774

Client Name: EXP Services Inc.

Project Ref: FRD00210166638-400-40

Page 2 of 3

Contact Name: Chris Kimmerly / Asmaait Tekie

Quote #:

Turnaround Time: ☑ 1 day ☐ 3 day ☐ 2 day ☐ Regular

Address: 2650 Queensview Drive, Ottawa. Suite 100

PO #:

E-mail: Chris.Kimmerly@exp.com

Telephone:

Date Required:

☐ REG 153/04 ☐ REG 406/19

☐ Table 1 ☐ Res/Park ☐ Med/Fine

☐ Table 2 ☐ Ind/Comm ☐ Coarse

☐ Table 3 ☐ Agri/Other

☐ Table ___

For RSC: ☐ Yes ☐ No

Other Regulation: ☐ REG 558 ☐ PWQO ☐ CCME ☐ MISA ☐ SU - Sani ☐ SU - Storm Mun: ___ ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

	Sample ID/Location Name		Matrix	Air Volume	# of Containers	Date	Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)						
1	Site 3: TP1	AR	S		2	Oct 2	8:45am													
2	TP2-1	AR	S		2	↓	9:20am													
3	BH3-1	AR	S		2	Oct 1	4:15pm	X												
4	BH4-1	AR	S		2		5:15pm	X												
5	BH5-1	AR	S		2		3:15pm													
6	BH1-1	AR	S		2		10:15am	X												
7	BH2-1	AR	S		2	↓	2:15pm	X												
8	Site 4 TP2-1	AR	S		2	Oct 2	10:10am													
9	TP2-2	AR	S		2	↓	10:15am													
10	BH1-1	AR	S		2	Oct 3	8:30am	X												

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct 12

Method of Delivery: Paracel Courier

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: Sunnyform Dhmal	Verified By: [signature]
Relinquished By (Print): Stefan Bilan	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12:30	Date/Time: Oct 22 2021 1:56
Date/Time: Oct 4/2021	Temperature: °C AM	Temperature: 6.3 °C	pH Verified: ☐ By:

Chain of Custody (Env) xlsx

Revision 4.0

PARACEL LABORATORIES LTD.

Paracel ID: 2143577

Paracel Order Number (Lab Use Only): 2143577

Chain Of Custody (Lab Use Only) № 133773

Client Name:	EXP Services Inc.
Contact Name:	Chris Kennedy / Ismail Taki
Address:	2650 Queensview Drive, Ottawa Suite 100.
Telephone:	
Project Ref:	FRD 0021016638-400-40
Quote #:	
PO #:	
E-mail:	chris.kennedy@exp.com

Page 3 of 3

Turnaround Time

☑ 1 day ☐ 3 day ☐ 2 day ☐ Regular

Date Required:

☐ REG 153/04 ☐ REG 406/19

☐ Table 1 ☐ Res/Park ☐ Med/Fine ☐ Table 2 ☐ Ind/Comm ☐ Coarse ☐ Table 3 ☐ Agri/Other ☐ Table ___ For RSC: ☐ Yes ☐ No

Other Regulation: ☐ REG 558 ☐ PWQO ☐ CCME ☐ MISA ☐ SU - Sani ☐ SU - Storm Mun: ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Date	Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)					
1	Site 4 BH 2-1 AB	S		2	Oct 3/2021	10:30am	X											
2	BH 5-1 AB	S		2	↓	11:15am												
3	BH 4-1 AB	S		2		1:15pm	X											
4	BH 3-1 AB	S		2		2:15pm	X											
5																		
6																		
7																		
8																		
9																		
10																		

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct /21

Method of Delivery: Paracel Courier

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: Simranpreet Dokram	Verified By: R
Relinquished By (Print): Stefan Bilan	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12.30	Date/Time: Oct 22 2021 1:56
Date/Time: Oct 4/2021	Temperature: °C N/A	Temperature: 6.3 °C	pH Verified: ☐ By:

Appendix D – Borehole Logs

Log of Borehole BH-01

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 6

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

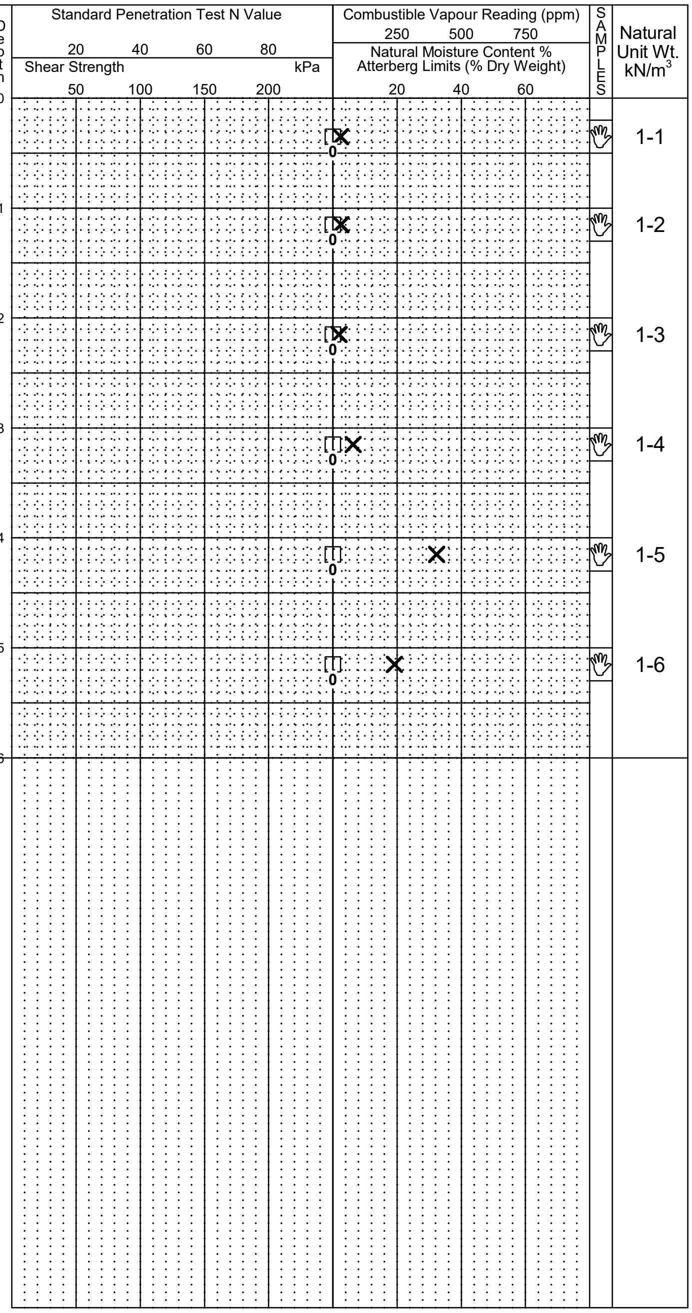
Drill Type:

Datum: Geodetic

Logged by: C.H.   Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Samples	Natural Unit Wt. kN/m³
			5.7	0		
		TOPSOIL ~50mm	5.7			
		SAND AND GRAVEL (GP) With boulders and cobbles, brown, moist to wet				1-1
				1		1-2
				2		1-3
				3		1-4
		wet at 3.7 m depth	1.7			
		SAND AND GRAVEL (SP) With silt, grey, wet		4		1-5
				5		1-6
			-0.3	6		
		Borehole Terminated at 6 m depth Due to cave-in				



NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.0	5.0

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-02

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 7

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	☒	Combustible Vapour Reading	□
Auger Sample	◫	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	⊢—○
Dynamic Cone Test	——	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Depth (m)	Soil Description	Geodetic (m)	Samples	Natural Unit Wt. kN/m³
0	**TOPSOIL** ~50mm	7.3		
	GRAVELLY SAND (SP) With boulders and cobbles, brown, moist	7.3	Grab	2-1
1			Grab	2-2
2			Grab	2-3
3			Grab	2-4
4			Grab	2-5
5			Grab	2-6
6			Grab	2-7
7			Grab	2-8
8	With silt, brown to dark brown, frozen below 8 m depth		Grab	2-9
8.8	**SILTY SAND (SM)** Brown, wet, frozen	-1.5	Grab	2-10
10	**Borehole Terminated at 10 m depth**	-2.7		

Standard Penetration Test N Value: 20, 40, 60, 80; Shear Strength (kPa): 50, 100, 150, 200

Combustible Vapour Reading (ppm): 250, 500, 750; Natural Moisture Content %; Atterberg Limits (% Dry Weight): 20, 40, 60

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2. Multi-bead thermistor string installed to 10.0 m depth upon completion
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-03

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 8

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

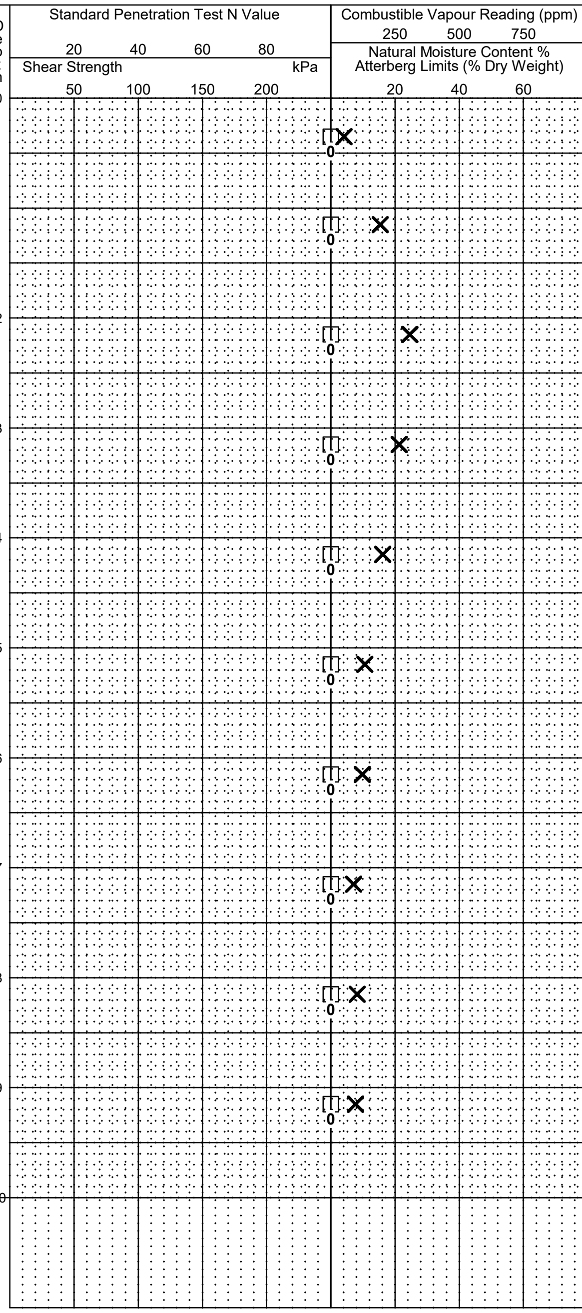
Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	─	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	SAMPLES	Natural Unit Wt. kN/m³
			9	0		
		TOPSOIL ~50mm	9.0			
		SAND AND GRAVEL With cobbles, brown, low moisture content			✋	3-1
		SILTY SAND (SM) Trace gravel, brown, wet	8.0	1	✋	3-2
		At 2 m, some small boulders, ice crystals and lenses		2	✋	3-3
				3	✋	3-4
				4	✋	3-5
		Large limestone boulder at 5 m depth	4.0	5		
		SAND AND GRAVEL (SW) Reddish brown, very moist			✋	3-6
				6	✋	3-7
				7	✋	3-8
				8	✋	3-9
		SANDY GRAVEL (GP) Some boulders, reddish brown, very moist, ice crystals and lenses	0.0	9	✋	3-10
		Borehole Terminated at 10 m depth	-1.0	10		



NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS		
Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD			
Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-04

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 9

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SOIL DESCRIPTION	Geodetic m	Depth (m)	Combustible Vapour Reading (ppm)	Samples	Natural Unit Wt. kN/m³
	TOPSOIL ~50mm	7.5 / 7.5	0	0	4-1	
	SANDY GRAVEL (GP) Well to poorley graded, some cobbles and small boulders, brown, slightly moist		1	0	4-2	
			2	0	4-3	
			3	0	4-4	
			4	0	4-5	
	GRAVELLY SAND (SP) Trace silt, brown, very moist	2.5	5	0	4-6	
			6	0	4-7	
	With cobbles and some boulders at 7 m		7	0	4-8	
			8	0	4-9	
			9	0	4-10	
	Borehole Terminated at 10 m depth	-2.5	10			

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60.

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-05

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 10

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol
Split Spoon Sample	⊠
Auger Sample	◨
SPT (N) Value	○
Dynamic Cone Test	—
Shelby Tube	■
Shear Strength by Vane Test	+ S
Combustible Vapour Reading	□
Natural Moisture Content	✕
Atterberg Limits	⊢○
Undrained Triaxial at % Strain at Failure	⊕
Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth (m)	Samples	Natural Unit Wt. kN/m³
			6.3	0		
		TOPSOIL ~50mm	6.3			
		SANDY GRAVEL (GP) With cobbles and small boulders, brown, slightly moist			5-1	
				1	5-2	
				2	5-3	
				3	5-4	
		dark brown, wet below 4 m depth		4	5-5	
		GRAVELLY SAND (SP) Trace silt, brown, very moist	1.3	5	5-6	
				6	5-7	
				7	5-8	
				8	5-9	
				9	5-10	
		Borehole Terminated at 10 m depth	-3.7	10		

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content % / Atterberg Limits (% Dry Weight) 20, 40, 60. Combustible vapour reading 0 for all samples.

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-06

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 11

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Samples	Natural Unit Wt. kN/m³
			7.7	0		
		TOPSOIL ~50mm	7.7			
		SANDY GRAVEL (GP) With cobbles and small boulders, brown to greyish brown, damp			6-1	
				1	6-2	
				2	6-3	
				3	6-4	
		SILTY SAND (SM) Some gravel, occasional cobbles, dark grey, wet	3.7	4	6-5	
				5	6-6	
				6	6-7	
				7	6-8	
				8	6-9	
				9	6-10	
		Borehole Terminated at 10 m depth	-2.3	10		

Standard Penetration Test N Value: 20 40 60 80
Shear Strength (kPa): 50 100 150 200
Combustible Vapour Reading (ppm): 250 500 750
Natural Moisture Content % / Atterberg Limits (% Dry Weight): 20 40 60

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-07

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 12

Page. 1 of 1

Date Drilled: 'Sept 30, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	⊢⊖
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Soil Description	Geodetic (m)	Depth (m)	Samples	Natural Unit Wt. kN/m³
	6.6	0		
GRANULAR FILL (GP) Crusher run 3/4" limestone, grey, moist, well compacted			7-1, 7-2	
	4.6	2		
GRAVELLY SAND (SP) Poorly graded, with cobbles and boulders, brown, moist			7-3	
	3.6	3		
SILTY SAND (SM) Some gravel, dark grey, moist to wet below 4 m depth			7-4, 7-5	
	1.6	5		
SAND AND GRAVEL (GP) Some cobbles and boulders, becomes silty with depth, reddish brown, moist			7-6, 7-7, 7-8	
	-1.4	8		
SAND (SW) Trace silt, trace gravel, black, wet			7-9, 7-10	
	-3.4	10		
Borehole Terminated at 10 m depth				

Graph headings: Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200); Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)

Combustible vapour readings: 0 at all samples.

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	3.7	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-1

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 13

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	Symbol	Soil Description	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %; Atterberg Limits (% Dry Weight) (20, 40, 60)	Samples	Natural Unit Wt. kN/m³
			6.4	0				
		TOPSOIL ~50mm	6.4					
		SANDY GRAVEL (GP) With small boulders and cobbles, approximately 70% oversize materials, brown, moist, not frozen. Large boulders at 1.2 m depth.				X		TP1
			5.2	1				
		Backhoe Shovel Refusal at 1.2 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-2

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 1

Location: ARCTIC BAY, NU

Figure No. 14

Page. 1 of 1

Date Drilled: 'Sept 29, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Symbol	Legend
⊠	Split Spoon Sample
◨	Auger Sample
○	SPT (N) Value
—	Dynamic Cone Test
■	Shelby Tube
+ S	Shear Strength by Vane Test
□	Combustible Vapour Reading
✕	Natural Moisture Content
├─○	Atterberg Limits
⊕	Undrained Triaxial at % Strain at Failure
▲	Shear Strength by Penetrometer Test

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			6.7	0				
		TOPSOIL ~50mm	6.7					
		SANDY GRAVEL (GP) With small boulders and cobbles, approximately 70% oversize materials, brown, moist, not frozen. Large boulders at 1.2 m depth.	5.5	1		✕		TP2
		Backhoe Shovel Refusal at 1.2 m depth						

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Business Case for New Water Treatment Facilities & Associated Infrastructure
Phase I & II Environmental Site Assessment, Proposed Site 3, Arctic Bay, Nunavut

Client:
Government of Nunavut

Type of Document:
Final

Project Name:
Phase I & II Environmental Site Assessment

Project Number:

FRE-21016638-A0

Prepared By:
Carl Hentschel, P.Eng., PMP, Environmental Engineer

Reviewed By:
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Date Submitted:
2021-12-22

Legal Notification

This report was prepared by EXP Services Inc. for the account of the **Government of Nunavut**.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. EXP Services Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this project.

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Executive Summary

EXP Services Inc. (EXP) was retained by the Government of Nunavut to complete a Phase I Environmental Site Assessment (ESA) and Limited Phase II ESA for the undeveloped property in Arctic Bay, Nunavut, hereinafter referred to as the 'subject site'. This site is also known as "Site 3" for the purpose of the overall project.

The purpose of this Phase I ESA is to determine if past or present site activities have resulted in actual or potential contamination at the subject site.

The purpose of the limited Phase II ESA was to collect surface soil samples at Site 3 as part of a screening level investigation. These would be sent for laboratory analysis of the most likely contaminants of concern (COC), as determined by the Phase I ESA findings. In the absence of any findings, the analysis would default to the most common COC which is petroleum hydrocarbons.

It is understood that the report will be used as part of a business case for the development of a new community water treatment facility.

The Phase I ESA was completed in general accordance with CSA Standard Z768-01 (R2016). Subject to this standard of care, EXP makes no express or implied warranties regarding its services to any third-party, and no third-party beneficiaries re intended. Limitation of liability, scope of report and third-party reliance are outlined in Section 9 of this report.

The subject site is located along the north side the Nanisivik Highway in Arctic Bay, Nunavut. The subject site has an area of approximately 0.1 hectares. At the time of the investigation, the subject site was undeveloped land. The groundwater flow direction is anticipated to be southerly towards the Arctic Ocean found roughly 125 m to the south.

A review of historical aerial photographs and other records for the subject site found no evidence that it had never been developed. This concurred with information gathered during an on-site interview.

There were no water bodies on the subject site. The closest body of water is the Arctic Ocean (i.e., Arctic Bay) found 125 m to the south. Based on the existing geological mapping information, overburden stratigraphy generally consisted of silty gravelly sand to sandy gravel overburden with some soil and/or granite bedrock outcropping throughout.

Based on the findings of the Phase I ESA completed at the subject site, EXP identified the following potentially contaminating activities:

- The adjacent power plant to the west, serviced by two large diesel fuel tanks; and,
- The Hamlet fuel depot to the south.

In both cases, the contaminant of concern was petroleum hydrocarbons.

The findings of the Phase II ESA are the following:

- Five (5) boreholes were advanced on the subject site, from which four (4) soil samples were selected for environmental laboratory analysis;
- The surface soil consisted of a brown, moist, sand, gravel, and cobble till; and,
- No petroleum hydrocarbons or BTEX parameters above the federal soil quality standards were detected in any of the soil samples submitted for analysis.

Based on the findings of the Phase I ESA and Phase II ESA completed at the subject site (i.e., Site 3), EXP did not identify any areas of potential environmental concern. No further environmental assessment work is recommended.

This executive summary is a brief synopsis of the report and should not be read in lieu of reading the report in its entirety.

1.0 Introduction

EXP Services Inc. (EXP) was retained by the Government of Nunavut to complete a Phase I Environmental Site Assessment (ESA) and Limited Phase II ESA for the undeveloped property in Arctic Bay, Nunavut, hereinafter referred to as the 'subject site'. This site is also known as “Site 3” for the purpose of the overall project.

1.1 Objective

The purpose of this Phase I ESA is to determine if past or present site activities have resulted in actual or potential contamination at subject site.

The Phase I ESA was completed in general accordance with CSA Standard Z768-01 (R2016). Subject to this standard of care, EXP makes no express or implied warranties regarding its services to any third-party, and no third-party beneficiaries re intended. Limitation of liability, scope of report and third-party reliance are outlined in Section 9 of this report.

The purpose of the limited Phase II ESA was to collect surface soil samples at Site 3 as part of a screening level investigation. These would be sent for laboratory analysis of the most likely contaminants of concern (COC), as determined by the Phase I ESA findings. In the absence of any findings, the analysis would default to the most common COC which is petroleum hydrocarbons.

It is understood that the report will be used as part of a business case for the development of a new community water treatment facility.

1.2 Site Description

The subject site is located along the north side the Nanisivik Highway in Arctic Bay, Nunavut. The subject site has an area of approximately 0.1 hectares. At the time of the investigation, the subject site was undeveloped land. The groundwater flow direction is anticipated to be southerly towards the Arctic Ocean found roughly 125 m to the south.

2.0 Scope of Phase I ESA Investigation

The scope of work for the Phase I ESA consisted of the following activities:

- Reviewing the historical occupancy of the subject site through the use of available archived and relevant municipal materials, and aerial photographs;
- Reviewing municipal and territorial records to determine whether activities that have occurred within the Phase I study area pose a potential environmental concern to the subject site;
- Obtaining an EcoLog Environmental Risk Information Services Ltd. (ERIS) report for the subject site and surrounding properties within a 250-metre radius of the subject site;
- Reviewing available geological maps for the vicinity of the subject site;
- Conducting a reconnaissance of the subject site and surrounding properties within a 150-metre radius of the subject site in order to identify the presence of actual and/or potential environmental contaminants or concerns of significance;
- Conducting interviews with designated representative(s) as a resource for current and historical information;
- Reviewing the current use of the subject site and any land use practices that may have impacted its environmental condition; and,
- Preparing a report to document the findings.

In completing the scope of work, EXP did not conduct any intrusive investigations, including sampling, analyses, or monitoring. EXP has confirmed neither the completeness nor the accuracy of any of the records that were obtained or of any of the statements made by others.

EXP personnel who conducted assessment work for this project included Carl Hentschel, P.Eng., PMP, and Mark McCalla, P.Geo. An outline of their qualifications is provided in Section 9.0.

3.0 Phase I ESA Records Review

3.1 Phase I ESA Study Area Determination

For the purpose of this assignment, the Phase I Study Area consists of neighbouring properties within a distance of approximately 250 metres from the Site boundaries. The Phase I Study Area is bounded by undeveloped land to the north, the Nanisivik Highway to the south, and structures to the west.

3.2 First Developed Use Determination

Based on a review of historical aerial photographs and other records, the subject site has never been developed.

3.3 Fire Insurance Plans

A search of The Catalogue of Canadian Fire Insurance Plans 1875 – 1975 (Catalogue) was conducted to determine if fire insurance plans (FIPs) for the site existed. No FIPs exist for the Phase I study area.

3.4 Chain of Title

A chain of title was not required for the subject site.

3.5 Environmental Reports

No environmental reports were provided for review.

3.6 Environmental Source Information

Information pertaining to the subject site was obtained by reviewing documents that are available to the public through local and territorial sources. EXP did not identify the need to contact any federal agencies.

3.6.1 Hazardous Materials Spill Database

On October 26, 2021, the Government of the Northwest Territories *Hazardous Materials Spill Database* website was searched for postings in the vicinity of the subject site. This database also includes properties in Nunavut and is used by both territories inclusively.

No records were found that posed an environmental concern to the subject site.

3.6.2 PCB Storage Sites

Documents entitled *National Inventory of PCBs in Use and PCB Wastes in Storage in Canada*, *2003 Annual Report* prepared by Environment Canada were reviewed. No records pertaining to PCB storage sites were identified within the Phase I study area.

3.7 EcoLog ERIS Database Search

A search of territorial and federal databases for records pertaining to the subject site and properties within the Phase I study area was conducted by EcoLog ERIS. EXP has confirmed neither the completeness nor the accuracy of the records that were provided. A summary of the more significant findings is provided below. A copy of the EcoLog ERIS report is provided in Appendix B.

No government database listings were found for the subject site or properties in the vicinity of the subject site.

3.8 Physical Setting Sources

3.8.1 Aerial Photographs

Aerial photographs dated 1969, 1985, and 1996 were reviewed. The following table summarizes the development and land use history of the subject site and adjacent properties as depicted on the reviewed aerial photographs.

Aerial Photograph (year)	Details
1969	The subject site and adjacent lands are undeveloped. Nanisivik Highway is visible.
1985	The subject site and adjacent properties remain undeveloped.
1999	The subject site remains undeveloped. Three large aboveground fuel tanks are now visible to the southwest across the Nanisivik Highway, and a small building is visible adjacent to the west.

Based on the review of the aerial photography, the three large fuel ASTs is a considered potentially contaminating activity and are an environmental concern to the subject site were found.

3.8.2 Topography, Hydrology, Geology

The following information sources were reviewed to determine the nature of the subsurface materials at the site:

- Geological Survey of Canada (2006), Generalized Bedrock Geology of Canada.
- Geological Survey of Canada (2006) Geology of Nunavut.

According to the above maps the grey and pink granite bedrock can be classified as granulite-facies granitoids of the Paleoproterozoic era. The site soil is comprised of silty gravelly sand to sandy gravel overburden with some topsoil and/or bedrock outcropping throughout.

Topographically, the subject site is located on the edge a significant downslope towards the south. Based on this slope and the proximity of the arctic ocean, the local direction of groundwater flow is inferred to be south. However due to the presence of permafrost, shallow groundwater is only able to migrate during the warm season when the active layer thaws.

3.8.3 Fill Materials

It is not anticipated that significant amounts of fill material are present at the subject site.

3.9 Site Operating Records

No site operating records were available for review.

3.10 Summary of Records Review

Based on a review of the available records, no areas of potential environmental concern were identified.

4.0 Phase I ESA Interviews

Interviews were conducted by EXP with the individuals identified to be the most knowledgeable about both the current and historical subject site uses. The purpose of interviews is to obtain information to assist in identifying areas of potential environmental concern and identify details of potentially contaminating activities or potential contaminant pathways, in, on or below the subject site.

The Hamlet of Arctic Bay was contacted on October 2, 2021. They provided the following information during that investigation:

- The subject site has never had a land use.
- There has never been stored on or a reported spill at the subject site.

Responses to other questions were made during site reconnaissance and are discussed in section 5.0.

5.0 Phase I ESA Site Reconnaissance

5.1 General Requirements

On October 2, 2021, Mr. Stefan Bilan of EXP conducted the site visit in accordance with EXP's internal health and safety protocols. The purpose of the site visit was to assess the current conditions of the subject site.

The general environmental management and housekeeping practices at the subject site were reviewed as part of this assessment insofar as they could impact the environmental condition of the property; however, a detailed review of regulatory compliance issues was beyond the scope of EXP's investigation.

Adjacent properties were observed from within the grounds of the subject site, as well as publicly accessible areas. Photographs documenting the site visit are included in Appendix A.

5.2 Specific Observations at the Subject Site

5.2.1 Buildings and Structures

The were no site buildings on the subject site.

5.2.2 Site Utilities and Services

The subject site is not serviced by any infrastructure.

5.3 Storage Tanks

5.3.1 Underground Storage Tanks

No UST were observed on the subject site and there was no evidence of historical UST.

5.3.2 Above Ground Storage Tanks

No AST were observed on the subject site and there was no evidence of historical UST.

5.4 Chemical Storage Handling and Floor Condition

No chemicals were observed on the subject site and there was no evidence of historical UST observed on the subject site.

5.5 Areas of Stained Soil, Pavement or Stressed Vegetation

The subject site was snow covered at the time of the site visit, therefore no evidence of possible significant staining of soil or stressed vegetation could be observed.

5.6 Fill and Debris

The subject site is at approximately the same elevation as the surrounding properties and as such substantial quantities of fill are not anticipated to be present at the subject site.

Regionally, the topography appears to slope down towards the northwest.

5.7 Air Emissions

No air emissions are associated with the property, other than those from the building heating system. There are no concerns.

5.8 Odours

No strong odours were present during the site visit.

5.9 Noise

No excessive noise was heard during the site visit.

5.10 Other Observations

There were no pits or lagoons, no railways or spurs, and no unidentified substances observed on the subject site.

5.11 Special Attention Items, Hazardous Building Materials and Designated Substances

5.11.1 Asbestos

As there is no structure on the subject site, asbestos is not considered a concern.

5.11.2 Ozone Depleting Substances (ODSs)

As there is no refrigeration equipment on the subject site, ODSs are not considered a concern.

5.11.3 Lead

As there is no structure on the subject site, lead is not considered a concern.

5.11.4 Mercury

As there is no equipment on the subject site, mercury is not considered a concern.

5.11.5 Polychlorinated Biphenyls (PCB)

As there is no equipment on the subject site, PCBs are not considered a concern.

5.11.6 Urea Formaldehyde Foam Insulation

There are no UFFI issues as the site is vacant.

5.11.7 Radon

Radon is not expected to be a problem for the site.

5.11.8 Mould

As there is no structure on the subject site, mould is not considered a concern.

5.11.9 Other Substances

No other special attention substances (such as acrylonitrile or isocyanates) were suspected to be present at the subject site at the time of site reconnaissance.

5.12 Processing and Manufacturing Operations

No processing or manufacturing operations were observed at the subject site.

5.13 Hazardous Materials Use and Storage

No hazardous materials are used or stored at the subject site.

5.14 Vehicle and Equipment Maintenance Areas

No vehicle and equipment maintenance activities were observed or reported.

5.15 Drains and Sumps

No drains or sumps were observed during the site visit.

5.16 Oil/Water Separators

No oil-water separators were observed at the subject site.

5.17 Sewage and Wastewater Disposal

No sewage and wastewater are generated at the subject site.

5.18 Solid Waste Generation, Storage & Disposal

Currently no solid wastes are generated at the subject site.

5.19 Liquid Waste Generation, Storage & Disposal

No liquid wastes are generated at the subject site.

5.20 Unidentified Substances

No unidentified substances were observed on the subject site at the time of the site visit. No dumping or any other deleterious materials were identified.

5.21 Hydraulic Lift Equipment

No hydraulic equipment was observed at the subject site.

5.22 Mechanical Equipment

No mechanical equipment of concern was present on the subject site.

5.23 Abandoned and Existing Wells

There is no evidence that there are any domestic water wells on the subject site.

5.24 Roads, Parking Facilities and Right of Ways

There is a no roadway access presently on the subject site.

5.25 Adjacent and Surrounding Properties

A visual inspection of the adjacent properties and properties within 250 m of the subject site was conducted from publicly accessible areas to identify the occupants and document the uses and sources of potential environmental concerns that may impact the subject site.

The following land uses border the subject site:

- North: Undeveloped lands;
- West: Built up gravel pad and new power plant. As this property is equipped with two large diesel tanks, it is considered an APEC;
- East: Foundation piles to be used for a new building followed by a small metal clad building; and,
- South: Nanisivik Highway followed by Hamlet fuel depot. These large tanks in close proximity to the Site are considered an APEC.

5.26 Summary and Written Description of Investigation

Based on the site reconnaissance, two APECs were identified.

- The adjacent power plant to the west, serviced by two large diesel fuel tanks; and,
- The Hamlet fuel depot to the south.

In both cases, the contaminant of concern was petroleum hydrocarbons.

6.0 Phase I ESA Conclusions

Based on the findings of the Phase I ESA completed at the subject site, EXP identified the following areas of potential environmental concern:

- The adjacent power plant to the west, serviced by two large diesel fuel tanks; and,
- The Hamlet fuel depot to the south.

In both cases, the contaminant of concern was petroleum hydrocarbons.

7.0 Phase II ESA Investigation

7.1 Methodology

On Oct 2, 2021, Mr. Stefan Bilan of EXP oversaw the drilling of five (5) boreholes on the subject site by Canadrill. The boreholes were advanced using an air hammer drilling rig, and samples were collected from cuttings at roughly 1 m intervals. All but one boreholes were terminated at 10 m below surface grade (bsg). Sampling for environmental purposes was only conducted on the sample collected within the top 1 m bsg interval. Soil samples were selected for laboratory analysis based on visual, olfactory evidence of impacts (if observed) as well as field screened for combustible organic vapour. The identified contaminants of concern were petroleum hydrocarbons and benzene, toluene, ethylbenzene, xylenes (BTEX). The following representative soil samples were submitted for laboratory analysis.

Table 7.1: Summary of Soil Samples Submitted for Laboratory Analyses

Borehole & Soil Sample Identification	Depth (m bsg)	Rationale for Submission	Analysis
BH1-1	0 - 1	Southwest corner - adjacent to power plant and closest point to the Hamlet fuel depot	PHC, BTEX
BH2-1	0 - 1	Representative soil sample	PHC, BTEX
BH3-1	0 - 1	Representative soil sample	PHC, BTEX
BH4-1	0 - 1	Northwest corner – adjacent to power pant	PHC, BTEX

Note:

PHC – petroleum hydrocarbons fractions F1 to F4

BTEX – benzene, toluene, ethylbenzene, xylenes

mbsg- metres below surface grade

Soil samples identified for possible laboratory analysis were collected from the dedicated sampling tube and placed directly into pre-cleaned, laboratory-supplied glass sample jars/vials. Samples to be analysed for PHC fraction F1 and BTEX were collected using a soil core sampler and placed into vials containing methanol as a preservative. The jars and vials were sealed with Teflon-lined lids to minimize headspace and reduce the potential for induced volatilization during storage/transport prior to analysis. All samples were then placed in a cooler containing icepacks for sample preservation purposes. The vials were inverted prior to being placed in a cooler to ensure that no headspace was present in the samples.

The representative samples were transported to Paracel Laboratories Limited (Paracel) in Ottawa, under Chain of Custody protocol for chemical analysis.

7.2 Applicable Site Condition Standards

Analytical results obtained for Site soil samples were assessed against the Canadian Council of Ministers of the Environment's (CCME) *Canada Wide Standard for Petroleum Hydrocarbons in Soil*, as set out by the Government of Nunavut's *Environmental Guideline for Management of Contaminated Sites, 1999 (revised 2014)*. This effects-based criteria is protective of human health and the environment for different groundwater conditions (potable and non-potable), land use scenarios (residential, parkland, institutional, commercial, industrial, community and agricultural/other), soil texture (coarse or medium/fine) and restoration depth (full or stratified).

For assessment purposes, EXP selected the CCME's Industrial Condition Standards (SCS) for a coarse textured soil. The selection of this category was based on the subject site being beside the Hydro Electric Plant and hamlet fuel tanks, and with a coarse soil.

5.2 Phase II ESA Findings

5.2.1 Native Material

Soils encountered consisted of moist brown sand, gravel, and cobble till. No odours or staining were observed in the soil samples.

5.2.2 Analytical Results

The soil analytical results are summarized below and the Certificates of Analysis are enclosed in Appendix C.

Table 7.2: Results of Laboratory Analyses for Soil Samples

Parameter	CCME Criteria [1]	BH1-1	BH2-1	BH3-1	BH4-1
Combustible Organic Vapours	n/a	0% LEL	0% LEL	0% LEL	0% LEL
Benzene	0.030	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.082	<0.05	<0.05	<0.05	<0.05
Toluene	0.37	<0.05	<0.05	<0.05	<0.05
Total Xylenes	11	<0.05	<0.05	<0.05	<0.05
Petroleum Fraction 1	320	<0.7	<0.7	<0.7	<0.7
Petroleum Fraction 2	260	<4	<4	<4	<4
Petroleum Fraction 3	1700	26	<8	<8	77
Petroleum Fraction4	3300	<6	<6	<6	25

Note:

1: CCME Canada Wide Standard - Industrial – Coarse Grained Soil
All results in ug/g

The concentrations of PHC and BTEX measured in all four analysed soil samples met the CCME SCS for all BTEX and petroleum hydrocarbon parameters.

8.0 Phase II ESA Conclusions and Recommendations

The findings of the Phase II ESA are the following:

- Five (5) boreholes were advanced on the subject site, from which four (4) soil samples were selected environmental laboratory analysis;
- The surface soil consisted of a brown, moist, sand, gravel, and cobble till;
- No petroleum hydrocarbons or BTEX parameters above the federal soil quality standards were detected in any of the soil samples submitted for analysis; and,
- Based on these findings EXP recommends no further environmental work be undertaken.

9.0 Qualifications of Assessors

The site visit and reporting were conducted by Carl Hentschel, P.Eng. (ON/NU/NWT), PMP. Mr. Hentschel has 20 years of experience in the environmental consulting field working primarily in Ontario, Quebec and the northern territories. He has managed and/or completed numerous Phase I Environmental Site Assessments (ESA); Phase II ESAs, soil and groundwater remediation projects, designated substance surveys, building demolition management, environmental effects evaluations (EEE), air quality assessments, bid specification preparation, and is an experienced technical report writer and reviewer.

The report was reviewed by Mark McCalla, P.Geo.. Mr. McCalla is a senior Environmental Scientist with EXP who has over 30 years of experience in the environmental consulting field. His technical undertakings have including work in the following fields: Phase I and II Environmental Site Assessments; Site Specific Risk Assessments; Petroleum and chlorinated hydrocarbon contaminated sites; Soil and groundwater remediation technologies; Hydrogeological, Terrain Analysis and Aggregate Assessments; Preparation of Ontario Ministry of Environment Certificate of Approvals and Records of Site Condition. Mr. McCalla is a Qualified Person for completing Phase I and II Environmental Site Assessments as per O.Reg. 153/04.

EXP Services Inc. is a full-service consulting and engineering firm and provides a full range of environmental services through the Environmental Services Group. EXP's Environmental Services Group has developed a strong working relationship with clients in both the private and public sectors and has developed a positive relationship with the various regulatory agencies. Personnel in the numerous branch offices form part of a large network of full-time dedicated environmental professionals in the EXP organization.

10.0 References

- Canadian Standards Association, *Phase One Environmental Site Assessment Z768-01 (R2016)*, November 2001.
- Dubreuil, L. and C. Woods, *Catalogue of Canadian Fire Insurance Plans, 1875 – 1975,* 2002.
- Environment Canada, *National Inventory of PCBs in Use and PCB Wastes in Storage in Canada, 2003 Annual Report*, 2004.
- Natural Resources Canada, The Atlas of Canada, *Toporama website* (atlas.gc.ca/toporama/en/)
- Government of the Northwest Territories, *Hazardous Materials Spill Database* (https://www.enr.gov.nt.ca/en/spills)

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

Basis of Report

This report ("Report") is based on site conditions known or inferred by the investigation undertaken as of the date of the Report. Should changes occur which potentially impact the condition of the site the recommendations of EXP may require re-evaluation. Where special concerns exist, or the Government of Nunavut ("the Client") has special considerations or requirements, these should be disclosed to EXP to allow for additional or special investigations to be undertaken not otherwise within the scope of investigation conducted for the purpose of the Report.

Reliance on Information Provided

The evaluation and conclusions contained in the Report are based on conditions in evidence at the time of site inspections and information provided to EXP by the Client and others. The Report has been prepared for the specific site, development, building, design or building assessment objectives and purpose as communicated by the Client. EXP has relied in good faith upon such representations, information and instructions and accepts no responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of any misstatements, omissions, misrepresentation or fraudulent acts of persons providing information. Unless specifically stated otherwise, the applicability and reliability of the findings, recommendations, suggestions or opinions expressed in the Report are only valid to the extent that there has been no material alteration to or variation from any of the information provided to exp. If new information about the environmental conditions at the Site is found, the information should be provided to EXP so that it can be reviewed and revisions to the conclusions and/or recommendations can be made, if warranted.

Standard of Care

The Report has been prepared in a manner consistent with the degree of care and skill exercised by engineering consultants currently practicing under similar circumstances and locale. No other warranty, expressed or implied, is made. Unless specifically stated otherwise, the Report does not contain environmental consulting advice.

Complete Report

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment form part of the Report. This material includes, but is not limited to, the terms of reference given to EXP by the Client, communications between EXP and the Client, other reports, proposals or documents prepared by EXP for the Client in connection with the site described in the Report. In order to properly understand the suggestions, recommendations and opinions expressed in the Report, reference must be made to the Report in its entirety. EXP is not responsible for use by any party of portions of the Report.

Use of Report

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. No other party may use or rely upon the Report in whole or in part without the written consent of EXP. Any use of the Report, or any portion of the Report, by a third party are the sole responsibility of such third party. EXP is not responsible for damages suffered by any third party resulting from unauthorised use of the Report.

Report Format

Where EXP has submitted both electronic file and a hard copy of the Report, or any document forming part of the Report, only the signed and sealed hard copy shall be the original documents for record and working purposes. In the event of a dispute or discrepancy, the hard copy shall govern. Electronic files transmitted by EXP utilize specific software and hardware systems. EXP makes no representation about the compatibility of these files with the Client's current or future software and hardware systems. Regardless of format, the documents described herein are EXP's instruments of professional service and shall not be altered without the written consent of EXP.

12.0 Signatures

We trust this report meets your current needs. If you have any questions pertaining to the investigation undertaken by EXP, please do not hesitate to contact the undersigned.

Carl Hentschel, P. Eng., PMP
Senior Engineer
Earth and Environment

Mark McCalla, P.Geo.(ON)
Senior Geoscientist
Earth and Environment

Figures

APPROXIMATE GEOTECHNICAL SITE EXTENTS - POINT TABLE (UTM ZONE 16)

SITE	POINT	EASTING	NORTHING
1	1-1	564866.368	8100568.480
1	1-2	564877.326	8100868.020
1	1-3	564977.259	8100864.365
1	1-4	564966.291	8100564.565
3	3-1	561869.994	8105140.846
3	3-2	561877.221	8105040.688
3	3-3	561777.580	8105033.796
3	3-4	561770.262	8105133.528
4	4-1	560738.257	8105656.109
4	4-2	560808.431	8105584.866
4	4-3	560737.188	8105514.691
4	4-4	560666.699	8105586.254

EXP Services Inc.
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1133 Regent Street, Suite 300
Fredericton, NB, E3B 3Z2
CANADA
www.exp.com

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:25000 (0 — 500 — 1000 m)

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
PHASE I & II ESA
OVERALL PLAN**

Project No. FRN-21016638-A0

Dwg. No. **AB3-1**

Rev. No. 0

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IAN BILLIALD

12/21/2021 2:27 PM

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No.	Issue	Date

N

No.	Revision	Date

PRELIMINARY

Drawn By:	IB
Dwg Standards Ckd By:	
Designed By:	CH
Design Checked By:	
Scale: 1:1000	0 20 40 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
PHASE I & II ESA
SITE 3

Project No.

FRN-21016638-A0

Dwg. No.	Rev. No.
AB3-2	0

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:5000 0 100 200 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
PHASE I ESA
STUDY AREA - SITE 3

Project No.

FRN-21016638-A0

Dwg. No. **AB3-3**

Rev. No. 0

Appendix A – Site Photographs

Photograph No. 1

View of diesel fuel storage tank at adjacent power plant property to the west (APEC).

Photograph No. 2

View of site looking southwest.

Photograph No. 3
View of Hamlet depot to south of Site (APEC).

Appendix B – ERIS Database Report

ERIS

HISTORICAL AERIALS

Project Property:	Phase I ESA - Air Photos Arctic Bay - Air Photos Arctic Bay NU
Project No:	FRN-21016638-A0 Phase 800 Task 30
Requested By:	exp Services Inc.
Order No:	21100400193
Date Completed:	November 10, 2021

Environmental Risk Information Services
A division of Glacier Media Inc.
1.866.517.5204 | info@erisinfo.com | erisinfo.com

Decade	Year	Image Scale	Source
1930	Not Available		
1960	1969	12000	NAPL
1980	1985	15000	NAPL
1990	1996	15000	NAPL
2000	Not Available		

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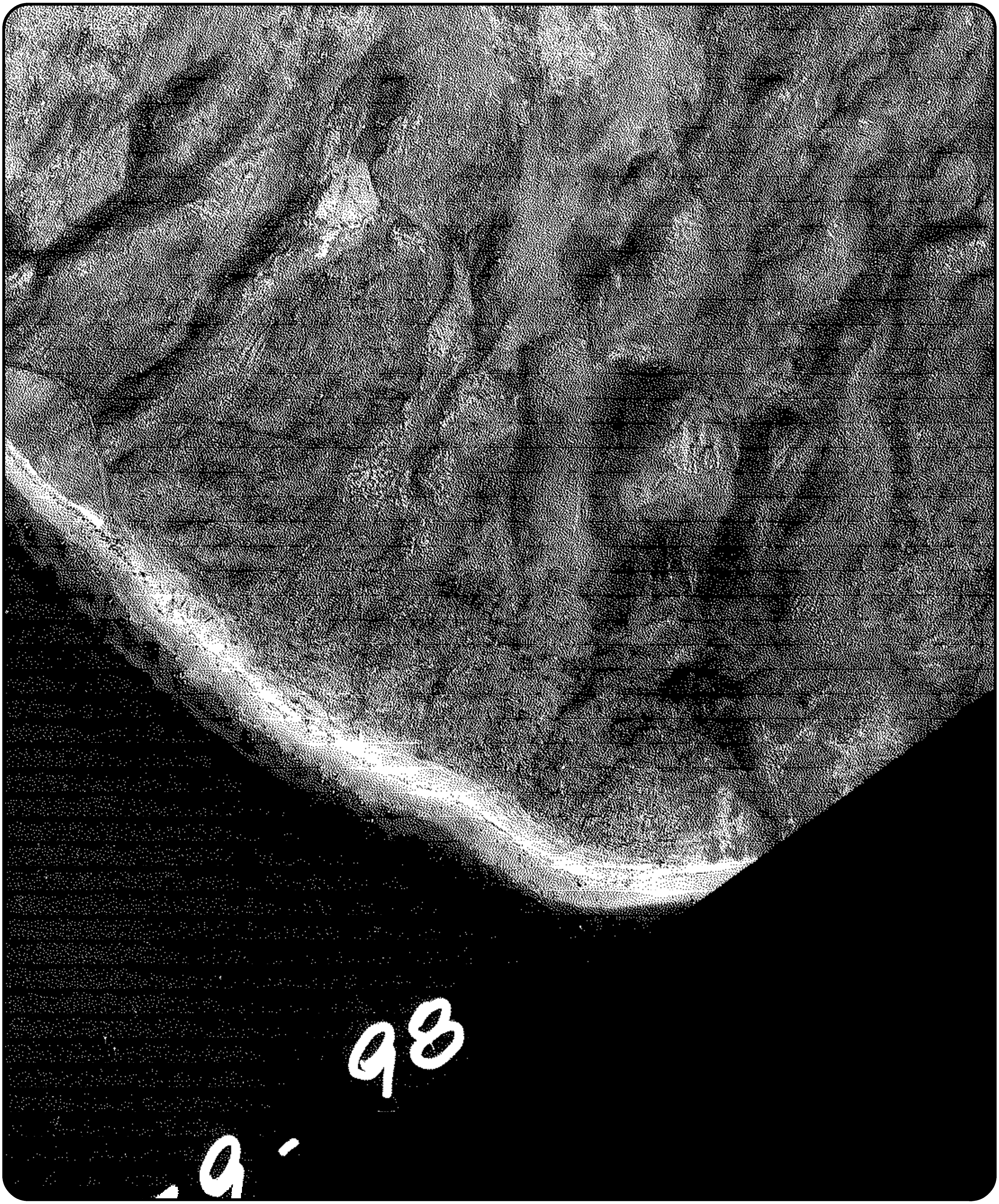
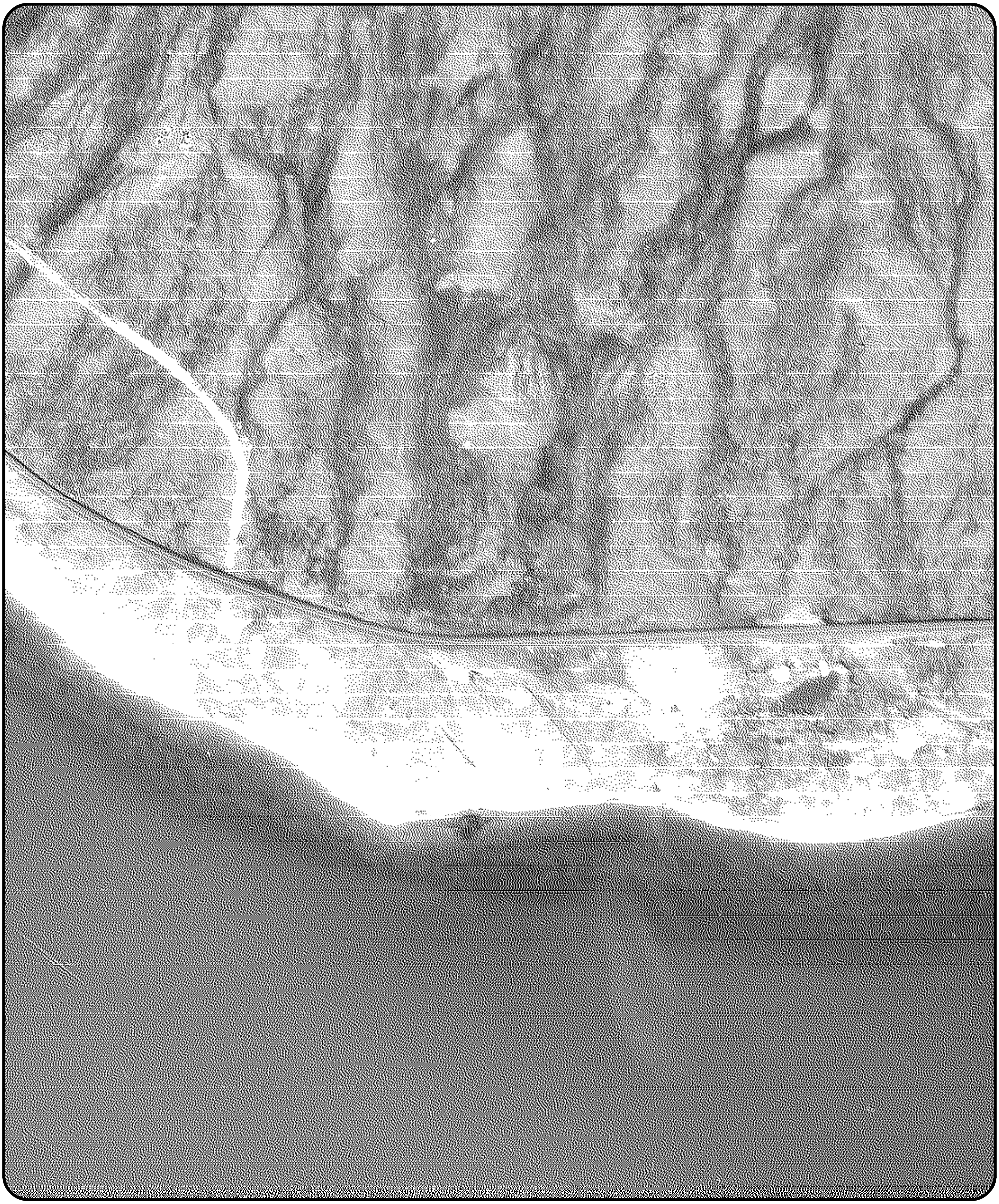


0 0.125 0.25 0.5
Kilometers

Order Number: 21100400193

Year: 1969
Source: NAPL
Map Scale: 1: 10000
Comments:



0 0.125 0.25 0.5
Kilometers

Order Number: 21100400193

Year: 1985
Source: NAPL
Map Scale: 1: 10000
Comments:

ERIS

0 0.125 0.25 0.5 Kilometers

Order Number: 21100400193

Year: 1996
Source: NAPL
Map Scale: 1: 10000
Comments:

ERIS

Appendix C – Certificates of Analysis

300 - 2319 St. Laurent Blvd
Ottawa, ON, K1G 4J8
1-800-749-1947
www.paracellabs.com

Certificate of Analysis

exp Services Inc. (Ottawa)

100-2650 Queensview Dr.
Ottawa, ON K2B 8K2
Attn: Chris Kimmerly

Client PO:
Project: FRD0021016633840040
Custody: 133772/73/74

Report Date: 25-Oct-2021
Order Date: 22-Oct-2021

Order #: 2143577

This Certificate of Analysis contains analytical data applicable to the following samples as submitted:

Paracel ID	Client ID
2143577-03	Site 1 BH4-2 AB
2143577-05	Site 1 BH1-2 AB
2143577-07	Site 1 BH6-1 AB
2143577-09	Site 1 BH7-1 AB
2143577-13	Site 3 BH3-1 AB
2143577-14	Site 3 BH4-1 AB
2143577-16	Site 3 BH1-1 AB
2143577-17	Site 3 BH2-1 AB
2143577-20	Site 4 BH1-1 AB
2143577-21	Site 4 BH2-1 AB
2143577-23	Site 4 BH4-1 AB
2143577-24	Site 4 BH3-1 AB

Approved By:

Dale Robertson, BSc
Laboratory Director

Any use of these results implies your agreement that our total liabilty in connection with this work, however arising, shall be limited to the amount paid by you for this work, and that our employees or agents shall not under any circumstances be liable to you in connection with this work.

Certificate of Analysis
Client: **exp Services Inc. (Ottawa)**
Client PO:

Report Date: 25-Oct-2021
Order Date: 22-Oct-2021
Project Description: FRD0021016633840040

Analysis Summary Table

Analysis	Method Reference/Description	Extraction Date	Analysis Date
BTEX by P&T GC-MS	EPA 8260 - P&T GC-MS	22-Oct-21	25-Oct-21
PHC F1	CWS Tier 1 - P&T GC-FID	22-Oct-21	25-Oct-21
PHCs F2 to F4	CWS Tier 1 - GC-FID, extraction	22-Oct-21	23-Oct-21
Solids, %	Gravimetric, calculation	22-Oct-21	23-Oct-21

Certificate of Analysis

Client: exp Services Inc. (Ottawa)

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

	MDL/Units	Site 1 BH4-2 AB	Site 1 BH1-2 AB	Site 1 BH6-1 AB	Site 1 BH7-1 AB
Sample Date:		29-Sep-21 17:05	29-Sep-21 13:45	30-Sep-21 14:15	30-Sep-21 16:35
Sample ID:		2143577-03	2143577-05	2143577-07	2143577-09
		Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	98.5	99.0	96.9	98.5
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	97.2%	96.9%	101%	98.0%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	221 [1]	182 [1]	<8 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	51 [1]	45 [1]	<6 [1]	<6 [1]

Client ID:	MDL/Units	Site 3 BH3-1 AB	Site 3 BH4-1 AB	Site 3 BH1-1 AB	Site 3 BH2-1 AB
Sample Date:		01-Oct-21 16:15	01-Oct-21 17:15	01-Oct-21 10:15	01-Oct-21 14:15
Sample ID:		2143577-13	2143577-14	2143577-16	2143577-17
		Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	89.6	88.0	90.8	84.2
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	115%	109%	110%	134%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	<8 [1]	77 [1]	26 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	<6 [1]	25 [1]	<6 [1]	<6 [1]

Certificate of Analysis

Client: exp Services Inc. (Ottawa)

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

	MDL/Units	Site 4 BH1-1 AB	Site 4 BH2-1 AB	Site 4 BH4-1 AB	Site 4 BH3-1 AB
Client ID:		Site 4 BH1-1 AB	Site 4 BH2-1 AB	Site 4 BH4-1 AB	Site 4 BH3-1 AB
Sample Date:		03-Oct-21 08:30	03-Oct-21 10:30	03-Oct-21 13:15	03-Oct-21 14:15
Sample ID:		2143577-20	2143577-21	2143577-23	2143577-24
		Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	86.7	85.3	86.3	87.9
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	116%	110%	126%	132%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	<8 [1]	<8 [1]	<8 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	<6 [1]	<6 [1]	<6 [1]	<6 [1]

Method Quality Control: Blank

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	ND	7	mg/kg						
F2 PHCs (C10-C16)	ND	4	mg/kg						
F3 PHCs (C16-C34)	ND	8	mg/kg						
F4 PHCs (C34-C50)	ND	6	mg/kg						
Volatiles									
Benzene	ND	0.02	mg/kg						
Ethylbenzene	ND	0.05	mg/kg						
Toluene	ND	0.05	mg/kg						
m,p-Xylenes	ND	0.05	mg/kg						
o-Xylene	ND	0.05	mg/kg						
Xylenes, total	ND	0.05	mg/kg						
Surrogate: Toluene-d8	*7.62*		*mg/kg*		*95.3*	*50-140*			

Certificate of Analysis

Client: exp Services Inc. (Ottawa)

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

Method Quality Control: Duplicate

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	349	7	mg/kg dry	247			34.2	40	
F2 PHCs (C10-C16)	ND	4	mg/kg dry	ND			NC	30	
F3 PHCs (C16-C34)	ND	8	mg/kg dry	ND			NC	30	
F4 PHCs (C34-C50)	ND	6	mg/kg dry	ND			NC	30	
Physical Characteristics									
% Solids	69.2	0.1	% by Wt.	69.8			0.9	25	
Volatiles									
Benzene	ND	0.02	mg/kg dry	ND			NC	50	
Ethylbenzene	1.46	0.05	mg/kg dry	0.983			38.8	50	
Toluene	ND	0.05	mg/kg dry	ND			NC	50	
m,p-Xylenes	1.13	0.05	mg/kg dry	0.764			39.1	50	
o-Xylene	ND	0.05	mg/kg dry	ND			NC	50	
Surrogate: Toluene-d8	*8.61*		*mg/kg dry*		*97.7*	*50-140*			

Method Quality Control: Spike

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	190	7	mg/kg	ND	95.2	80-120			
F2 PHCs (C10-C16)	98	4	mg/kg	ND	97.5	60-140			
F3 PHCs (C16-C34)	246	8	mg/kg	ND	99.4	60-140			
F4 PHCs (C34-C50)	160	6	mg/kg	ND	102	60-140			
Volatiles									
Benzene	2.86	0.02	mg/kg	ND	71.4	60-130			
Ethylbenzene	3.18	0.05	mg/kg	ND	79.6	60-130			
Toluene	3.05	0.05	mg/kg	ND	76.2	60-130			
m,p-Xylenes	6.34	0.05	mg/kg	ND	79.3	60-130			
o-Xylene	3.15	0.05	mg/kg	ND	78.8	60-130			
Surrogate: Toluene-d8	*7.50*		*mg/kg*		*93.7*	*50-140*			

Qualifier Notes:

Login Qualifiers :

Container and COC sample IDs don't match - ID on Jar lid reads: "SIte 4 BH2-1". ID on Jar label reads: "Site 4 BH4-1".

Applies to samples: Site 4 BH2-1 AB

Sample - One or more parameter received past hold time - PHC F2-F4, CCME

Applies to samples: Site 1 BH4-2 AB, Site 1 BH1-2 AB, Site 1 BH6-1 AB, Site 1 BH7-1 AB, Site 3 BH3-1 AB, Site 3 BH4-1 AB, Site 3 BH1-1 AB, Site 3 BH2-1 AB, Site 4 BH1-1 AB, Site 4 BH2-1 AB, Site 4 BH4-1 AB, Site 4 BH3-1 AB

Sample Qualifiers :

1 : Holding time had been exceeded upon receipt of the sample at the laboratory.

Sample Data Revisions

None

Work Order Revisions / Comments:

MeOH Vial: Full of soil.

Other Report Notes:

n/a: not applicable
ND: Not Detected
MDL: Method Detection Limit
Source Result: Data used as source for matrix and duplicate samples
%REC: Percent recovery.
RPD: Relative percent difference.
NC: Not Calculated

Soil results are reported on a dry weight basis when the units are denoted with 'dry'.
Where %Solids is reported, moisture loss includes the loss of volatile hydrocarbons.

CCME PHC additional information:

- The method for the analysis of PHCs complies with the Reference Method for the CWS PHC and is validated for use in the laboratory. All prescribed quality criteria identified in the method has been met.
- F1 range corrected for BTEX.
- F2 to F3 ranges corrected for appropriate PAHs where available.
- The gravimetric heavy hydrocarbons (F4G) are not to be added to C6 to C50 hydrocarbons.
- In the case where F4 and F4G are both reported, the greater of the two results is to be used for comparison to CWS PHC criteria.
- When reported, data for F4G has been processed using a silica gel cleanup.

Paracel ID: 2143577

PARACEL LABORATORIES LTD.

Paracel Order Number (Lab Use Only)	Chain Of Custody (Lab Use Only)
2143577	№ 133772

Client Name: EXP Services Inc.	Project Ref: FRD00210166 38-400-40		Page 1 of 3
Contact Name: Chris Kimmerly / Ksmil Tak	Quote #:		Turnaround Time
Address: 2650 Queensview Drive, Ottawa. Suite 100	PO #:		☑ 1 day ☐ 3 day
	E-mail: chris.kimmerly@exp.com		☐ 2 day ☐ Regular
Telephone:			Date Required:

☐ REG 153/04 ☐ REG 406/19 | Other Regulation
☐ Table 1 ☐ Res/Park ☐ Med/Fine | ☐ REG 558 ☐ PWQO
☐ Table 2 ☐ Ind/Comm ☐ Coarse | ☐ CCME ☐ MISA
☐ Table 3 ☐ Agri/Other | ☐ SU - Sani ☐ SU - Storm
☐ Table ___ | Mun: ___
For RSC: ☐ Yes ☐ No | ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Date	Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)						
1	Site 1 TP1 AB	S		2	Sep 29/21	4pm													
2	BH4-1 AB	S		2		5pm													
3	BH4-2 AB	S		2		5:05pm	X												
4	BH1-1 AB	S		2		3:35pm													
5	BH1-2 AB	S		2		3:45pm	X												
6	BH2-2 AB	S		2	Sep 30/21	8:35am	X												
7	BH6-1 AB	S		2		2:15pm	X												
8	BH3-1 AB	S		2		3:30pm													
9	BH7-1 AB	S		2		4:35pm	X												
10	BH2-1 AB	S		2		8:32am													

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct 1/21

Method of Delivery: PARACEL COURIER

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: Sirnesporn Dokmaai	Verified By: [signature]
Relinquished By (Print): Stefan Biton	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12:20	Date/Time: Oct 22 21 1:56
Date/Time: Oct 4/2021	Temperature: °C Amb	Temperature: 6.3 °C	pH Verified: ☐ By:

Chain of Custody (Env) xlsx

Revision 4.0

Paracel ID: 2143577

PARACEL LABORATORIES LTD.

www.paracellabs.com

Paracel Order Number (Lab Use Only)	Chain Of Custody (Lab Use Only)
2143577	№ 133774

Client Name: EXP Services Inc.	Project Ref: FRD-00210166-38-400-40		Page 2 of 3
Contact Name: Chris Kimmerly / Asmamit Taki	Quote #:		Turnaround Time
Address: 2650 Queensview Drive, Ottawa. Suite 100	PO #:		☑ 1 day ☐ 3 day
	Email: chris.kimmerly@exp.com		☐ 2 day ☐ Regular
Telephone:			Date Required:

☐ REG 153/04 ☐ REG 406/19 — Other Regulation

☐ Table 1 ☐ Res/Park ☐ Med/Fine ☐ REG 558 ☐ PWQO

☐ Table 2 ☐ Ind/Comm ☐ Coarse ☐ CCME ☐ MISA

☐ Table 3 ☐ Agri/Other ☐ SU - Sani ☐ SU - Storm

☐ Table ___ Mun: ___

For RSC: ☐ Yes ☐ No ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

#	Sample ID/Location Name		Matrix	Air Volume	# of Containers	Sample Taken Date	Sample Taken Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)						
1	Site 3: TP1	AR	S		2	Oct 2	8:45am													
2	TP2-1	AR	S		2	↓	8:20am													
3	BH3-1	AR	S		2	Oct 1	4:15pm	X												
4	BH4-1	AR	S		2		5:15pm	X												
5	BH5-1	AR	S		2		3:15pm													
6	BH1-1	AR	S		2		10:15am	X												
7	BH2-1	AR	S		2	↓	2:15pm	X												
8	Site 4 TP2-1	AR	S		2	Oct 2	10:10am													
9	TP2-2	AR	S		2	↓	10:15am													
10	BH1-1	AR	S		2	Oct 3	8:30am	X												

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct 12

Method of Delivery: Paracel Courier

Relinquished By (Sign): [signature]	Received By Driver/Depot: A. Rouse	Received at Lab: Sunnyform Dhvanil	Verified By: [signature]
Relinquished By (Print): Stefan Bilan	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12:30	Date/Time: Oct 22 2021 1:56
Date/Time: Oct 4/2021	Temperature: °C Air	Temperature: 6.3 °C	pH Verified: ☐ By:

Chain of Custody (Env) xlsx

Revision 4.0

PARACEL LABORATORIES LTD.

Paracel ID: 2143577

Paracel Order Number (Lab Use Only)	Chain Of Custody (Lab Use Only)
2143577	№ 133773

Client Name: EXP Services Inc.	Project Ref: FRD 0021016638-400-40		Page 3 of 3
Contact Name: Chris Kennedy / Ismail Taki	Quote #:		Turnaround Time
Address: 2650 Queensview Drive, Ottawa Suit 100.	PO #:		☑ 1 day ☐ 3 day
	Email: chris.kennedy@exp.com		☐ 2 day ☐ Regular
Telephone:			Date Required:

☐ REG 153/04 ☐ REG 406/19

☐ Table 1 ☐ Res/Park ☐ Med/Fine
☐ Table 2 ☐ Ind/Comm ☐ Coarse
☐ Table 3 ☐ Agri/Other
☐ Table ___
For RSC: ☐ Yes ☐ No

Other Regulation
☐ REG 558 ☐ PWQO
☐ CCME ☐ MISA
☐ SU - Sani ☐ SU - Storm
Mun: ______
☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Sample Taken Date	Sample Taken Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)					
1	Site 4 BH 2-1 AB	S		2	Oct 3/2021	10:30am	X											
2	BH 5-1 AB	S		2		11:15am												
3	BH 4-1 AB	S		2		1:15pm	X											
4	BH 3-1 AB	S		2		2:15pm	X											
5																		
6																		
7																		
8																		
9																		
10																		

Comments:
Transported in cooler with ice packs from Arctic Bay to Ottawa Oct /21

Method of Delivery: Paracel Courier

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: Sivanesperan Dokmai	Verified By: R
Relinquished By (Print): Stefan Bilan	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12.30	Date/Time: Oct 22, 2021 1:56
Date/Time: Oct 4/2021	Temperature: °C N/A	Temperature: 6.3 °C	pH Verified: ☐ By:

Appendix D – Borehole Logs

Log of Borehole BH-01

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 31

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Geodetic m	Depth (m)	Soil Description	Samples	Natural Unit Wt. kN/m³
14.1	0	**TOPSOIL** ~50mm		
14.1		**SAND AND GRAVEL (GM)** With small boulders and cobbles, reddish brown, moist to wet	Auger	1-1
13.1	1	**SILTY SAND (SM)** Trace gravel, reddish brown, moist	Auger	1-2
12.1	2	**CLAYEY SILTY SAND (SM-SC)** Trace to some gravel, cohesive, reddish brown, wet to moist	Auger	1-3
	3		Auger	1-4
	4		Auger	1-5
	5	occassional boulders around 5 m to 6 m depth	Auger	1-6
8.1	6	**SAND AND GRAVEL (GM)** Trace silt, reddish brown, moist to very moist, occasional cobbles/boulders	Auger	1-7
	7		Auger	1-8
	8		Auger	1-9
	9		Auger	1-10
4.1	10	**Borehole Terminated at 10 m depth** Due to cave-in		

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content % / Atterberg Limits (% Dry Weight) 20, 40, 60. Combustible vapour readings of 0 recorded at each sample.

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-02

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 32

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample		Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	
Dynamic Cone Test		Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			16.4	0				
		TOPSOIL ~50mm	16.4					
		SAND AND GRAVEL (GM) With small boulders and cobbles, brown, moist to very moist				0		2-1
				1		0		2-2
			14.4					
		SILTY SAND (SM) Some gravel, reddish brown, wet		2		0		2-3
				3		0		2-4
				4		0		2-5
			11.9					
		SAND AND GRAVEL (GM) Reddish brown, moist, bouldery below 5 m depth		5		0		2-6
				6		0		2-7
				7		0		2-8
			8.4					
		SILTY SAND (SM) Some gravel, occasional boulders, reddish brown, moist		8		0		2-9
				9		0		2-10
			6.4	10				
		Borehole Terminated at 10 m depth						

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-03

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 33

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

SOIL DESCRIPTION	Geodetic m	Depth (m)	Sample	Natural Unit Wt. kN/m³
	27	0		
TOPSOIL ~50mm	27.0			
SAND AND GRAVEL (GM) With cobbles and small boulders, brown, moist			Auger	3-1
		1	Auger	3-2
SILTY SAND (SM) Some cobbles and boulders, reddish brown, moist to wet, ice lenses and crystals	25.0	2	Auger	3-3
		3	Auger	3-4
CLAYEY SILTY SAND (SM-SC) Trace gravel, reddish brown, wet	23.0	4	Auger	3-5
SILTY SAND (SM) Some gravel, reddish brown to brown, moist	22.0	5	Auger	3-6
		6	Auger	3-7
		7	Auger	3-8
SAND AND GRAVEL (GM) Bouldery, grey, moist	19.0	8	Auger	3-9
		9	Auger	3-10
Borehole Terminated at 10 m depth	17.0	10		

Standard Penetration Test N Value: 20 40 60 80; Shear Strength (kPa): 50 100 150 200

Combustible Vapour Reading (ppm): 250 500 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight): 20 40 60

Combustible vapour readings: 0 at each sample.

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS		
Date	Water Level (m)	Hole Open To (m)
Upon Completion	3.0	open

CORE DRILLING RECORD			
Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-04

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 34

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Split Spoon Sample	☒	Combustible Vapour Reading	☐
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├──○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m^3
			26.1	0				
		TOPSOIL ~50mm	26.1					
		SAND AND GRAVEL (GM) With cobbles and small boulders, brown, moist				0		4-1
				1		0		4-2
		reddish brown, bouldery at 2 m		2		0		4-3
		grey, ice lenses/crystals below 3 m depth		3		0		4-4
		CLAYEY SILTY SAND (SM-SC) Trace to some gravel, occasional boulders, reddish brown to grey, wet	22.1	4		0		4-5
				5		0		4-6
				6		0		4-7
		SAND AND GRAVEL (GM) Some boulders, grey, moist	19.1	7		0		4-8
		Silty sand layer from 8 m to 9 m depth		8		0		4-9
				9		0		4-10
		Borehole Terminated at 10 m depth	16.1	10				

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	4.6	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-05

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 35

Page. 1 of 1

Date Drilled: 'Oct 1, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend		Legend	
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

Geodetic m	Depth (m)	Soil Description	Sample	Combustible Vapour Reading (ppm)	Natural Unit Wt. kN/m³
18.8	0	**TOPSOIL** ~50mm			
18.8	0	**SAND AND GRAVEL (GM)** With cobbles and small boulders, trace to some silty clay, reddish brown, wet	5-1	0	
17.8	1	**CLAYEY SILTY SAND (SM-SC)** Some gravel, reddish brown, wet; ice lenses and/or crystals below 2 m depth	5-2, 5-3, 5-4	0	
14.8	4	**SAND AND GRAVEL (GM)** Bouldery, reddish brown, moist	5-5, 5-6	0	
12.8	6	**SILTY SAND (SM)** Some gravel, trace clay, reddish brown, moist	5-7, 5-8	0	
10.8	8	**GRAVELLY SAND (SP)** Silty, some boulders, reddish brown, moist	5-9, 5-10	0	
8.8	10	**Borehole Terminated at 10 m depth**			

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2. Multi-bead thermistor string installed to 10.0 m depth upon completion
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	1.5	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

LOG OF BOREHOLE FRN-21016638 ARCTIC BAY SITE 3 BH LOGS.GPJ TROW OTTAWA.GDT 1/27/22

Log of Borehole TP-1

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 36

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	⊢—○
Dynamic Cone Test	——	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			27.2	0				
		TOPSOIL ~50mm	27.2					
		SAND AND GRAVEL (GM) With silt, boulders and cobbles, less than 5% oversize materials, reddish brown, moist, not frozen. Large boulders at 1.7 m depth.		1		0	TP-1	
			25.5					
		Backhoe Shovel Refusal at 1.7 m depth						

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-2

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 3

Location: ARCTIC BAY, NU

Figure No. 37

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◫	Natural Moisture Content	X
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			19.3	0				
		TOPSOIL ~50mm	19.3					
		SAND AND GRAVEL (GM) With silt, boulders and cobbles, less than 5% oversize materials, reddish brown, moist, not frozen. Large boulders at 1.4 m depth.	17.9	1		□ 0; X		TP-2
		Backhoe Shovel Refusal at 1.4 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Business Case for New Water Treatment Facilities & Associated Infrastructure
Phase I & II Environmental Site Assessment, Proposed Site 4, Arctic Bay, Nunavut

Client:
Government of Nunavut

Type of Document:
Final

Project Name:
Phase I & II Environmental Site Assessment

Project Number:

FRE-21016638-A0

Prepared By:
Carl Hentschel, P.Eng., PMP, Environmental Engineer

Reviewed By:
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Date Submitted:
2021-12-22

Legal Notification

This report was prepared by EXP Services Inc. for the account of the **Government of Nunavut**.

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Executive Summary

EXP Services Inc. (EXP) was retained by the Government of Nunavut to complete a Phase I Environmental Site Assessment (ESA) and Limited Phase II ESA for the undeveloped property in Arctic Bay, Nunavut, hereinafter referred to as the 'subject site'. This site is also known as "Site 4" for the purpose of the overall project.

The purpose of this Phase I ESA is to determine if past or present site activities have resulted in actual or potential contamination at the subject site.

The purpose of the limited Phase II ESA was to collect surface soil samples at Site 4 as part of a screening level investigation. These would be sent for laboratory analysis of the most likely contaminants of concern (COC), as determined by the Phase I ESA findings. In the absence of any findings, the analysis would default to the most common COC which is petroleum hydrocarbons.

It is understood that the report will be used as part of a business case for the development of a new community water treatment facility.

The Phase I ESA was completed in general accordance with CSA Standard Z768-01 (R2016). Subject to this standard of care, EXP makes no express or implied warranties regarding its services to any third-party, and no third-party beneficiaries re intended. Limitation of liability, scope of report and third-party reliance are outlined in Section 9 of this report.

The subject site is located along the north side of the Nanisivik Highway in Arctic Bay, Nunavut. The subject site has an area of approximately 0.1 hectares. At the time of the investigation, the subject site was undeveloped land. The groundwater flow direction is anticipated to be southerly towards the Arctic Ocean found roughly 0.1 km to the south. The subject site is located on the eastern edge of the Hamlet core.

A review of historical aerial photographs and other records for the subject site found no evidence that it had never been developed. This concurred with information gathered during an on-site interview.

There were no water bodies on the subject site. The closest body of water is Arctic Bay (i.e., Arctic Ocean) found 100 m to the south. The existing geological mapping information identified overburden stratigraphy generally consisted of silty gravelly sand to sandy gravel overburden with some soil and/or granite bedrock outcropping throughout.

The findings of the Phase II ESA are the following:

- Five (5) boreholes were advanced on the subject site, from which four (4) soil samples were selected environmental laboratory analysis;
- The surface soil consisted of a black weathered shale and boulders over brown, moist sand;
- No petroleum hydrocarbons or BTEX parameters above the federal soil quality standards were detected in any of the soil samples submitted for analysis.

Based on the findings of the Phase I ESA and Phase II ESA completed at the subject site (i.e., Site 4), EXP did not identify any areas of potential environmental concern. No further environmental assessment work is recommended.

This executive summary is a brief synopsis of the report and should not be read in lieu of reading the report in its entirety.

1.0 Introduction

EXP Services Inc. (EXP) was retained by the Government of Nunavut to complete a Phase I Environmental Site Assessment (ESA) and Limited Phase II ESA for the undeveloped property in Arctic Bay, Nunavut, hereinafter referred to as the 'subject site'. This site is also known as “Site 4” for the purpose of the overall project.

1.1 Objective

The purpose of this Phase I ESA is to determine if past or present site activities have resulted in actual or potential contamination at subject site.

The Phase I ESA was completed in general accordance with CSA Standard Z768-01 (R2016). Subject to this standard of care, EXP makes no express or implied warranties regarding its services to any third-party, and no third-party beneficiaries re intended. Limitation of liability, scope of report and third-party reliance are outlined in Section 9 of this report.

The purpose of the limited Phase II ESA was to collect surface soil samples at Site 4 as part of a screening level investigation. These would be sent for laboratory analysis of the most likely contaminants of concern (COC), as determined by the Phase I ESA findings. In the absence of any findings, the analysis would default to the most common COC which is petroleum hydrocarbons.

It is understood that the report will be used as part of a business case for the development of a new community water treatment facility.

1.2 Site Description

The subject site is located along the north side of the Nanisivik Highway in Arctic Bay, Nunavut. The subject site has an area of approximately 0.1 hectares. At the time of the investigation, the subject site was undeveloped land. The groundwater flow direction is anticipated to be southerly towards the Arctic Ocean found roughly 0.1 km to the south. The subject site is located on the eastern edge of the Hamlet core.

2.0 Scope of Phase I ESA Investigation

The scope of work for the Phase I ESA consisted of the following activities:

- Reviewing the historical occupancy of the subject site through the use of available archived and relevant municipal materials, and aerial photographs;
- Reviewing municipal and territorial records to determine whether activities that have occurred within the Phase I study area pose a potential environmental concern to the subject site;
- Obtaining an EcoLog Environmental Risk Information Services Ltd. (ERIS) report for the subject site and surrounding properties within a 250-metre radius of the subject site;
- Reviewing available geological maps for the vicinity of the subject site;
- Conducting a reconnaissance of the subject site and surrounding properties within a 150-metre radius of the subject site in order to identify the presence of actual and/or potential environmental contaminants or concerns of significance;
- Conducting interviews with designated representative(s) as a resource for current and historical information;
- Reviewing the current use of the subject site and any land use practices that may have impacted its environmental condition; and,
- Preparing a report to document the findings.

In completing the scope of work, EXP did not conduct any intrusive investigations, including sampling, analyses, or monitoring. EXP has confirmed neither the completeness nor the accuracy of any of the records that were obtained or of any of the statements made by others.

EXP personnel who conducted assessment work for this project included Carl Hentschel, P.Eng., PMP, and Mark McCalla, P.Geo. An outline of their qualifications is provided in Section 9.0.

3.0 Phase I ESA Records Review

3.1 Phase I ESA Study Area Determination

For the purpose of this assignment, the Phase I Study Area consists of neighbouring properties within a distance of approximately 250 metres from the Site boundaries. The Phase I Study Area is bounded by undeveloped land to the north, east, residences to the west, and the Nanisivik Highway to the south.

3.2 First Developed Use Determination

Based on a review of records, the subject site has never been developed.

3.3 Fire Insurance Plans

A search of The Catalogue of Canadian Fire Insurance Plans 1875 – 1975 (Catalogue) was conducted to determine if fire insurance plans (FIPs) for the site existed. No FIPs exist for the Phase I study area.

3.4 Chain of Title

A chain of title was not required for the subject site.

3.5 Environmental Reports

No environmental reports were provided for review.

3.6 Environmental Source Information

Information pertaining to the subject site was obtained by reviewing documents that are available to the public through local and territorial sources. EXP did not identify the need to contact any federal agencies.

3.6.1 Hazardous Materials Spill Database

On October 26, 2021, the Government of the Northwest Territories *Hazardous Materials Spill Database* website was searched for postings in the vicinity of the subject site. This database also includes properties in Nunavut and is used by both territories inclusively.

No records were found that posed an environmental concern to the subject site.

3.6.2 PCB Storage Sites

Documents entitled *National Inventory of PCBs in Use and PCB Wastes in Storage in Canada*, *2003 Annual Report* prepared by Environment Canada were reviewed. No records pertaining to PCB storage sites were identified within the Phase I study area.

3.7 EcoLog ERIS Database Search

A search of territorial and federal databases for records pertaining to the subject site and properties within the Phase I study area was conducted by EcoLog ERIS. EXP has confirmed neither the completeness nor the accuracy of the records that were provided. A summary of the more significant findings is provided below. A copy of the EcoLog ERIS report is provided in Appendix B.

One database listing was found for the former power plant, 230 m to the west. This was not considered an area of potential environmental concern.

3.8 Physical Setting Sources

3.8.1 Aerial Photographs

No historical aerial photographs showing the subject site were available for review.

3.8.2 Topography, Hydrology, Geology

The following information sources were reviewed to determine the nature of the subsurface materials at the site:

- Geological Survey of Canada (2006), Generalized Bedrock Geology of Canada.
- Geological Survey of Canada (2006) Geology of Nunavut.

According to the above maps the grey and pink granite bedrock can be classified as granulite-facies granitoids of the Paleoproterozoic era. The site soil is comprised of silty gravelly sand to sandy gravel overburden with some topsoil and/or bedrock outcropping throughout.

Topographically, the subject site is located on the edge a significant downslope towards the south. Based on this slope and the proximity of the arctic ocean, the local direction of groundwater flow is inferred to be south. However due to the presence of permafrost, shallow groundwater is only able to migrate during the warm season when the active layer thaws.

3.8.3 Fill Materials

It is not anticipated that significant amounts of fill material are present at the subject site.

3.9 Site Operating Records

No site operating records were available for review.

3.10 Summary of Records Review

Based on a review of the available records, no areas of potential environmental concern were identified.

4.0 Phase I ESA Interviews

Interviews were conducted by EXP with the individuals identified to be the most knowledgeable about both the current and historical subject site uses. The purpose of interviews is to obtain information to assist in identifying areas of potential environmental concern and identify details of potentially contaminating activities or potential contaminant pathways, in, on or below the subject site.

The Hamlet of Arctic Bay was contacted on October 2, 2021. They provided the following information during that investigation:

- The subject site has never had a land use.
- There has never been stored on or a reported spill at the subject site.

Responses to other questions were made during site reconnaissance and are discussed in section 5.0.

5.0 Phase I ESA Site Reconnaissance

5.1 General Requirements

On October 2, 2021, Mr. Stefan Bilan of EXP conducted the site visit in accordance with EXP's internal health and safety protocols. The purpose of the site visit was to assess the current conditions of the subject site.

The general environmental management and housekeeping practices at the subject site were reviewed as part of this assessment insofar as they could impact the environmental condition of the property; however, a detailed review of regulatory compliance issues was beyond the scope of EXP's investigation.

Adjacent properties were observed from within the grounds of the subject site, as well as publicly accessible areas. Photographs documenting the site visit are included in Appendix A.

5.2 Specific Observations at the Subject Site

5.2.1 Buildings and Structures

The were no site buildings on the subject site.

5.2.2 Site Utilities and Services

The subject site is not serviced by any infrastructure.

5.3 Storage Tanks

5.3.1 Underground Storage Tanks

No UST were observed on the subject site and there was no evidence of historical UST.

5.3.2 Above Ground Storage Tanks

No AST were observed on the subject site and there was no evidence of historical UST.

5.4 Chemical Storage Handling and Floor Condition

No chemicals were observed on the subject site and there was no evidence of historical UST observed on the subject site.

5.5 Areas of Stained Soil, Pavement or Stressed Vegetation

The subject site was snow covered at the time of the site visit, therefore no evidence of possible significant staining of soil or stressed vegetation could be observed.

5.6 Fill and Debris

The subject site is at approximately the same elevation as the surrounding properties and as such substantial quantities of fill are not anticipated to be present at the subject site.

Regionally, the topography appears to slope down towards the northwest.

5.7 Air Emissions

No air emissions are associated with the property, other than those from the building heating system. There are no concerns.

5.8 Odours

No strong odours were present during the site visit.

5.9 Noise

No excessive noise was heard during the site visit.

5.10 Other Observations

There were no pits or lagoons, no railways or spurs, and no unidentified substances observed on the subject site.

5.11 Special Attention Items, Hazardous Building Materials and Designated Substances

5.11.1 Asbestos

As there is no structure on the subject site, asbestos is not considered a concern.

5.11.2 Ozone Depleting Substances (ODSs)

As there is no refrigeration equipment on the subject site, ODSs are not considered a concern.

5.11.3 Lead

As there is no structure on the subject site, lead is not considered a concern.

5.11.4 Mercury

As there is no equipment on the subject site, mercury is not considered a concern.

5.11.5 Polychlorinated Biphenyls (PCB)

As there is no equipment on the subject site, PCBs are not considered a concern.

5.11.6 Urea Formaldehyde Foam Insulation

There are no UFFI issues as the site is vacant.

5.11.7 Radon

Radon is not expected to be a problem for the site.

5.11.8 Mould

As there is no structure on the subject site, mould is not considered a concern.

5.11.9 Other Substances

No other special attention substances (such as acrylonitrile or isocyanates) were suspected to be present at the subject site at the time of site reconnaissance.

5.12 Processing and Manufacturing Operations

No processing or manufacturing operations were observed at the subject site.

5.13 Hazardous Materials Use and Storage

No hazardous materials are used or stored at the subject site.

5.14 Vehicle and Equipment Maintenance Areas

No vehicle and equipment maintenance activities were observed or reported.

5.15 Drains and Sumps

No drains or sumps were observed during the site visit.

5.16 Oil/Water Separators

No oil-water separators were observed at the subject site.

5.17 Sewage and Wastewater Disposal

No sewage and wastewater are generated at the subject site.

5.18 Solid Waste Generation, Storage & Disposal

Currently no solid wastes are generated at the subject site.

5.19 Liquid Waste Generation, Storage & Disposal

No liquid wastes are generated at the subject site.

5.20 Unidentified Substances

No unidentified substances were observed on the subject site at the time of the site visit. No dumping or any other deleterious materials were identified.

5.21 Hydraulic Lift Equipment

No hydraulic equipment was observed at the subject site.

5.22 Mechanical Equipment

No mechanical equipment of concern was present on the subject site.

5.23 Abandoned and Existing Wells

There is no evidence that there are any domestic water wells on the subject site.

5.24 Roads, Parking Facilities and Right of Ways

There is a no roadway access presently on the subject site.

5.25 Adjacent and Surrounding Properties

A visual inspection of the adjacent properties and properties within 250 m of the subject site was conducted from publicly accessible areas to identify the occupants and document the uses and sources of potential environmental concerns that may impact the subject site.

The following land uses border the subject site:

- North: Undeveloped lands;
- West: Residential properties;
- East by: Undeveloped lands; and,
- South: Nanisivik Highway followed by undeveloped lands and Arctic Ocean.

5.26 Summary and Written Description of Investigation

Based on the site reconnaissance, no APECs were identified.

6.0 Phase I ESA Conclusions

Based on the findings of the Phase I ESA completed at the subject site, EXP did not identify any areas of potential environmental concern.

7.0 Phase II ESA Investigation

7.1 Methodology

On Oct 2, 2021, Mr. Stefan Bilan of EXP oversaw the drilling of five (5) boreholes on the subject site by Canadrill. The boreholes were advanced using an air hammer drilling rig, and samples were collected from cuttings at roughly 1 m intervals. All but one boreholes were terminated at 10 m below surface grade (bsg). Sampling for environmental purposes was only conducted on the sample collected within the top 1 m bsg interval. Soil samples were selected for laboratory analysis based on visual, olfactory evidence of impacts (if observed) as well as field screened for combustible organic vapours. In the absence of any areas of potential environmental concern identified in the Phase I ESA, the soil samples were submitted for the most common contaminants of concern which are petroleum hydrocarbons and benzene, toluene, ethylbenzene, xylenes (BTEX). The following representative soil samples were submitted for laboratory analysis.

Table 7.1: Summary of Soil Samples Submitted for Laboratory Analyses

Borehole & Soil Sample Identification	Depth (m bsg)	Rationale for Submission	Analysis
BH1-1	0 – 1	Representative soil sample	PHC, BTEX
BH2-1	0 – 1	Representative soil sample	PHC, BTEX
BH3-1	0 - 1	Representative soil sample	PHC, BTEX
BH4-1	0 - 1	Representative soil sample	PHC, BTEX

Note:

PHC – petroleum hydrocarbons fractions F1 to F4

BTEX – benzene, toluene, ethylbenzene, xylenes

mbsg- metres below surface grade

Soil samples identified for possible laboratory analysis were collected from the dedicated sampling tube and placed directly into pre-cleaned, laboratory-supplied glass sample jars/vials. Samples to be analysed for PHC fraction F1 and BTEX were collected using a soil core sampler and placed into vials containing methanol as a preservative. The jars and vials were sealed with Teflon-lined lids to minimize head-space and reduce the potential for induced volatilization during storage/transport prior to analysis. All samples were then placed in a cooler containing icepacks for sample preservation purposes. The vials were inverted prior to being placed in a cooler to ensure that no head-space was present in the samples.

The representative samples were transported to Paracel Laboratories Limited (Paracel) in Ottawa, under Chain of Custody protocol for chemical analysis.

7.2 Applicable Site Condition Standards

Analytical results obtained for Site soil samples were assessed against the Canadian Council of Ministers of the Environment's (CCME) *Canada Wide Standard for Petroleum Hydrocarbons in Soil*, as set out by the Government of Nunavut's *Environmental Guideline for Management of Contaminated Sites, 1999 (revised 2014)*. This effects based criteria is protective of human health and the environment for different groundwater conditions (potable and non-potable), land use scenarios (residential, parkland, institutional, commercial, industrial, community and agricultural/other), soil texture (coarse or medium/fine) and restoration depth (full or stratified).

For assessment purposes, EXP selected the CCME's Agriculture/Wildland Site Condition Standards (SCS) for a coarse textured soil. The selection of this category was based on the subject site being open tundra, without any neighbouring built-up properties, and with a coarse soil.

5.2 Phase II ESA Findings

5.2.1 Native Material

Soils encountered consisted of black weathered shale and boulders over brown, moist sand. No odours or staining were observed in the soil samples.

5.2.2 Analytical Results

The soil analytical results are summarized below and the Certificates of Analysis are enclosed in Appendix C.

Table 7.2: Results of Laboratory Analyses for Soil Samples

Parameter	CCME Criteria [1]	BH1-1	BH2-1	BH3-1	BH4-1
Combustible Organic Vapours	n/a	0% LEL	0% LEL	0% LEL	0% LEL
Benzene	0.030	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.082	<0.05	<0.05	<0.05	<0.05
Toluene	0.37	<0.05	<0.05	<0.05	<0.05
Total Xylenes	11	<0.05	<0.05	<0.05	<0.05
Petroleum Fraction 1	320	<0.7	<0.7	<0.7	<0.7
Petroleum Fraction 2	260	<4	<4	<4	<4
Petroleum Fraction 3	1700	<8	<8	<8	<8
Petroleum Fraction4	3300	<6	<6	<6	<6

Note:

1: CCME Canada Wide Standard - Industrial – Coarse Grained Soil
All results in ug/g

The concentrations of PHC and BTEX measured in all five analysed soil samples met the CCME SCS for all BTEX and petroleum hydrocarbon parameters.

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8.0 Phase II ESA Conclusions and Recommendations

The findings of the Phase II ESA are the following:

- Five (5) boreholes were advanced on the subject site, from which four (4) soil samples were selected environmental laboratory analysis;
- The surface soil consisted of a black weathered shale and boulders over brown, moist sand;
- No petroleum hydrocarbons or BTEX parameters above the federal soil quality standards were detected in any of the soil samples submitted for analysis; and,
- Based on these findings EXP recommends no further environmental work be undertaken.

9.0 Qualifications of Assessors

The site visit and reporting were conducted by Carl Hentschel, P.Eng. (ON/NU/NWT), PMP. Mr. Hentschel has 20 years of experience in the environmental consulting field working primarily in Ontario, Quebec and the northern territories. He has managed and/or completed numerous Phase I Environmental Site Assessments (ESA); Phase II ESAs, soil and groundwater remediation projects, designated substance surveys, building demolition management, environmental effects evaluations (EEE), air quality assessments, bid specification preparation, and is an experienced technical report writer and reviewer.

The report was reviewed by Mark McCalla, P.Geo.. Mr. McCalla is a senior Environmental Scientist with EXP who has over 30 years of experience in the environmental consulting field. His technical undertakings have including work in the following fields: Phase I and II Environmental Site Assessments; Site Specific Risk Assessments; Petroleum and chlorinated hydrocarbon contaminated sites; Soil and groundwater remediation technologies; Hydrogeological, Terrain Analysis and Aggregate Assessments; Preparation of Ontario Ministry of Environment Certificate of Approvals and Records of Site Condition. Mr. McCalla is a Qualified Person for completing Phase I and II Environmental Site Assessments as per O.Reg. 153/04.

EXP Services Inc. is a full-service consulting and engineering firm and provides a full range of environmental services through the Environmental Services Group. EXP's Environmental Services Group has developed a strong working relationship with clients in both the private and public sectors and has developed a positive relationship with the various regulatory agencies. Personnel in the numerous branch offices form part of a large network of full-time dedicated environmental professionals in the EXP organization.

10.0 References

- Canadian Standards Association, *Phase One Environmental Site Assessment Z768-01 (R2016)*, November 2001.
- Dubreuil, L. and C. Woods, *Catalogue of Canadian Fire Insurance Plans, 1875 – 1975,* 2002.
- Environment Canada, *National Inventory of PCBs in Use and PCB Wastes in Storage in Canada, 2003 Annual Report*, 2004.
- Natural Resources Canada, The Atlas of Canada, *Toporama website* (atlas.gc.ca/toporama/en/)
- Government of the Northwest Territories, *Hazardous Materials Spill Database* (https://www.enr.gov.nt.ca/en/spills)

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

Basis of Report

This report ("Report") is based on site conditions known or inferred by the investigation undertaken as of the date of the Report. Should changes occur which potentially impact the condition of the site the recommendations of EXP may require re-evaluation. Where special concerns exist, or the Government of Nunavut ("the Client") has special considerations or requirements, these should be disclosed to EXP to allow for additional or special investigations to be undertaken not otherwise within the scope of investigation conducted for the purpose of the Report.

Reliance on Information Provided

The evaluation and conclusions contained in the Report are based on conditions in evidence at the time of site inspections and information provided to EXP by the Client and others. The Report has been prepared for the specific site, development, building, design or building assessment objectives and purpose as communicated by the Client. EXP has relied in good faith upon such representations, information and instructions and accepts no responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of any misstatements, omissions, misrepresentation or fraudulent acts of persons providing information. Unless specifically stated otherwise, the applicability and reliability of the findings, recommendations, suggestions or opinions expressed in the Report are only valid to the extent that there has been no material alteration to or variation from any of the information provided to exp. If new information about the environmental conditions at the Site is found, the information should be provided to EXP so that it can be reviewed and revisions to the conclusions and/or recommendations can be made, if warranted.

Standard of Care

The Report has been prepared in a manner consistent with the degree of care and skill exercised by engineering consultants currently practicing under similar circumstances and locale. No other warranty, expressed or implied, is made. Unless specifically stated otherwise, the Report does not contain environmental consulting advice.

Complete Report

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment form part of the Report. This material includes, but is not limited to, the terms of reference given to EXP by the Client, communications between EXP and the Client, other reports, proposals or documents prepared by EXP for the Client in connection with the site described in the Report. In order to properly understand the suggestions, recommendations and opinions expressed in the Report, reference must be made to the Report in its entirety. EXP is not responsible for use by any party of portions of the Report.

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The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. No other party may use or rely upon the Report in whole or in part without the written consent of EXP. Any use of the Report, or any portion of the Report, by a third party are the sole responsibility of such third party. EXP is not responsible for damages suffered by any third party resulting from unauthorised use of the Report.

Report Format

Where EXP has submitted both electronic file and a hard copy of the Report, or any document forming part of the Report, only the signed and sealed hard copy shall be the original documents for record and working purposes. In the event of a dispute or discrepancy, the hard copy shall govern. Electronic files transmitted by EXP utilize specific software and hardware systems. EXP makes no representation about the compatibility of these files with the Client's current or future software and hardware systems. Regardless of format, the documents described herein are EXP's instruments of professional service and shall not be altered without the written consent of EXP.

12.0 Signatures

We trust this report meets your current needs. If you have any questions pertaining to the investigation undertaken by EXP, please do not hesitate to contact the undersigned.

Carl Hentschel, P. Eng., PMP
Senior Engineer
Earth and Environment

Mark McCalla, P.Geo.(ON)
Senior Geoscientist
Earth and Environment

Figures

APPROXIMATE GEOTECHNICAL SITE EXTENTS - POINT TABLE (UTM ZONE 16)

SITE	POINT	EASTING	NORTHING
1	1-1	564866.368	8100568.480
1	1-2	564877.326	8100868.020
1	1-3	564977.259	8100864.365
1	1-4	564966.291	8100564.565
3	3-1	561869.994	8105140.846
3	3-2	561877.221	8105040.688
3	3-3	561777.580	8105033.796
3	3-4	561770.262	8105133.528
4	4-1	560738.257	8105656.109
4	4-2	560808.431	8105584.866
4	4-3	560737.188	8105514.691
4	4-4	560666.699	8105586.254

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:25000 (0 — 500 — 1000 m)

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

**ARCTIC BAY
PHASE I & II ESA
OVERALL PLAN**

Project No. FRN-21016638-A0

Dwg. No. **AB4-1**

Rev. No. 0

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No.	Issue	Date

N

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:1000 — 0 20 40 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
PHASE I & II ESA
SITE 4

Project No. FRN-21016638-A0

Dwg. No. **AB4-2**

Rev. No. 0

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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

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Dwg Standards Ckd By:

Designed By: CH

Design Checked By:

Scale: 1:1000 — 0, 20, 40 m

Project Title

HIGH ARCTIC WATER
WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY
PHASE I ESA
STUDY AREA - SITE 4

Project No.

FRN-21016638-A0

Dwg. No.: **AB4-3**

Rev. No.: 0

Appendix A – Site Photographs

Photograph No. 1
View from site looking west.

Photograph No. 2
View from site looking north.

Appendix B – ERIS Database Report

DATABASE REPORT

Project Property:	*Phase I ESA* *Site 4* *Arctic Bay NU*
Project No:	*FRN-21016638-A0 Phase 800 Task 30*
Report Type:	*Standard Report NT,NU*
Order No:	*21092700231*
Requested by:	*exp Services Inc.*
Date Completed:	*September 30, 2021*

Environmental Risk Information Services
A division of Glacier Media Inc.
1.866.517.5204 | info@erisinfo.com | erisinfo.com

Table of Contents

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Executive Summary

Property Information:

Project Property: *Phase I ESA*
Site 4 Arctic Bay NU

Project No: *FRN-21016638-A0 Phase 800 Task 30*

Coordinates:

Latitude:	*73.0374113*
Longitude:	*-85.1363784*
UTM Northing:	*8,105,597.13*
UTM Easting:	*560,678.16*
UTM Zone:	*16X*

Elevation: *93 FT*
28.45 M

Order Information:

Order No: *21092700231*
Date Requested: *September 27, 2021*
Requested by: *exp Services Inc.*
Report Type: *Standard Report NT,NU*

Historical/Products:

Executive Summary: Report Summary

Database	Name	Searched	Project Property	Within 0.25 km	Total
AUWR	***Automobile Wrecking & Supplies***	*Y*	*0*	*0*	*0*
CDRY	***Dry Cleaning Facilities***	*Y*	*0*	*0*	*0*
CFST	***Crown Land Fuel Storage Tanks***	*Y*	*0*	*0*	*0*
CHM	***Chemical Register***	*Y*	*0*	*0*	*0*
CNG	***Compressed Natural Gas Stations***	*Y*	*0*	*0*	*0*
EHS	***ERIS Historical Searches***	*Y*	*0*	*0*	*0*
FCON	***Federal Convictions***	*Y*	*0*	*0*	*0*
FCS	***Contaminated Sites on Federal Land***	*Y*	*0*	*0*	*0*
FRST	***Federal Identification Registry for Storage Tank Systems (FIRSTS)***	*Y*	*0*	*0*	*0*
GHG	***Greenhouse Gas Emissions from Large Facilities***	*Y*	*0*	*0*	*0*
IAFT	***Indian & Northern Affairs Fuel Tanks***	*Y*	*0*	*0*	*0*
MINE	***Canadian Mine Locations***	*Y*	*0*	*0*	*0*
MNR	***Mineral Occurrences***	*Y*	*0*	*0*	*0*
NATE	***National Analysis of Trends in Emergencies System (NATES)***	*Y*	*0*	*0*	*0*
NDSP	***National Defense & Canadian Forces Spills***	*Y*	*0*	*0*	*0*
NDWD	***National Defence & Canadian Forces Waste Disposal Sites***	*Y*	*0*	*0*	*0*
NEBI	***National Energy Board Pipeline Incidents***	*Y*	*0*	*0*	*0*
NEBT	***National Energy Board Wells***	*Y*	*0*	*0*	*0*
NEES	***National Environmental Emergencies System (NEES)***	*Y*	*0*	*0*	*0*
NPCB	***National PCB Inventory***	*Y*	*0*	*0*	*0*
NPRI	***National Pollutant Release Inventory***	*Y*	*0*	*1*	*1*
OGWE	***Oil and Gas Wells***	*Y*	*0*	*0*	*0*
RST	***Retail Fuel Storage Tanks***	*Y*	*0*	*0*	*0*
SCT	***Scott's Manufacturing Directory***	*Y*	*0*	*0*	*0*
SPL	***Spills***	*Y*	*0*	*0*	*0*
		Total:	*0*	*1*	*1*

Executive Summary: Site Report Summary - Project Property

Map Key	DB	Company/Site Name	Address	Dir/Dist (m)	Elev diff (m)	Page Number

No records found in the selected databases for the project property.

Executive Summary: Site Report Summary - Surrounding Properties

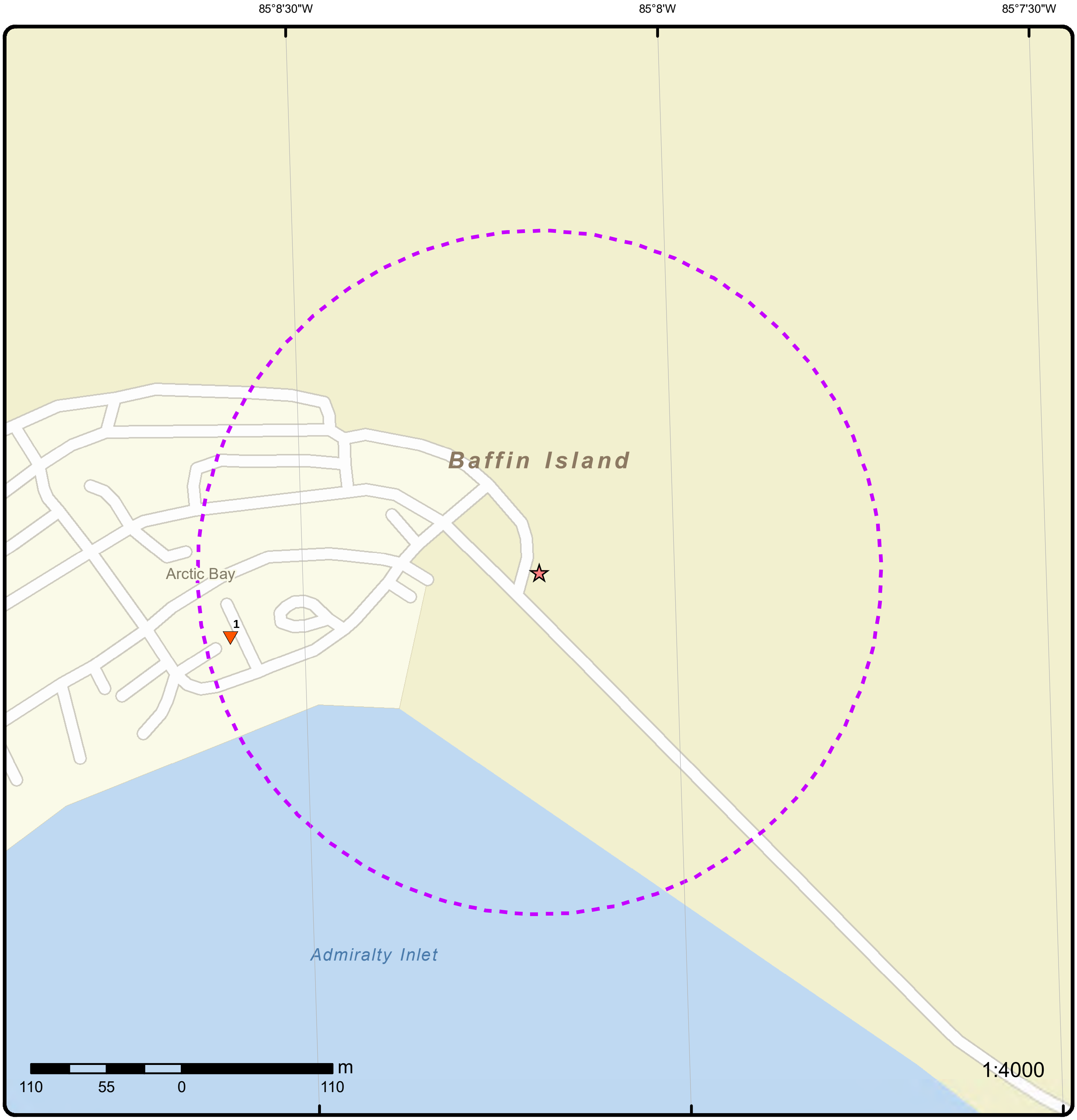
Map Key	DB	Company/Site Name	Address	Dir/Dist (m)	Elev Diff (m)	Page Number
1	NPRI	QULLIQ ENERGY CORPORATION	NOT AVAILABLE Arctic Bay NU X0A 0A0	W/230.6	-21.49	11

Executive Summary: Summary By Data Source

NPRI - National Pollutant Release Inventory

A search of the NPRI database, dated 1993-May 2017 has found that there are 1 NPRI site(s) within approximately 0.25 kilometers of the project property.

Lower Elevation	Address	Direction	Distance (m)	Map Key
QULLIQ ENERGY CORPORATION	NOT AVAILABLE Arctic Bay NU X0A 0A0	W	230.58	1



Map: 0.25 Kilometer Radius

Order Number: 21092700231

Address: Site 4, Arctic Bay, NU

Project Property	Freeways; Highways	Beach	Shopping & Sports Area
Buffer Outline	Traffic Circle; Ramp	Airport	University/College
Eris Sites with Higher Elevation	Major Arterial; Minor Arterial	Industrial Area	Cemetery; Golf Course
Eris Sites with Same Elevation	Local Road	Military Base	Parkt (National)
Eris Sites with Lower Elevation	Service Road; Traffic Circle; Ramp	Aircraft Roads	Park (City/County)
Eris Sites with Unknown Elevation	Rail	Native Reservation	
		Hospital	

Source: © 2021 ESRI StreetMap Premium.

© ERIS Information Limited Partnership

Aerial

Year: 2017

Order Number: 21092700231

Address: Site 4, Arctic Bay, NU

Source: ESRI World Imagery

© ERIS Information Limited Partnership

Topographic Map

Order Number: 21092700231

Address: Site 4, NU

Source: ESRI World Topographic Map

© ERIS Information Limited Partnership

Detail Report

Map Key	Number of Records	Direction/ Distance (m)	Elev/Diff (m)	Site	DB
1	1 of 1	W/230.6	7.0 / -21.49	QULLIQ ENERGY CORPORATION NOT AVAILABLE Arctic Bay NU X0A 0A0	NPRI

NPRI ID:	17381	***Org ID:***	100882
Other ID:		***Submit Date:***	4/22/2015
No Other ID:		***Last Modified:***	5/29/2015 3:28:24 PM
Track ID:	125338	***Contact ID:***	
Report ID:	47847	***Cont Type:***	
Report Type:	NPRI	***Contact Title:***	
Rpt Type ID:	1	***Cont First Name:***	
Report Year:	2014	***Cont Last Name:***	
Not-Current Rpt?:	No	***Contact Position:***	
Yr of Last Filed Rpt:	2014	***Contact Fax:***	
Fac ID:	232346	***Contact Ph.:***	
Fac Name:	Arctic Bay	***Cont Area Code:***	
Fac Address1:	NOT AVAILABLE	***Contact Tel.:***	
Fac Address2:		***Contact Ext.:***	
Fac Postal Zip:	X0A 0A0	***Cont Fax Area Cde:***	
Facility Lat:	73.0006	***Contact Fax:***	
Facility Long:	-85.0028	***Contact Email:***	
DLS (Last Filed Rpt):	LOT 148 73025 CLSR NU	***Latitude:***	73.037042
Facility DLS:	LOT 148 73025 CLSR NU	***Longitude:***	-85.143345
Datum:	1983	***UTM Zone:***	
Facility Cmnts:		***UTM Northing:***	
URL:		***UTM Easting:***	
No of Empl.:	2	***Waste Streams:***	
Parent Co.:		***No Streams:***	
No Parent Co.:		***Waste Off Sites:***	
Pollut Prev Cmnts:		***No Off Sites:***	
Stacks:		***Shutdown:***	
No of Stacks:		***No of Shutdown:***	

Canadian SIC Code (2 digit):
Canadian SIC Code:
SIC Code Description:
American SIC Code:

NAICS Code (2 digit):	22
NAICS 2 Description:	Utilities
NAICS Code (4 digit):	2211
NAICS 4 Description:	Electric power generation, transmission and distribution
NAICS Code (6 digit):	221112
NAICS 6 Description:	Fossil-fuel electric power generation

Substance Release Report

Category Type ID:	1
Category Type Desc:	Stack / Point
Category Type Desc (fr):	Rejets de cheminée ou ponctuels
Grouping:	Total Air
Trans Code:	ASta
Chem:	PM2.5 - Particulate Matter <= 2.5 Microns
Chem (fr):	PM2,5 - Matière particulaire <= 2,5 microns
Quantity:	.693
Unit:	tonnes
Basis of Estimate Cd:	O

Basis of Estimate Desc: O- Engineering Estimates

Category Type ID: 1
Category Type Desc: Stack / Point
Category Type Desc (fr): Rejets de cheminée ou ponctuels
Grouping: Total Air
Trans Code: ASta
Chem: PM10 - Particulate Matter <= 10 Microns
Chem (fr): PM10 - Matière particulaire <= 10 microns
Quantity: .717
Unit: tonnes
Basis of Estimate Cd: O
Basis of Estimate Desc: O- Engineering Estimates

Category Type ID: 1
Category Type Desc: Stack / Point
Category Type Desc (fr): Rejets de cheminée ou ponctuels
Grouping: Total Air
Trans Code: ASta
Chem: Nitrogen oxides (expressed as NO2)
Chem (fr): Oxydes d'azote (exprimés en NO2)
Quantity: 46.274
Unit: tonnes
Basis of Estimate Cd: O
Basis of Estimate Desc: O- Engineering Estimates

Unplottable Summary

Total: 0 Unplottable sites

DB	Company Name/Site Name	Address	City	Postal

Unplottable Report

No unplottable records were found that may be relevant for the search criteria.

Appendix: Database Descriptions

*Environmental Risk Information Services (ERIS) can search the following databases. The extent of historical information varies with each database and current information is determined by what is publicly available to ERIS at the time of update. **Note:** Databases denoted with " * " indicates that the database will no longer be updated. See the individual database description for more information.*

Automobile Wrecking & Supplies: Private AUWR

This database provides an inventory of known locations that are involved in the scrap metal, automobile wrecking/recycling, and automobile parts & supplies industry. Information is provided on the company name, location and business type.

Government Publication Date: 1999-Dec 31, 2020

Dry Cleaning Facilities: Federal CDRY

List of dry cleaning facilities made available by Environment and Climate Change Canada. Environment and Climate Change Canada's Tetrachloroethylene (Use in Dry Cleaning and Reporting Requirements) Regulations (SOR/2003-79) are intended to reduce releases of tetrachloroethylene to the environment from dry cleaning facilities.

Government Publication Date: Jan 2004-Dec 2018

Crown Land Fuel Storage Tanks: Territorial CFST

The Department of Indian and Northern Affairs Canada mandates that all fuel storage tanks on Crown Land be recorded, when an individual applies for a land use permit or surface lease. Please note that there are numerous records in the database where the "Commencement Date" is previous to 1997. However, since INAC only began registering tank locations in 1997, any tanks installed previous to that may or may not be in the database, due to lack of regulations. Note the following descriptions: Commencement Date is the original file date, Fuel Application Date is the date an application was submitted for a tank, and the Fuel Confirmation Date is the date the department accepted the application and confirmed the information submitted.

Government Publication Date: Oct 1997-Nov 2019

Chemical Register: Private CHM

This database includes a listing of locations of facilities within the Province or Territory that either manufacture and/or distributes chemicals.

Government Publication Date: 1999-Dec 31, 2020

Compressed Natural Gas Stations: Private CNG

Canada has a network of public access compressed natural gas (CNG) refuelling stations. These stations dispense natural gas in compressed form at 3,000 pounds per square inch (psi), the pressure which is allowed within the current Canadian codes and standards. The majority of natural gas refuelling is located at existing retail gasoline that have a separate refuelling island for natural gas. This list of stations is made available by the Canadian Natural Gas Vehicle Alliance.

Government Publication Date: Dec 2012 -Aug 2021

ERIS Historical Searches: Private EHS

ERIS has compiled a database of all environmental risk reports completed since March 1999. Available fields for this database include: site location, date of report, type of report, and search radius. As per all other databases, the ERIS database can be referenced on both the map and "Statistical Profile" page.

Government Publication Date: 1999-Jun 30, 2021

Federal Convictions: Federal FCON

Environment Canada maintains a database referred to as the "Environmental Registry" that details prosecutions under the Canadian Environmental Protection Act (CEPA) and the Fisheries Act (FA). Information is provided on the company name, location, charge date, offence and penalty.

Government Publication Date: 1988-Jun 2007*

Contaminated Sites on Federal Land: Federal FCS

The Federal Contaminated Sites Inventory includes information on known federal contaminated sites under the custodianship of departments, agencies and consolidated Crown corporations as well as those that are being or have been investigated to determine whether they have contamination arising from past use that could pose a risk to human health or the environment. The inventory also includes non-federal contaminated sites for which the Government of Canada has accepted some or all financial responsibility. It does not include sites where contamination has been caused by, and which are under the control of, enterprise Crown corporations, private individuals, firms or other levels of government. Includes fire training sites and sites at which Per- and Polyfluoroalkyl Substances (PFAS) are a concern.

Government Publication Date: Jun 2000-Aug 2021

Federal Identification Registry for Storage Tank Systems (FIRSTS): Federal FRST

A list of federally regulated Storage tanks from the Federal Identification Registry for Storage Tank Systems (FIRSTS). FIRSTS is Environment and Climate Change Canada's database of storage tank systems subject to the Storage Tank for Petroleum Products and Allied Petroleum Products Regulations. The main objective of the Regulations is to prevent soil and groundwater contamination from storage tank systems located on federal and aboriginal lands. Storage tank systems that do not have a valid identification number displayed in a readily visible location on or near the storage tank system may be refused product delivery.

Government Publication Date: May 31, 2018

Greenhouse Gas Emissions from Large Facilities: Federal GHG

List of greenhouse gas emissions from large facilities made available by Environment Canada. Greenhouse gas emissions in kilotonnes of carbon dioxide equivalents (kt CO2 eq).

Government Publication Date: 2013-Dec 2019

Indian & Northern Affairs Fuel Tanks: Federal IAFT

The Department of Indian & Northern Affairs Canada (INAC) maintains an inventory of aboveground & underground fuel storage tanks located on both federal and crown land. Our inventory provides information on the reserve name, location, facility type, site/facility name, tank type, material & ID number, tank contents & capacity, and date of tank installation.

Government Publication Date: 1950-Aug 2003*

Canadian Mine Locations: Private MINE

This information is collected from the Canadian & American Mines Handbook. The Mines database is a national database that provides over 290 listings on mines (listed as public companies) dealing primarily with precious metals and hard rocks. Listed are mines that are currently in operation, closed, suspended, or are still being developed (advanced projects). Their locations are provided as geographic coordinates (x, y and/or longitude, latitude). As of 2002, data pertaining to Canadian smelters and refineries has been appended to this database.

Government Publication Date: 1998-2009*

Mineral Occurrences: Territorial MNR

The C.S. Lord Northern Geoscience Centre maintains a database of mineral showings (commodity occurrences) for both the Northwest Territories and Nunavut. The database provides Showing ID, latitude, longitude, Showing Name, commodity type, current development stage, and general comments on lithology, mineralization and geological settings.

Government Publication Date: 1900-Sep 2018

National Analysis of Trends in Emergencies System (NATES): Federal NATE

In 1974 Environment Canada established the National Analysis of Trends in Emergencies System (NATES) database, for the voluntary reporting of significant spill incidents. The data was to be used to assist in directing the work of the emergencies program. NATES ran from 1974 to 1994. Extensive information is available within this database including company names, place where the spill occurred, date of spill, cause, reason and source of spill, damage incurred, and amount, concentration, and volume of materials released.

Government Publication Date: 1974-1994*

National Defense & Canadian Forces Spills: Federal NDSP

The Department of National Defense and the Canadian Forces maintains an inventory of spills to land and water. All spill sites have been classified under the "Transportation of Dangerous Goods Act - 1992". Our inventory provides information on the facility name, location, spill ID #, spill date, type of spill, as well as the quantity of substance spilled & recovered.

Government Publication Date: Mar 1999-Apr 2018

National Defence & Canadian Forces Waste Disposal Sites: Federal NDWD

The Department of National Defence and the Canadian Forces maintains an inventory of waste disposal sites located on DND lands. Where available, our inventory provides information on the base name, location, type of waste received, area of site, depth of site, year site opened/closed and status.

Government Publication Date: 2001-Apr 2007*

National Energy Board Pipeline Incidents: Federal NEBI

Locations of pipeline incidents from 2008 to present, made available by the Canada Energy Regulator (CER) - previously the National Energy Board (NEB). Includes incidents reported under the Onshore Pipeline Regulations and the Processing Plant Regulations related to pipelines under federal jurisdiction, does not include incident data related to pipelines under provincial or territorial jurisdiction.

Government Publication Date: 2008-Jun 30, 2021

National Energy Board Wells: Federal NEBT

The NEBW database contains information on onshore & offshore oil and gas wells that are outside provincial jurisdiction(s) and are thereby regulated by the National Energy Board. Data is provided regarding the operator, well name, well ID No./UWI, status, classification, well depth, spud and release date.

Government Publication Date: 1920-Feb 2003*

National Environmental Emergencies System (NEES): Federal NEES

In 2000, the Emergencies program implemented NEES, a reporting system for spills of hazardous substances. For the most part, this system only captured data from the Atlantic Provinces, some from Quebec and Ontario and a portion from British Columbia. Data for Alberta, Saskatchewan, Manitoba and the Territories was not captured. However, NEES is also a repository for previous Environment Canada spill datasets. NEES is composed of the historic datasets ' or Trends ' which dates from approximately 1974 to present. NEES Trends is a compilation of historic databases, which were merged and includes data from NATES (National Analysis of Trends in Emergencies System), ARTS (Atlantic Regional Trends System), and NEES. In 2001, the Emergencies Program determined that variations in reporting regimes and requirements between federal and provincial agencies made national spill reporting and trend analysis difficult to achieve. As a consequence, the department has focused efforts on capturing data on spills of substances which fall under its legislative authority only (CEPA and FA). As such, the NEES database will be decommissioned in December 2004.

Government Publication Date: 1974-2003*

National PCB Inventory: Federal NPCB

Environment Canada's National PCB inventory includes information on in-use PCB containing equipment in Canada including federal, provincial and private facilities. Federal out-of-service PCB containing equipment and PCB waste owned by the federal government or by federally regulated industries such as airlines, railway companies, broadcasting companies, telephone and telecommunications companies, pipeline companies, etc. are also listed. Although it is not Environment Canada's mandate to collect data on non-federal PCB waste, the National PCB inventory includes some information on provincial and private PCB waste and storage sites. Some addresses provided may be Head Office addresses and are not necessarily the location of where the waste is being used or stored.

Government Publication Date: 1988-2008*

National Pollutant Release Inventory: Federal NPRI

Environment Canada has defined the National Pollutant Release Inventory ("NPRI") as a federal government initiative designed to collect comprehensive national data regarding releases to air, water, or land, and waste transfers for recycling for more than 300 listed substances.

Government Publication Date: 1993-May 2017

Oil and Gas Wells: Private OGWE

The Nickle's Energy Group (publisher of the Daily Oil Bulletin) collects information on drilling activity including operator and well statistics. The well information database includes name, location, class, status and depth. The main Nickle's database is updated on a daily basis, however, this database is updated on a monthly basis. More information is available at www.nickles.com.

Government Publication Date: 1988-Feb 28, 2021

Retail Fuel Storage Tanks: Private RST

This database includes an inventory of retail fuel outlet locations (including marinas) that have on their property gasoline, oil, waste oil, natural gas and / or propane storage tanks.

Government Publication Date: 1999-Dec 31, 2020

Scott's Manufacturing Directory: Private SCT

Scott's Directories is a data bank containing information on over 200,000 manufacturers across Canada. Even though Scott's listings are voluntary, it is the most comprehensive database of Canadian manufacturers available. Information concerning a company's address, plant size, and main products are included in this database.

Government Publication Date: 1992-Mar 2011*

Spills: Territorial SPL

The Department of Environment and Natural Resource (ENR) in Yellowknife maintains an inventory of spill locations through the "Hazardous Materials Spills Database". Information is provided on the spill number, date, location, spill description, quantity & commodity spilled and all applicable parties involved. Data previously maintained and made available by the Department of Resources, Wildlife & Economic Development (RWED).

Government Publication Date: Aug 31, 2021

Definitions

Database Descriptions: This section provides a detailed explanation for each database including: source, information available, time coverage, and acronyms used. They are listed in alphabetic order.

Detail Report: This is the section of the report which provides the most detail for each individual record. Records are summarized by location, starting with the project property followed by records in closest proximity.

Distance: The distance value is the distance between plotted points, not necessarily the distance between the sites' boundaries. All values are an approximation.

Direction: The direction value is the compass direction of the site in respect to the project property and/or center point of the report.

Elevation: The elevation value is taken from the location at which the records for the site address have been plotted. All values are an approximation. Source: Google Elevation API.

Executive Summary: This portion of the report is divided into 3 sections:

'Report Summary'- Displays a chart indicating how many records fall on the project property and, within the report search radii.

'Site Report Summary'-Project Property'- This section lists all the records which fall on the project property. For more details, see the 'Detail Report' section.

'Site Report Summary-Surrounding Properties'- This section summarizes all records on adjacent properties, listing them in order of proximity from the project property. For more details, see the 'Detail Report' section.

Map Key: The map key number is assigned according to closest proximity from the project property. Map Key numbers always start at #1. The project property will always have a map key of '1' if records are available. If there is a number in brackets beside the main number, this will indicate the number of records on that specific property. If there is no number in brackets, there is only one record for that property.

The symbol and colour used indicates 'elevation': the red inverted triangle will dictate 'ERIS Sites with Lower Elevation', the yellow triangle will dictate 'ERIS Sites with Higher Elevation' and the orange square will dictate 'ERIS Sites with Same Elevation.'

Unplottables: These are records that could not be mapped due to various reasons, including limited geographic information. These records may or may not be in your study area, and are included as reference.

Appendix C – Certificates of Analysis

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Certificate of Analysis

exp Services Inc. (Ottawa)

100-2650 Queensview Dr.
Ottawa, ON K2B 8K2
Attn: Chris Kimmerly

Client PO:
Project: FRD0021016633840040
Custody: 133772/73/74

Report Date: 25-Oct-2021
Order Date: 22-Oct-2021

Order #: 2143577

This Certificate of Analysis contains analytical data applicable to the following samples as submitted:

Paracel ID	Client ID
2143577-03	Site 1 BH4-2 AB
2143577-05	Site 1 BH1-2 AB
2143577-07	Site 1 BH6-1 AB
2143577-09	Site 1 BH7-1 AB
2143577-13	Site 3 BH3-1 AB
2143577-14	Site 3 BH4-1 AB
2143577-16	Site 3 BH1-1 AB
2143577-17	Site 3 BH2-1 AB
2143577-20	Site 4 BH1-1 AB
2143577-21	Site 4 BH2-1 AB
2143577-23	Site 4 BH4-1 AB
2143577-24	Site 4 BH3-1 AB

Approved By:

Dale Robertson, BSc
Laboratory Director

Any use of these results implies your agreement that our total liabilty in connection with this work, however arising, shall be limited to the amount paid by you for this work, and that our employees or agents shall not under any circumstances be liable to you in connection with this work.

Analysis Summary Table

Analysis	Method Reference/Description	Extraction Date	Analysis Date
BTEX by P&T GC-MS	EPA 8260 - P&T GC-MS	22-Oct-21	25-Oct-21
PHC F1	CWS Tier 1 - P&T GC-FID	22-Oct-21	25-Oct-21
PHCs F2 to F4	CWS Tier 1 - GC-FID, extraction	22-Oct-21	23-Oct-21
Solids, %	Gravimetric, calculation	22-Oct-21	23-Oct-21

Client ID:		Site 1 BH4-2 AB	Site 1 BH1-2 AB	Site 1 BH6-1 AB	Site 1 BH7-1 AB
Sample Date:		29-Sep-21 17:05	29-Sep-21 13:45	30-Sep-21 14:15	30-Sep-21 16:35
Sample ID:		2143577-03	2143577-05	2143577-07	2143577-09
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	98.5	99.0	96.9	98.5
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	97.2%	96.9%	101%	98.0%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	221 [1]	182 [1]	<8 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	51 [1]	45 [1]	<6 [1]	<6 [1]

Client ID:		Site 3 BH3-1 AB	Site 3 BH4-1 AB	Site 3 BH1-1 AB	Site 3 BH2-1 AB
Sample Date:		01-Oct-21 16:15	01-Oct-21 17:15	01-Oct-21 10:15	01-Oct-21 14:15
Sample ID:		2143577-13	2143577-14	2143577-16	2143577-17
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	89.6	88.0	90.8	84.2
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	115%	109%	110%	134%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	<8 [1]	77 [1]	26 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	<6 [1]	25 [1]	<6 [1]	<6 [1]

Certificate of Analysis

Client: exp Services Inc. (Ottawa)

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

	MDL/Units	Site 4 BH1-1 AB	Site 4 BH2-1 AB	Site 4 BH4-1 AB	Site 4 BH3-1 AB
Sample Date:		03-Oct-21 08:30	03-Oct-21 10:30	03-Oct-21 13:15	03-Oct-21 14:15
Sample ID:		2143577-20	2143577-21	2143577-23	2143577-24
		Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	86.7	85.3	86.3	87.9
Volatiles					
Benzene	0.02 mg/kg dry	<0.02	<0.02	<0.02	<0.02
Ethylbenzene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
m,p-Xylenes	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
o-Xylene	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Xylenes, total	0.05 mg/kg dry	<0.05	<0.05	<0.05	<0.05
Toluene-d8	Surrogate	116%	110%	126%	132%
Hydrocarbons					
F1 PHCs (C6-C10)	7 mg/kg dry	<7	<7	<7	<7
F2 PHCs (C10-C16)	4 mg/kg dry	<4 [1]	<4 [1]	<4 [1]	<4 [1]
F3 PHCs (C16-C34)	8 mg/kg dry	<8 [1]	<8 [1]	<8 [1]	<8 [1]
F4 PHCs (C34-C50)	6 mg/kg dry	<6 [1]	<6 [1]	<6 [1]	<6 [1]

PARACEL LABORATORIES LTD.

Order #: 2143577

Certificate of Analysis

Client: **exp Services Inc. (Ottawa)**

Client PO:

Report Date: 25-Oct-2021

Order Date: 22-Oct-2021

Project Description: FRD0021016633840040

Method Quality Control: Blank

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	ND	7	mg/kg						
F2 PHCs (C10-C16)	ND	4	mg/kg						
F3 PHCs (C16-C34)	ND	8	mg/kg						
F4 PHCs (C34-C50)	ND	6	mg/kg						
Volatiles									
Benzene	ND	0.02	mg/kg						
Ethylbenzene	ND	0.05	mg/kg						
Toluene	ND	0.05	mg/kg						
m,p-Xylenes	ND	0.05	mg/kg						
o-Xylene	ND	0.05	mg/kg						
Xylenes, total	ND	0.05	mg/kg						
Surrogate: Toluene-d8	*7.62*		*mg/kg*		*95.3*	*50-140*			

Certificate of Analysis
Client: exp Services Inc. (Ottawa)
Client PO:

Report Date: 25-Oct-2021
Order Date: 22-Oct-2021
Project Description: FRD0021016633840040

Method Quality Control: Duplicate

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	349	7	mg/kg dry	247			34.2	40	
F2 PHCs (C10-C16)	ND	4	mg/kg dry	ND			NC	30	
F3 PHCs (C16-C34)	ND	8	mg/kg dry	ND			NC	30	
F4 PHCs (C34-C50)	ND	6	mg/kg dry	ND			NC	30	
Physical Characteristics									
% Solids	69.2	0.1	% by Wt.	69.8			0.9	25	
Volatiles									
Benzene	ND	0.02	mg/kg dry	ND			NC	50	
Ethylbenzene	1.46	0.05	mg/kg dry	0.983			38.8	50	
Toluene	ND	0.05	mg/kg dry	ND			NC	50	
m,p-Xylenes	1.13	0.05	mg/kg dry	0.764			39.1	50	
o-Xylene	ND	0.05	mg/kg dry	ND			NC	50	
Surrogate: Toluene-d8	*8.61*		*mg/kg dry*		*97.7*	*50-140*			

Method Quality Control: Spike

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Hydrocarbons									
F1 PHCs (C6-C10)	190	7	mg/kg	ND	95.2	80-120			
F2 PHCs (C10-C16)	98	4	mg/kg	ND	97.5	60-140			
F3 PHCs (C16-C34)	246	8	mg/kg	ND	99.4	60-140			
F4 PHCs (C34-C50)	160	6	mg/kg	ND	102	60-140			
Volatiles									
Benzene	2.86	0.02	mg/kg	ND	71.4	60-130			
Ethylbenzene	3.18	0.05	mg/kg	ND	79.6	60-130			
Toluene	3.05	0.05	mg/kg	ND	76.2	60-130			
m,p-Xylenes	6.34	0.05	mg/kg	ND	79.3	60-130			
o-Xylene	3.15	0.05	mg/kg	ND	78.8	60-130			
Surrogate: Toluene-d8	*7.50*		*mg/kg*		*93.7*	*50-140*			

Qualifier Notes:

Login Qualifiers :

Container and COC sample IDs don't match - ID on Jar lid reads: "SIte 4 BH2-1". ID on Jar label reads: "Site 4 BH4-1".

Applies to samples: Site 4 BH2-1 AB

Sample - One or more parameter received past hold time - PHC F2-F4, CCME

Applies to samples: Site 1 BH4-2 AB, Site 1 BH1-2 AB, Site 1 BH6-1 AB, Site 1 BH7-1 AB, Site 3 BH3-1 AB, Site 3 BH4-1 AB, Site 3 BH1-1 AB, Site 3 BH2-1 AB, Site 4 BH1-1 AB, Site 4 BH2-1 AB, Site 4 BH4-1 AB, Site 4 BH3-1 AB

Sample Qualifiers :

1 : Holding time had been exceeded upon receipt of the sample at the laboratory.

Sample Data Revisions

None

Work Order Revisions / Comments:

MeOH Vial: Full of soil.

Other Report Notes:

n/a: not applicable
ND: Not Detected
MDL: Method Detection Limit
Source Result: Data used as source for matrix and duplicate samples
%REC: Percent recovery.
RPD: Relative percent difference.
NC: Not Calculated

Soil results are reported on a dry weight basis when the units are denoted with 'dry'.
Where %Solids is reported, moisture loss includes the loss of volatile hydrocarbons.

CCME PHC additional information:

- The method for the analysis of PHCs complies with the Reference Method for the CWS PHC and is validated for use in the laboratory. All prescribed quality criteria identified in the method has been met.
- F1 range corrected for BTEX.
- F2 to F3 ranges corrected for appropriate PAHs where available.
- The gravimetric heavy hydrocarbons (F4G) are not to be added to C6 to C50 hydrocarbons.
- In the case where F4 and F4G are both reported, the greater of the two results is to be used for comparison to CWS PHC criteria.
- When reported, data for F4G has been processed using a silica gel cleanup.

Paracel ID: 2143577

PARACEL LABORATORIES LTD.

Paracel Order Number (Lab Use Only)	Chain Of Custody (Lab Use Only)
2143577	№ 133772

Client Name: EXP Services Inc.	Project Ref: FRD00210166 38-400-40		Page 1 of 3
Contact Name: Chris Kimmerly / Ismail Taki	Quote #:		Turnaround Time
Address: 2650 Queensview Drive, Ottawa. Suite 100	PO #:		☑ 1 day ☐ 3 day
	E-mail: chris.kimmerly@exp.com		☐ 2 day ☐ Regular
Telephone:			Date Required:

☐ REG 153/04 ☐ REG 406/19 — Other Regulation

☐ Table 1 ☐ Res/Park ☐ Med/Fine ☐ REG 558 ☐ PWQO

☐ Table 2 ☐ Ind/Comm ☐ Coarse ☐ CCME ☐ MISA

☐ Table 3 ☐ Agri/Other ☐ SU - Sani ☐ SU - Storm

☐ Table ___ Mun: ______

For RSC: ☐ Yes ☐ No ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Date	Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)						
1	Site 1 TP1 AB	S		2	Sep 29/21	4pm													
2	BH4-1 AB	S		2		5pm													
3	BH4-2 AB	S		2		5:05pm	X												
4	BH1-1 AB	S		2		3:30pm													
5	BH1-2 AB	S		2		3:45pm	X												
6	BH2-2 AB	S		2	Sep 30/21	8:35am	X												
7	BH6-1 AB	S		2		2:15pm	X												
8	BH3-1 AB	S		2		3:30pm													
9	BH7-1 AB	S		2		4:35pm	X												
10	BH2-1 AB	S		2		8:32am													

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct 1/21

Method of Delivery: PARACEL COURIER

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: [signature]	Verified By: [signature]
Relinquished By (Print): Stefan Bitan	Date/Time: 22/10/21 11:24	Date/Time: OCT 22, 2021 12:20	Date/Time: Oct 22/21 1:56
Date/Time: Oct 4/2021	Temperature: °C AM	Temperature: 6.3 °C	pH Verified: ☐ By:

Paracel ID: 2143577

PARACEL LABORATORIES LTD.

www.paracellabs.com

Paracel Order Number (Lab Use Only): 2143577

Chain Of Custody (Lab Use Only) Nº 133774

Client Name: EXP Services Inc.

Contact Name: Chris Kimmerly / Asmaait Takie

Address: 2650 Queensview Drive, Ottawa. Suite 100

Telephone:

Project Ref: FRD-00210166-38-400-40

Quote #:

PO #:

Email: chris.kimmerly@exp.com

Page 2 of 3

Turnaround Time

☑ 1 day ☐ 3 day

☐ 2 day ☐ Regular

Date Required:

☐ REG 153/04 ☐ REG 406/19

☐ Table 1 ☐ Res/Park ☐ Med/Fine

☐ Table 2 ☐ Ind/Comm ☐ Coarse

☐ Table 3 ☐ Agri/Other

☐ Table ___

For RSC: ☐ Yes ☐ No

Other Regulation

☐ REG 558 ☐ PWQO

☐ CCME ☐ MISA

☐ SU - Sani ☐ SU - Storm

Mun: ___

☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

#	Sample ID/Location Name		Matrix	Air Volume	# of Containers	Sample Taken Date	Sample Taken Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)						
1	Site 3: TP1	AB	S		2	Oct 2	8:45am													
2	TP2-1	AB	S		2	↓	8:20am													
3	BH3-1	AB	S		2	Oct 1	4:15pm	X												
4	BH4-1	AB	S		2		5:15pm	X												
5	BH5-1	AB	S		2		3:15pm													
6	BH1-1	AB	S		2		10:15am	X												
7	BH2-1	AB	S		2	↓	2:15pm	X												
8	Site 4 TP2-1	AB	S		2	Oct 2	10:10am													
9	TP2-2	AB	S		2	↓	10:15am													
10	BH1-1	AB	S		2	Oct 3	8:30am	X												

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct 12

Method of Delivery: Paracel Courier

Relinquished By (Sign): [signature]

Relinquished By (Print): Stefan Bilan

Date/Time: Oct 4/2021

Received By Driver/Depot: [signature]

Date/Time: 22/10/21 11:24

Temperature: °C Air

Received at Lab: Sunneyform Dhmoll

Date/Time: Oct 22, 2021 12:30

Temperature: 6.3 °C

Verified By: [signature]

Date/Time: Oct 22 2021 1:56

pH Verified: ☐ By:

Chain of Custody (Env) xlsx

Revision 4.0

PARACEL LABORATORIES LTD.

Paracel ID: 2143577

Paracel Order Number (Lab Use Only)	Chain Of Custody (Lab Use Only)
2143577	№ 133773

Client Name: EXP Services Inc.	Project Ref: FRD 0021016638-400-40
Contact Name: Chris Kennedy / Ismail Taki	Quote #:
Address: 2650 Queensview Drive, Ottawa Suit 100.	PO #:
Telephone:	E-mail: chris.kennedy@exp.com

Page 3 of 3

Turnaround Time: ☑ 1 day ☐ 3 day ☐ 2 day ☐ Regular

Date Required:

☐ REG 153/04 ☐ REG 406/19 — ☐ Table 1 ☐ Res/Park ☐ Med/Fine ☐ Table 2 ☐ Ind/Comm ☐ Coarse ☐ Table 3 ☐ Agri/Other ☐ Table ___ For RSC: ☐ Yes ☐ No

Other Regulation: ☐ REG 558 ☐ PWQO ☐ CCME ☐ MISA ☐ SU - Sani ☐ SU - Storm Mun: ☐ Other:

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Required Analysis

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Sample Taken Date	Sample Taken Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)					
1	Site 4 BH 2-1 AB	S		2	Oct 3/2021	10:30am	X											
2	BH 5-1 AB	S		2		11:15am												
3	BH 4-1 AB	S		2		1:15pm	X											
4	BH 3-1 AB	S		2		2:15pm	X											
5																		
6																		
7																		
8																		
9																		
10																		

Comments: Transported in cooler with ice packs from Arctic Bay to Ottawa Oct /21

Method of Delivery: Paracel Courier

Relinquished By (Sign): [signature]	Received By Driver/Depot: [signature]	Received at Lab: Sirnequorn Dobmai	Verified By: R
Relinquished By (Print): Stefan Bilan	Date/Time: 22/10/21 11:24	Date/Time: Oct 22, 2021 12:30	Date/Time: Oct 22 2021 1:56
Date/Time: Oct 4/2021	Temperature: °C N/A	Temperature: 6.3 °C	pH Verified: ☐ By:

Appendix D – Borehole Logs

Log of Borehole BH-01

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 51

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	⊢○
Dynamic Cone Test	——	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	Symbol	Soil Description	Geodetic m	Depth (m)	Combustible Vapour Reading (ppm)	Samples	Natural Unit Wt. kN/m^3
		TOPSOIL ~50mm	31.1 / 31.1	0			
		FILL Silty sand with gravel, shaley, black, wet slumped from mountain face	30.1		1		1-1
		SAND AND GRAVEL (GM) Silty, bouldery, dark grey, wet		1	1		1-2
			28.1	2	0		1-3
		GRAVELLY SAND (SP) Bouldery, greyish brown to reddish brown, moist		3	0		1-4
				4	0		1-5
				5	0		1-6
		Large white boulder at 6 m depth	24.1	6	0		1-7
		SAND (SP) Trace gravel, black, moist		7	1		1-8
				8	1		1-9
			21.1	9	1		1-10
		Borehole Terminated at 10 m depth		10			

Graph axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength kPa 50, 100, 150, 200; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60.

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-02

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 52

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	
Split Spoon Sample	Combustible Vapour Reading
Auger Sample	Natural Moisture Content
SPT (N) Value	Atterberg Limits
Dynamic Cone Test	Undrained Triaxial at % Strain at Failure
Shelby Tube	Shear Strength by Penetrometer Test
Shear Strength by Vane Test	

Geodetic (m)	Depth (m)	Soil Description
32.8	0	**TOPSOIL** ~50mm
32.8		**FILL** Silty sand with some gravel, shaley, black, wet slumped from mountain face
31.8		**SILTY SAND (SM)** Some gravel, white and grey boulders, reddish brown and dark grey, ice lenses and crystals, wet
28.8		**GRAVELLY SAND (SP)** Some silt, reddish brown, moist to wet
24.3		**SAND (SP)** Trace to some gravel, black, moist
22.8	10	**Borehole Terminated at 10 m depth**

Standard Penetration Test N Value: 20, 40, 60, 80; Shear Strength (kPa): 50, 100, 150, 200

Combustible Vapour Reading (ppm): 250, 500, 750; Natural Moisture Content %; Atterberg Limits (% Dry Weight): 20, 40, 60

Sample	Combustible Vapour Reading (ppm)	Natural Unit Wt. kN/m³
2-1	1	
2-2	0	
2-3	0	
2-4	0	
2-5	0	
2-6	0	
2-7	0	
2-8	0	
2-9	1	
2-10	1	

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	3.7	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-03

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 53

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	⊢—○
Dynamic Cone Test	——	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■		
Shear Strength by Vane Test	+ S	Shear Strength by Penetrometer Test	▲

GWL	SOIL DESCRIPTION	Geodetic m	Depth (m)	Combustible Vapour Reading (ppm)	Samples	Natural Unit Wt. kN/m³
		17.6	0			
	TOPSOIL ~50mm	17.6				
	FILL Silty sand, some gravel, black, wet. Slumped from mountain face			1		3-1
			1	1		3-2
	SILTY SAND (SM) Some gravel, reddish brown, wet, some ice lenses and crystals	15.8	2	0		3-3
			3	0		3-4
	SILTY SAND (SM) Some gravel, green and white boulders, reddish brown to grey, very moist to moist, some ice lenses and crystals	13.6	4	0		3-5
			5	0		3-6
			6	0		3-7
			7	0		3-8
			8	0		3-9
			9	0		3-10
	Borehole Terminated at 10 m depth	7.6	10			

Standard Penetration Test N Value: 20 40 60 80

Shear Strength kPa: 50 100 150 200

Natural Moisture Content % / Atterberg Limits (% Dry Weight): 20 40 60

Combustible Vapour Reading (ppm): 250 500 750

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-04

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 54

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	✕
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	——	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Geodetic (m)	Depth (m)	Soil Description	Sample	Natural Unit Wt. kN/m³
19.9	0	**TOPSOIL** ~50mm		
19.9		**FILL** Silty sand some gravel, black, wet slumped from mountain face	4-1, 4-2, 4-3, 4-4	
15.9	4	**SILTY SAND (SM)** Gravelly, frequent boulders, greyish brown to grey, ice crystals and lenses, moist to wet	4-5, 4-6, 4-7	
12.9	7	**GRAVELLY SAND (SP)** Frequent boulders, ice lenses and crystals, grey, moist	4-8, 4-9, 4-10	
9.9	10	**Borehole Terminated at 10 m depth**		

Chart axes: Standard Penetration Test N Value 20, 40, 60, 80; Shear Strength 50, 100, 150, 200 kPa; Combustible Vapour Reading (ppm) 250, 500, 750; Natural Moisture Content %, Atterberg Limits (% Dry Weight) 20, 40, 60.

Combustible vapour readings (ppm): 4-1: 1; 4-2: 1; 4-3: 1; 4-4: 0; 4-5: 0; 4-6: 0; 4-7: 0; 4-8: 0; 4-9: 0; 4-10: 0

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	5.0	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole BH-05

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 55

Page. 1 of 1

Date Drilled: 'Oct 3, 2021

Drill Type:

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	───	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

Column headings: GWL | SYMBOL | SOIL DESCRIPTION | Geodetic m | Depth | Standard Penetration Test N Value (20, 40, 60, 80); Shear Strength kPa (50, 100, 150, 200) | Combustible Vapour Reading (ppm) (250, 500, 750); Natural Moisture Content %; Atterberg Limits (% Dry Weight) (20, 40, 60) | SAMPLES | Natural Unit Wt. kN/m^3

Geodetic (m)	Soil Description
25.8 / 25.8	**TOPSOIL** ~50mm
	SILT AND SAND FILL (ML) slumped from mountain face, some clay, black, wet
22.8	**SILTY SAND (SM)** Some gravel, bouldery, boulders are white, reddish brown, moist to very moist
20.8	**SILTY SAND (SM)** Trace clay, some gravel and white boulders, moist to wet; ice lenses and crystals below 6 m depth
15.8	**Borehole Terminated at 10 m depth**

Sample	Combustible Vapour Reading
5-1	1
5-2	1
5-3	1
5-4	0
5-5	0
5-6	0
5-7	0
5-8	0
5-9	0
5-10	0

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2. Multi-bead thermistor string installed to 10.0 m depth upon completion
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	7.0	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-1

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 56

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	⊠	Combustible Vapour Reading	□
Auger Sample	◨	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	⊢○
Dynamic Cone Test	—	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			34.1	0				
		TOPSOIL ~50mm	34.1					
		FILL Silty sand, some gravel, black, wet, slumped from mountain face. Limestone boulders at 0.9 m depth.	33.2			□ 0 ; ×	TP-1	
		Backhoe Shovel Refusal at 0.9 m depth						

NOTES:

1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Log of Borehole TP-2

Project No: FRN-21016638-A0

Project: New Water Treatment Facilities & Associated Infrastructure at Arctic Bay Site 4

Location: ARCTIC BAY, NU

Figure No. 57

Page. 1 of 1

Date Drilled: 'Oct 2, 2021

Drill Type: Rubber Tire Backhoe

Datum: Geodetic

Logged by: C.H. Checked by: S.K.A

Legend	Symbol	Legend	Symbol
Split Spoon Sample	☒	Combustible Vapour Reading	□
Auger Sample	◧	Natural Moisture Content	×
SPT (N) Value	○	Atterberg Limits	├─○
Dynamic Cone Test	──	Undrained Triaxial at % Strain at Failure	⊕
Shelby Tube	■	Shear Strength by Penetrometer Test	▲
Shear Strength by Vane Test	+ S		

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20, 40, 60, 80) / Shear Strength kPa (50, 100, 150, 200)	Combustible Vapour Reading (ppm) (250, 500, 750) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) (20, 40, 60)	SAMPLES	Natural Unit Wt. kN/m³
			14.8	0				
		TOPSOIL ~50mm	14.8					
		FILL Silty sand, some gravel, black, wet, slumped from mountain face.	14.0			0		TP2-1
		SAND (SP) Fine grained sand, weathered, brown, moist	13.6	1		0		TP2-2
		Backhoe Shovel Refusal at 1.2 m depth						

LOG OF BOREHOLE FRN-21016638 ARCTIC BAY SITE 4 BH LOGS.GPJ TROW OTTAWA.GDT 1/27/22

NOTES:
1. Borehole data requires interpretation by EXP before use by others
2.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. Log to be read with EXP Report FRN-21016638-A0

WATER LEVEL RECORDS

Date	Water Level (m)	Hole Open To (m)
Upon Completion	-	open

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %

Appendix F – Wind Blowing & Snow Drifting Assessment

1. **Wind & Snow Assessment (SLR) – Arctic Bay, Nunavut – (April 5, 2022)**

SLR

100 Stone Road West, Suite 201
Guelph, Ontario, N1G 5L3
226.706.8080 | www.slrconsulting.com

Date: April 5 2022

To: exp
8616 51 Ave NW, Suite 101
Edmonton, AB T6E 6E6

Re: **Wind & Snow Assessment – Draft**
Water Treatment Plant Options
Arctic Bay, Nunavut
SLR Project #241.30470.00000

Team: Tahrana Lovlin, MAES, P.Eng.
Principal, Microclimate

Bill Waechter, C.E.T.
Senior Microclimate Consultant

Credit: https://ntip.gov.nu.ca/community/arctic-bay

REGISTERED PROFESSIONAL ENGINEER
T.B. LOVLIN
LICENSEE
05/04/2022
NT/NU

SLR

TABLE OF CONTENTS

1.0 INTRODUCTION

SLR Consulting (SLR) was retained by exp to conduct a wind and snow assessment for the proposed three site options of the water treatment plant in Arctic Bay, Nunavut. This document provides comments and guidance on the proposed three site plans, as well as recommendations as to which site would require the least snow removal efforts.

1.1 Community Information

Arctic Bay is located at the northwest corner of Baffin Island, in Nunavut (**Figure 1**). The community is located at the northwest corner of the bay, while the airport is located at the southeast corner (**Figure 2**). The ridge to the north of Sites 3 and 4 is approximately 140 m tall, while the hill to the north of Marcil Lake (Site 1) is approximately 580 m tall at the peak.

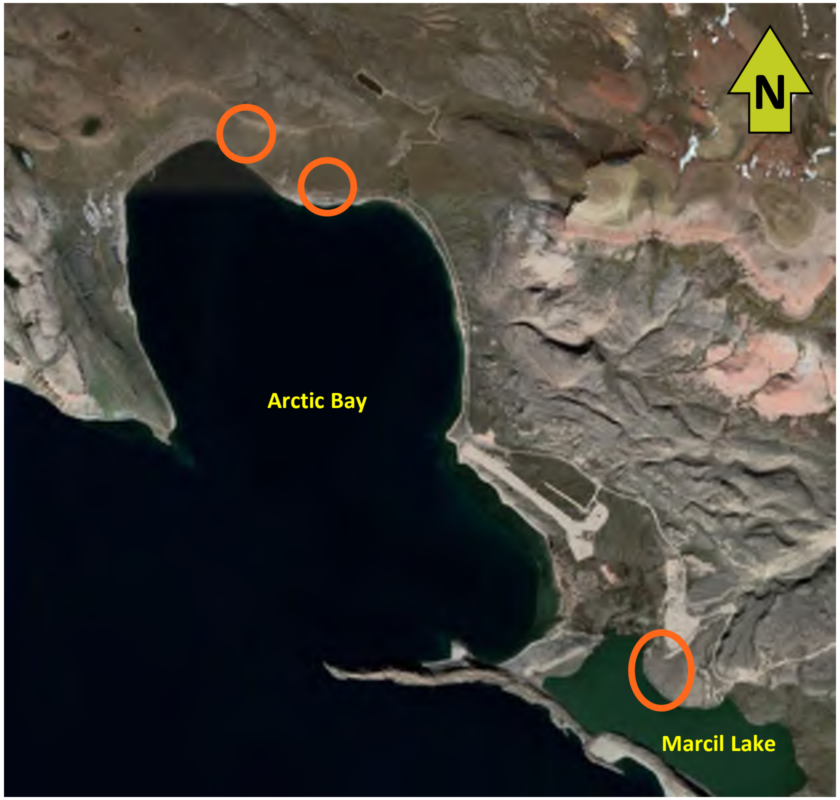
1.2 Proposed Sites & Surroundings

Site 4 is located on the west edge of the town, north of the Nanisivik Highway. Site 3 is also north of the Nanisivik Highway, approximately 1.2 km east of town, near the power plant. Both of these site will require a buried overland hose to connect to the pump station at Site 1, on the north edge of Marcil Lake.

In addition, all three sites will include one treated water storage tank and one wastewater storage tank. Both tanks are approximately 7 m in diameter and 6 m tall. There is also a one-storey plant building (approximately 13 m by 26 m).

The location of the three sites is shown in **Figure 2**.

Figure 1: Location of Arctic Bay, Nunavut
Credit: Google Earth, dated December 13, 2015



Aerial view of community, with general area of sites marked
Credit: Google Earth, dated July 12, 2020

Proposed sites (Sites 1, 3 and 4)
Credit: exp, received March 9, 2022

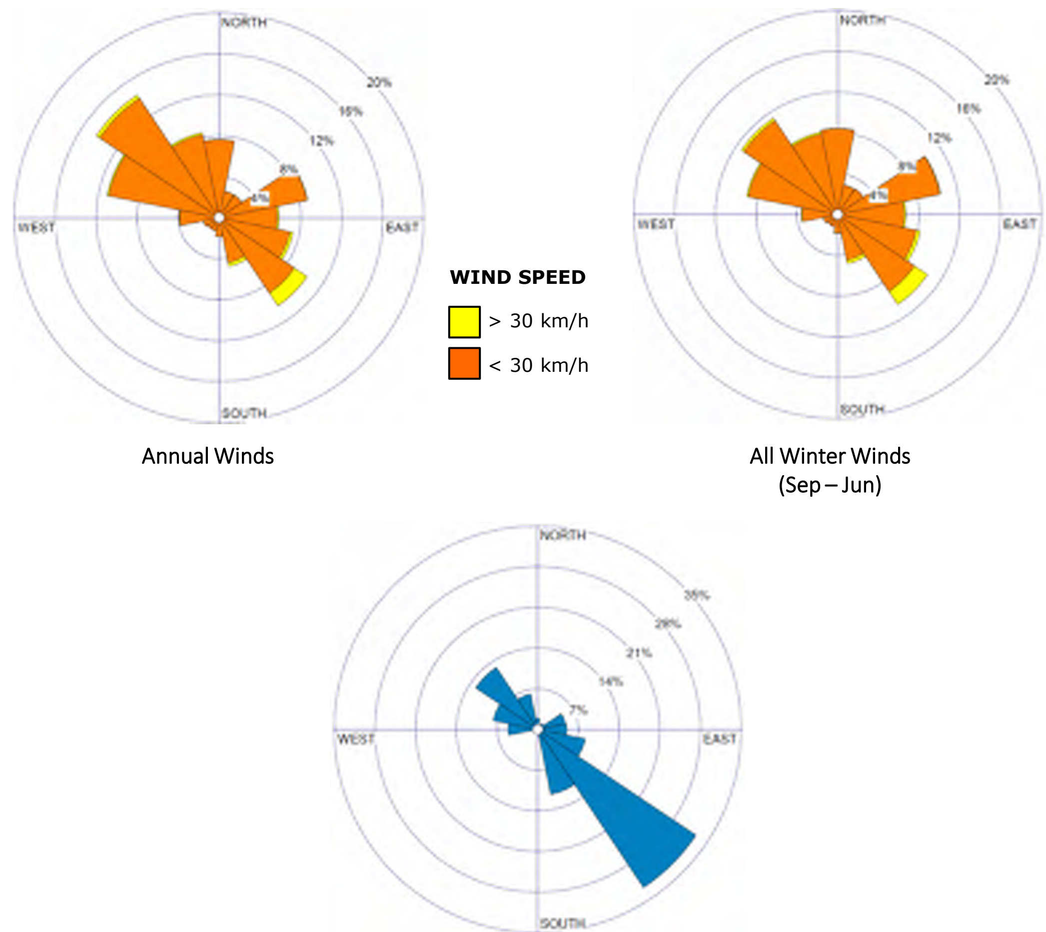
Figure 2: Aerial views of community and sites

2.0 CLIMATE DATA

Based on 16 years of wind records from Environment Canada, prevailing winds at Arctic Bay Airport are shown in **Figure 3**. The airport indicates annual prevailing annual winds occur from the northwest, west-northwest, and southeast directions. Secondary winds are from the east-northeast and north-northwest (top left wind rose). Strong winds, greater than 30 km/h, are predominantly from the southeast and northwest (yellow, left wind rose). During the winter season, which extends from September to June, similar prevailing winds occur (top right wind rose). Winds greater than 23 km/h are most common from the southeast, south-southeast and northwest directions (bottom wind rose). These strong wind flows account for 6% of the time in the winter.

Environment Canada had wind data for Arctic Bay but no precipitation data. Historic climate data for the Nanisivik Airport, located on a plateau 16 km to the east-southeast, were reviewed and indicated that southeast winds prevail annually and during the winter. Snowfall data for Nanisivik Airport indicated an average of 191 cm snow, annually.

For the purpose of this analysis, we will consider winds from the following wind directions: southeast, northwest, and south-southeast.



Annual Winds

All Winter Winds (Sep – Jun)

Winter Winds > 23 km/h (Sep – Jun)

Figure 3: Wind Roses for Arctic Bay Airport (2003-2019)

3.0 METHODOLOGY

This assessment incorporates an experience-based review of meteorological data, project drawings, and site information to derive design guidance relating to the expected snow drift conditions that will influence function of the proposed building as well as accessibility to it and its neighbours. This review is augmented with decades of past experience including field observation.

3.1 Snow Drift Criteria

Determining whether the predicted snow deposition patterns will create a potential problem is based on reasonable guidelines that help assess if mitigation measures should be contemplated. The depth of the predicted snow drift in a key area is an obvious factor that must be considered. However, perhaps first and foremost, the use and type of development being studied needs to be considered in the decision-making process. For example, a medium depth snowdrift near a main entrance to a warehouse is far less critical than a similar snowdrift in front of a hospital's emergency entrance. The usage of an area also plays a role in this assessment where, for example, a medium depth drift around an infrequently used maintenance door can be tolerated more so than a comparable sized drift in a main entrance area.

The frequency of occurrence of the wind direction associated with the drift deposition is also important, as is the number of wind directions that create a snowdrift in the same area. A significant drift that occasionally builds up against a door for a single wind direction can be dealt with through normal snow clearing operations, unless a low-cost mitigation strategy and/or a minor redesign can be incorporated.

The predicted snow drift conditions derived through this assessment are discussed in this report in terms of being low, medium or heavy drifts. For this assessment, which represents a typical storm:

- a **light** snowdrift can be dealt with through normal maintenance procedures;
- a **medium** snowdrift requires extra effort on the part of maintenance and the design team should consider the suggestions presented; and,
- a **heavy** drift will impede accessibility and the design team should consider the recommendations suggested.

3.2 Prevailing Wind Considerations

The wind data for Arctic Bay, as shown in **Figure 3**, presents an interesting challenge as it shows winds from the northwest quadrant are frequent, but strong winds are from the southeast. Therefore, our analysis considered winds from the southeast, south-southeast, and northwest.

However, the design team should note that strong winds (greater than 23 km/h), with or without snow, occur for less than 7% of the time during the winter. Thus, snow drifting may not be a significant issue, so much as snow accumulation.

4.0 SNOW DRIFTING CONDITIONS

Snow drifting conditions in areas of interest are predicted using SLR's engineering judgement and significant experience, which yields an assessment that is qualitative in nature.

4.1 Comments – Site 4

Site 4, the westernmost site, is exposed to the prevailing southeasterly and northwesterly winds. During southeast winds a medium drift will form in the middle of the driveway, away from the south facade. A similar drift is anticipated along the north side of the building (Appendix A). A medium to heavy drift is expected against the west side of the building. We generally expect the tanks to be scoured of snow, as they are located upwind of the building.

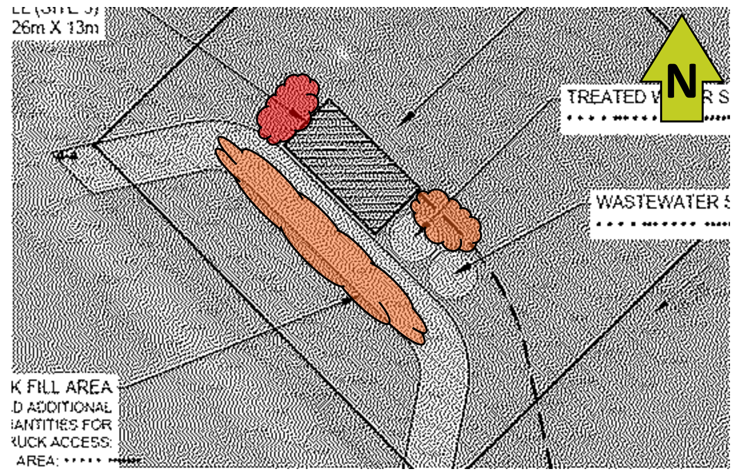
During northwest winds a medium snowdrift is expected a few metres from the south and north facades of the building. This places the drift in the middle of the driveway. The west façade of the building will also be scoured of snow, with a medium drift forming a few metres away from the building. Medium to heavy snowdrifts are also expected around the tanks, as they are located downwind of the building.

South-southeasterly winds will also scour the south side of the building, depositing medium snowdrifts in the middle of the driveway. Medium to heavy snowdrifts are expected against the north and west sides of the building, while the tanks will be partially scoured. Medium snowdrifts are predicted on the north side of the tanks (Appendix A).

A summary of the expected snow accumulations on the site is provided in Figure 4.

We suggest placing the base of the tank stairs in the middle of the south or southwest side of each tank. Thus, the base of the stairs and area around them will generally be scoured by the prevailing winds.

Also, we recommend the main access points to the plant building be located along the south facade, with secondary access on the east side.



Snowdrift Conditions

- Low
- Medium
- Heavy

Figure 4: Site 4 – Summary of expected snowdrift conditions

4.2 Comments – Site 3

Site 3 is located approximately 1 km from town, on the north side of the Nanisivik Highway. It is completely exposed to the prevailing southeasterly and northwesterly winds. A summary of the expected snow accumulations on the site is provided in Figure 5.

Due to the alignment of the tank and the building, a medium snowdrift is expected to form along the driveway, south of the tanks, during southeast winds; this drift is not expected to extend along the entire length of the building (Appendix A). Medium to heavy drifts are expected along the north and west sides of the building. We expect the tanks to be scoured of snow during southeast winds.

During northwest winds, a medium snowdrift is expected to form adjacent the south side of the building. A medium snowdrift is also anticipated along the centre of the driveway (Appendix A). Between the west tank and the building, a medium to heavy drift is expected. A medium to heavy drift is also anticipated on the southeast side of the east tank.

South-southeast winds will deposit medium snowdrifts on the driveway to the south of the building and tanks, while scouring snow away from the south facade of the building. Medium to heavy snowdrifts are expected to form against the north and west sides of the building. Similar drifts are anticipated along the north side of the tanks.

We suggest placing the base of the tank stairs on the south or southwest side of the two tanks. Thus, the base of the stairs and area around them will generally be scoured by the prevailing winds.

Also, we recommend the main access points to the plant building be located along the south facade, with secondary access on the east side.

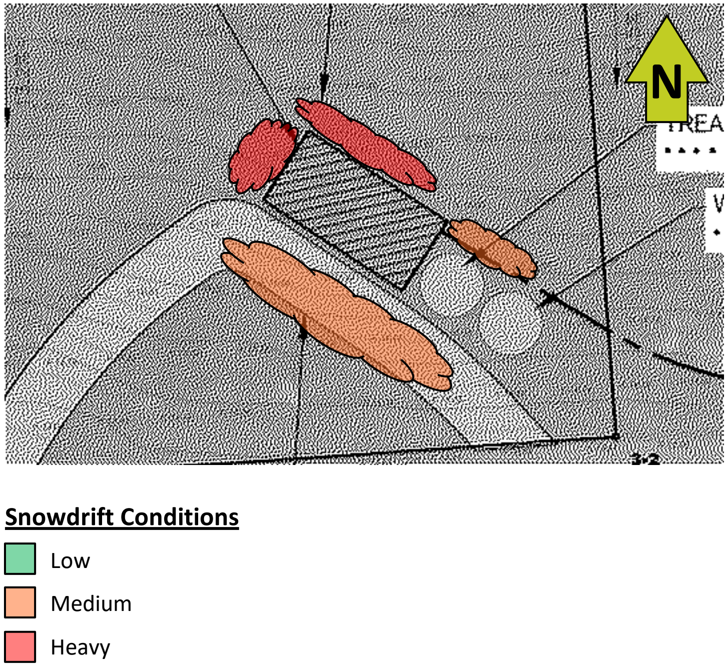


Figure 5: Site 3 – Summary of expected snowdrift conditions

4.3 Comments – Site 1

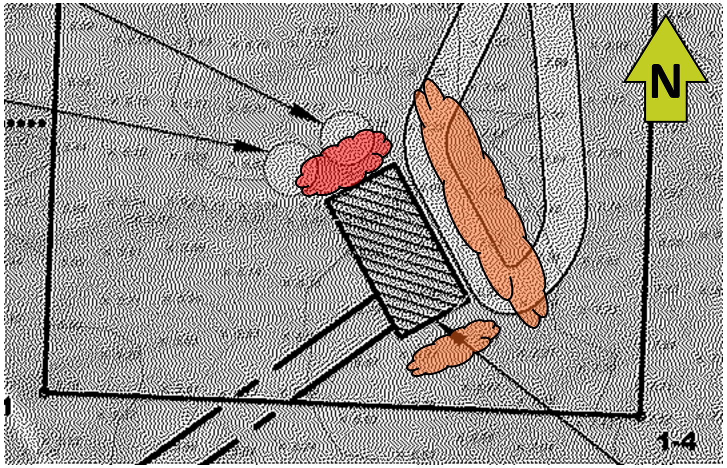
Site 1 is located on the north side of Marcil Lake, approximately 6.5 km from town, at the existing pump station. The site is completely exposed to the prevailing winds. During southeast winds the east side of the building is scoured of snow and a medium snowdrift is deposited a few metres from the north facade. A medium to heavy drift will form along the west and north sides of the building, as well as around and between the tanks, which are located to the north of the building (**Appendix A**).

During northwest winds, a medium to heavy snowdrift will be deposited along the east and south sides of the building, extending on to the nearby driveway. A medium snowdrift will also form a few metres to the east of the eastmost tank, extending into the driveway. We expect the tanks to be scoured of snow during northwest winds, as they are fully exposed to the wind.

South-southeast winds will also deposit medium snowdrifts on the driveway to the east of the building, while medium to heavy snowdrifts will form against the north and east sides of the building due to roof blown snow. These medium to heavy snowdrifts will envelop the east tank, while a medium to heavy snowdrift is anticipated on the north side of the westmost tank.

A summary of the expected snow accumulations on the site is provided in **Figure 6**.

We suggest placing the base of the tank stairs on the northeast side of the east tank and on the west or north side of the west tank. Thus, the base of the stairs and area around them will generally be scoured by the prevailing winds. We recommend the main access points to the plant building be located along the long east facade, with secondary access on the south side.



Snowdrift Conditions

- Low
- Medium
- Heavy

Figure 6: Site 1 – Summary of expected snowdrift conditions

5.0 CONCLUSIONS & KEY RECOMMENDATIONS

The snow drifting conditions predicted for the proposed three water treatment plant sites in Arctic Bay have been assessed through experience-based interpretation. Based on the results of our snow drift assessment, the following conclusions and recommendations have been reached:

- In terms of wind and snow drifting, the preferred site is 4, followed by Site 3, follow by Site 1.
- Sites 3 and 4 will still require a small pump house building at Marcil Lake. Depending on the nature of the snowdrifts, snow removal efforts may require mechanical means. To reduce snow removal efforts, we recommend placing the access door to the pump house on the north side of the building, so the door can be scoured by the prevailing winds.
- To reduce the snow removal efforts for Site 4, we recommend placing the main access doors on the south side of the building, with secondary access on the east side. In addition, the base of the tank stairs should be located in the middle of the southwest side of each tank.
- To reduce snow removal efforts for Site 3, we recommend placing the main access doors on the south side of the building. Secondary access doors should be placed on the east facade. In addition, the base of the tank stairs should be located in the southwest side of each tank.
- For Site 1, we recommend placing the main access doors on the east side of the building to reduce snow removal efforts. Secondary access doors should be placed on the south side of the building. Also, the base of the west tank stairs should be located on the north side of the tank, while the base of the east tank stairs should be located on the northeast side of the tank.

6.0 ASSESSMENT APPLICABILITY

This assessment provides a qualitative overview of the anticipated snow drift conditions on and surrounding the proposed development. Any subsequent alterations to the design may influence these findings, possibly requiring further review by SLR. Should you have any questions or concerns, please do not hesitate to contact the undersigned.

Sincerely,

SLR Consulting (Canada) Ltd.

Tahrana Lovlin, MAES, P.Eng.
Principal, Microclimate

Bill Waechter, C.E.T.
Senior Microclimate Consultant

Appendix A

Estimated Snow Drift Patterns

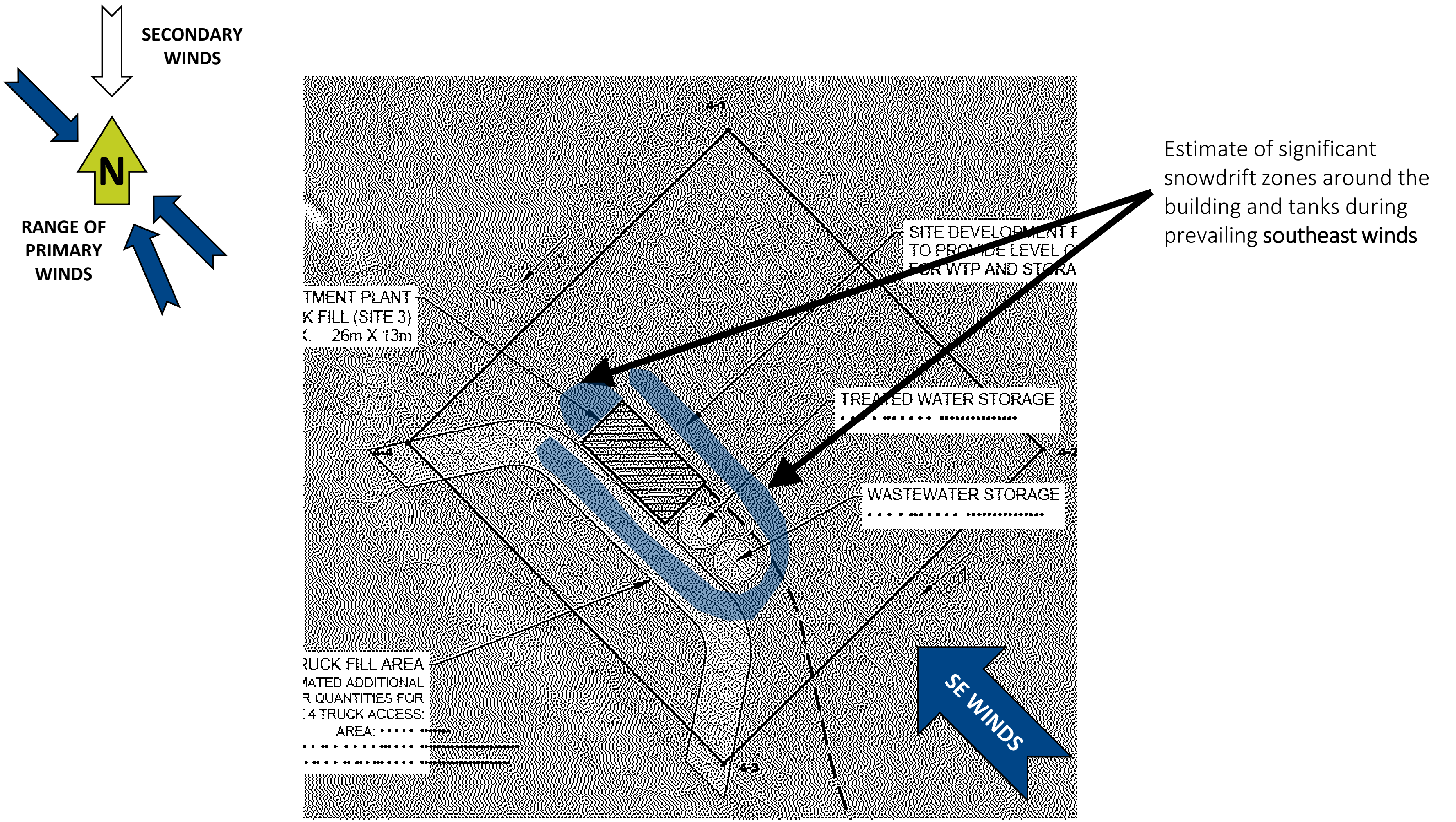


Figure A1a: Site 4 – Anticipated areas of snow accumulation during southeast winds

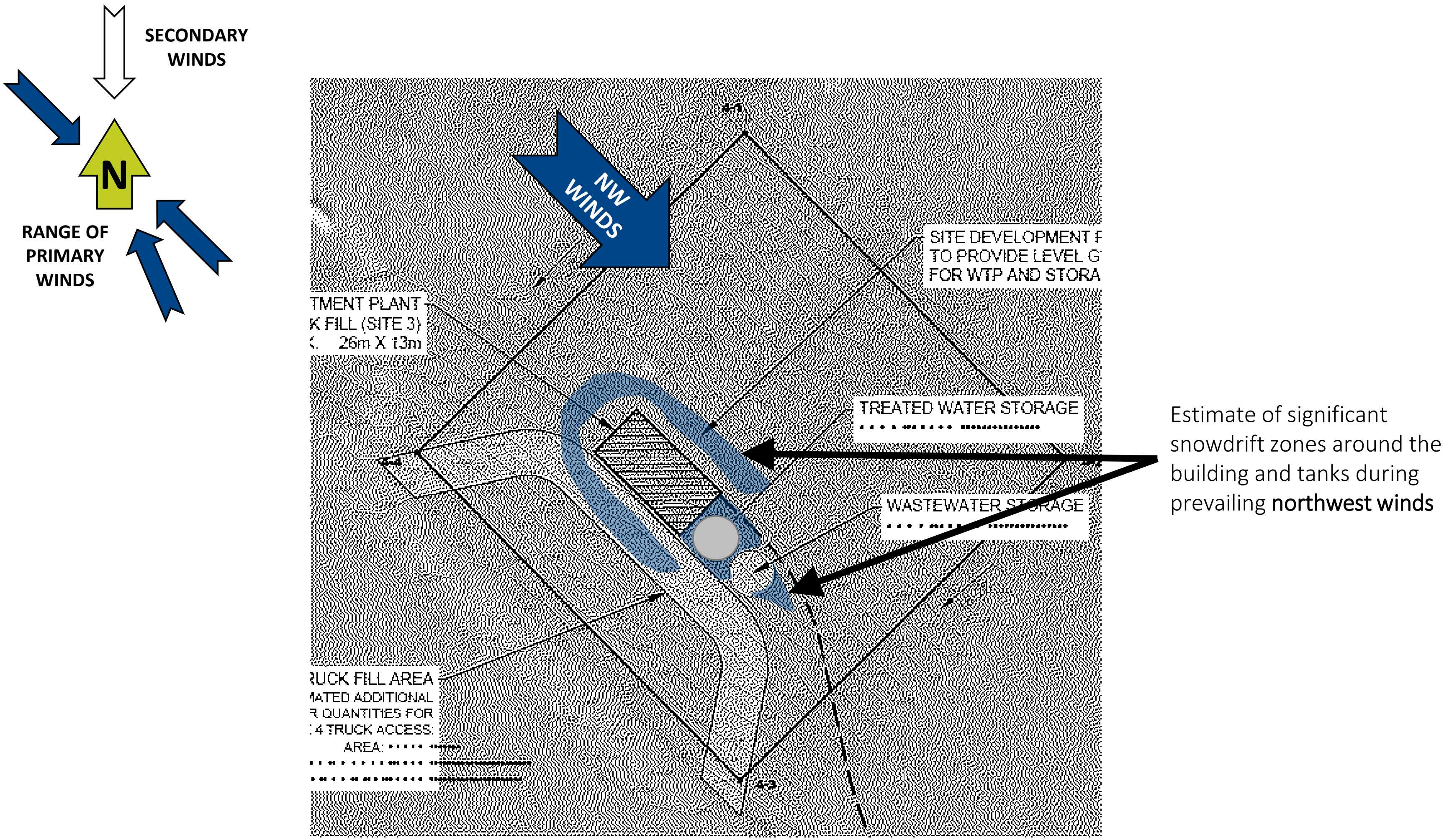


Figure A1b: Site 4 – Anticipated areas of snow accumulation during northwest winds

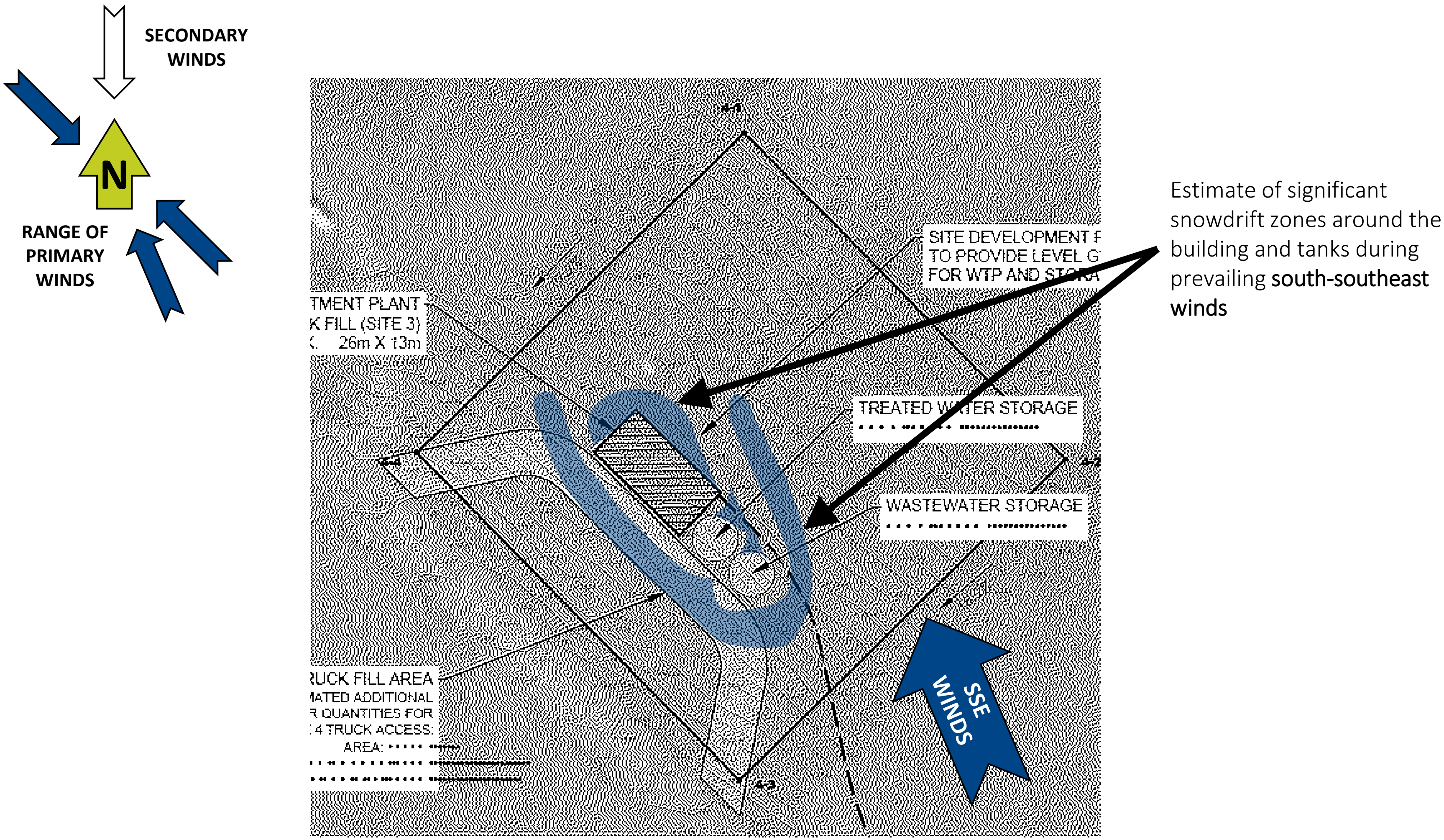


Figure A1c: Site 4 – Anticipated areas of snow accumulation during south-southeast winds

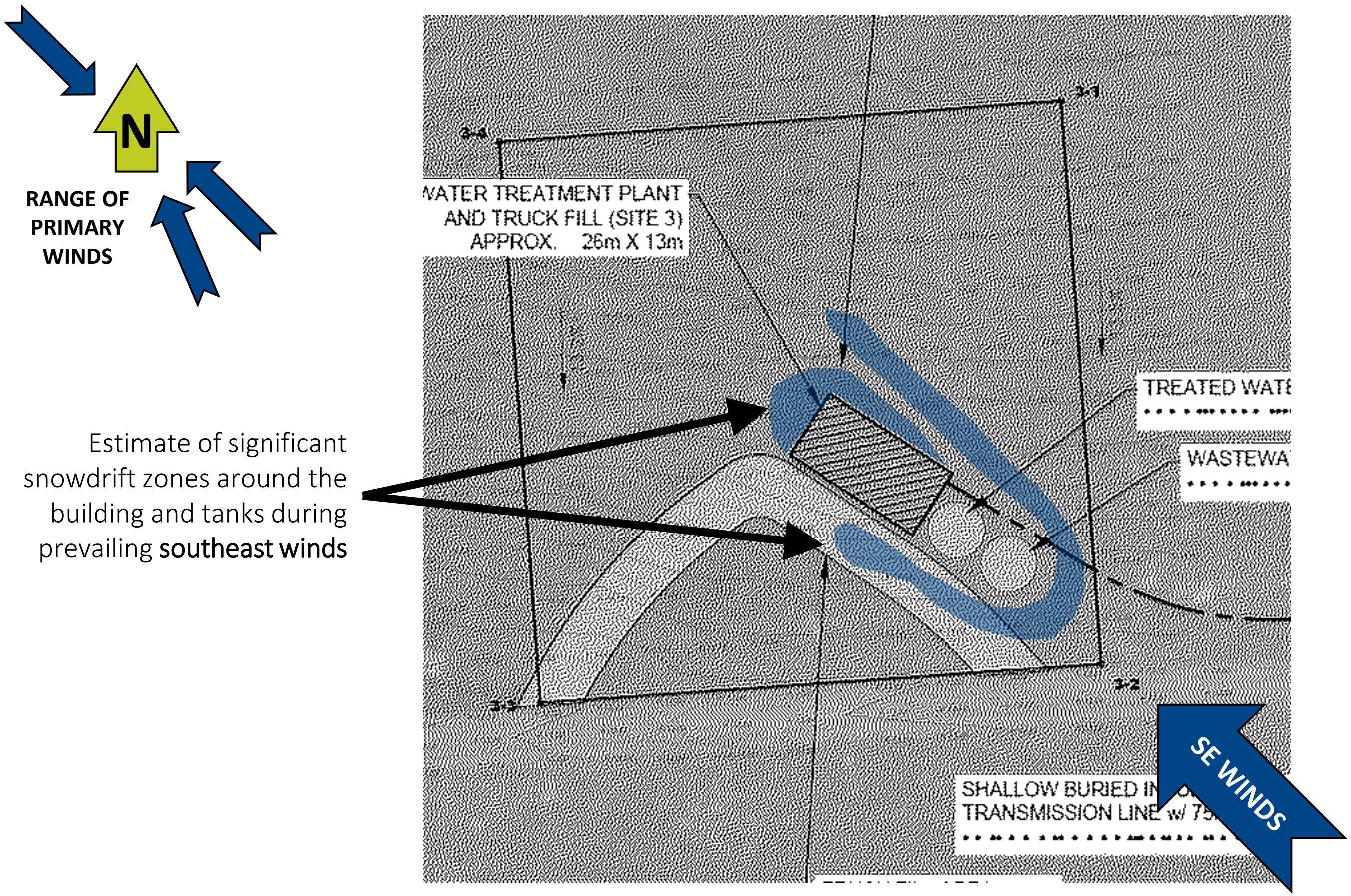


Figure A2a: Site 3 – Anticipated areas of snow accumulation during southeast winds

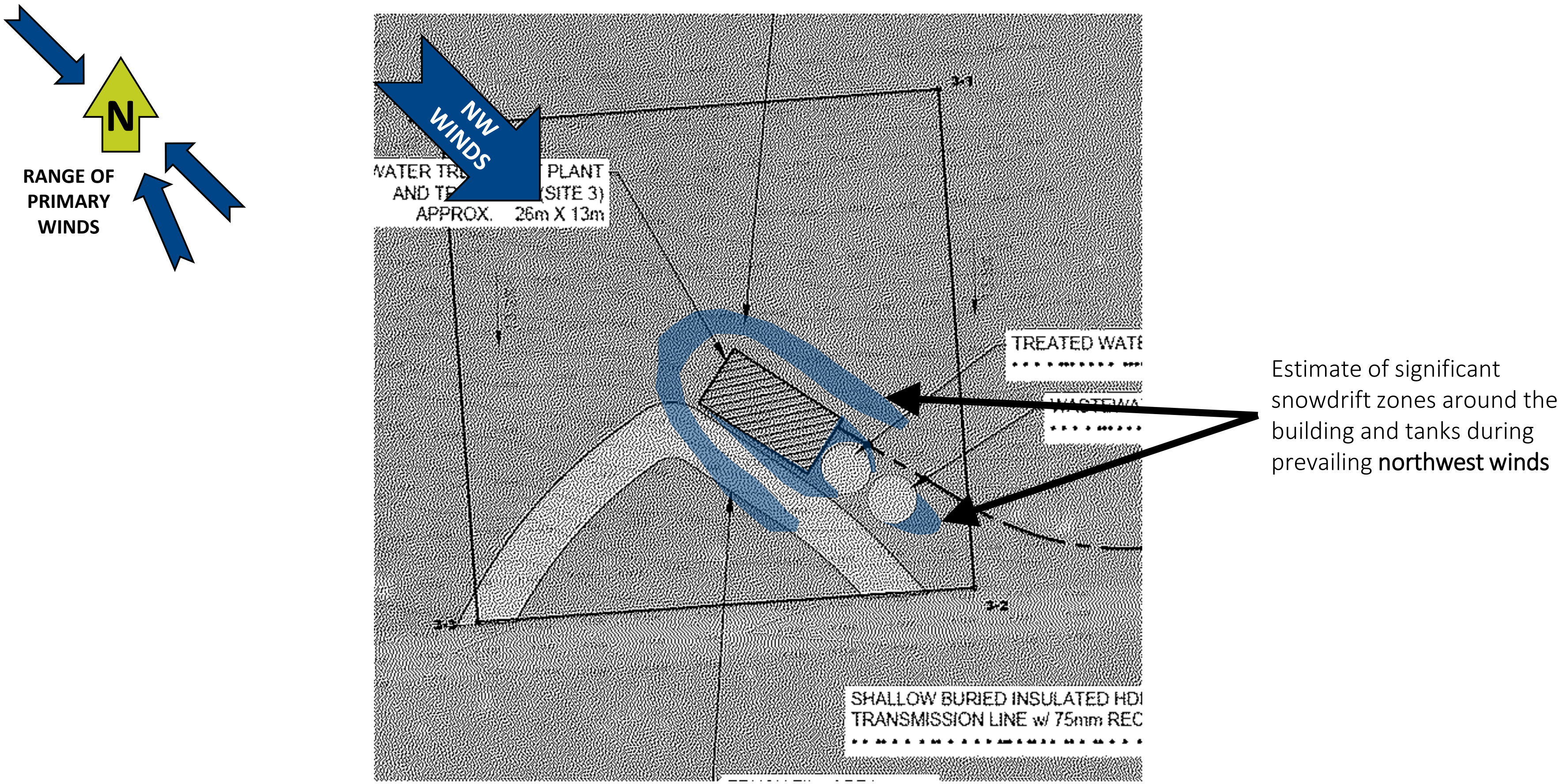


Figure A2b: Site 3 – Anticipated areas of snow accumulation during northwest winds

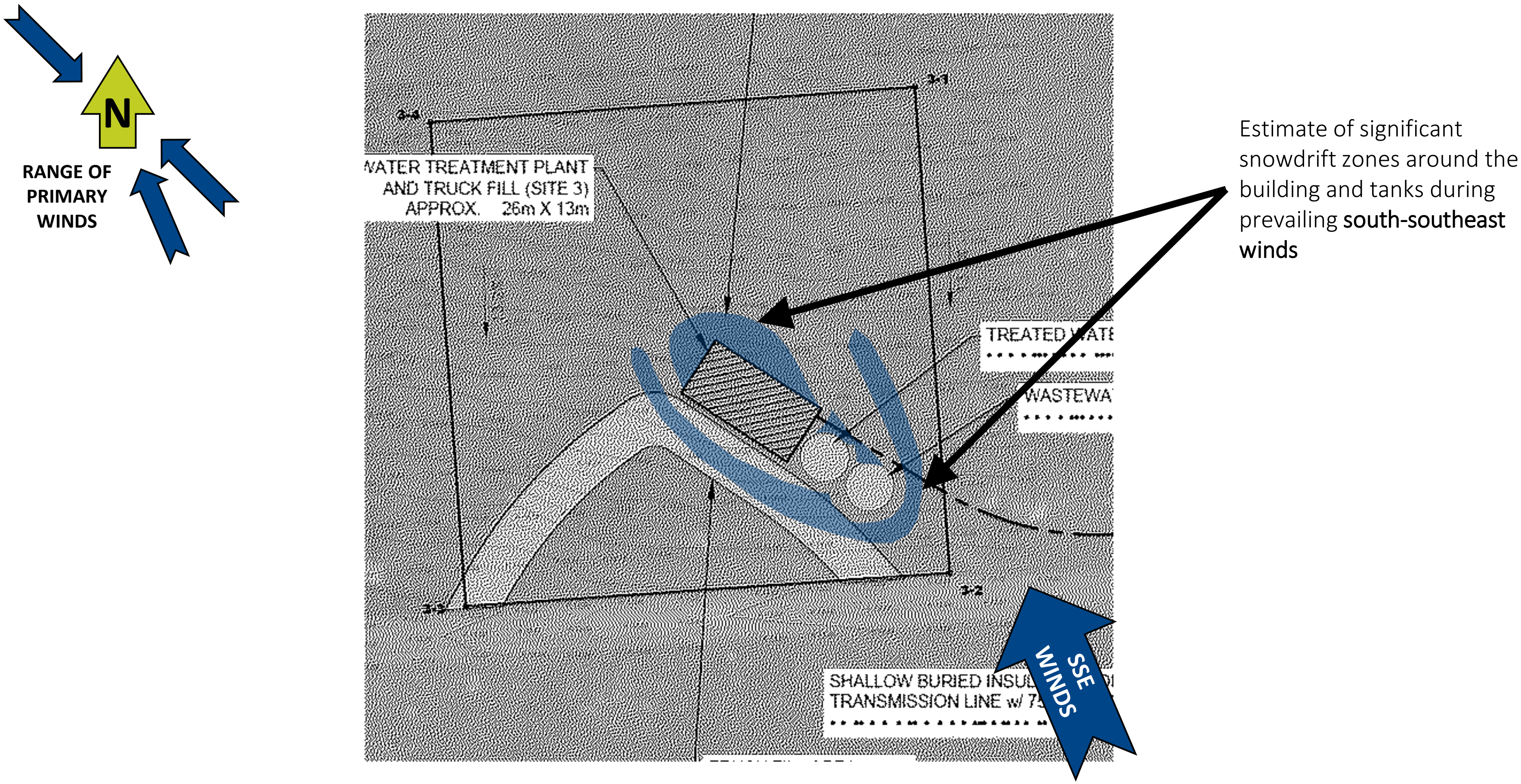


Figure A2c: Site 3 – Anticipated areas of snow accumulation during south-southeast winds

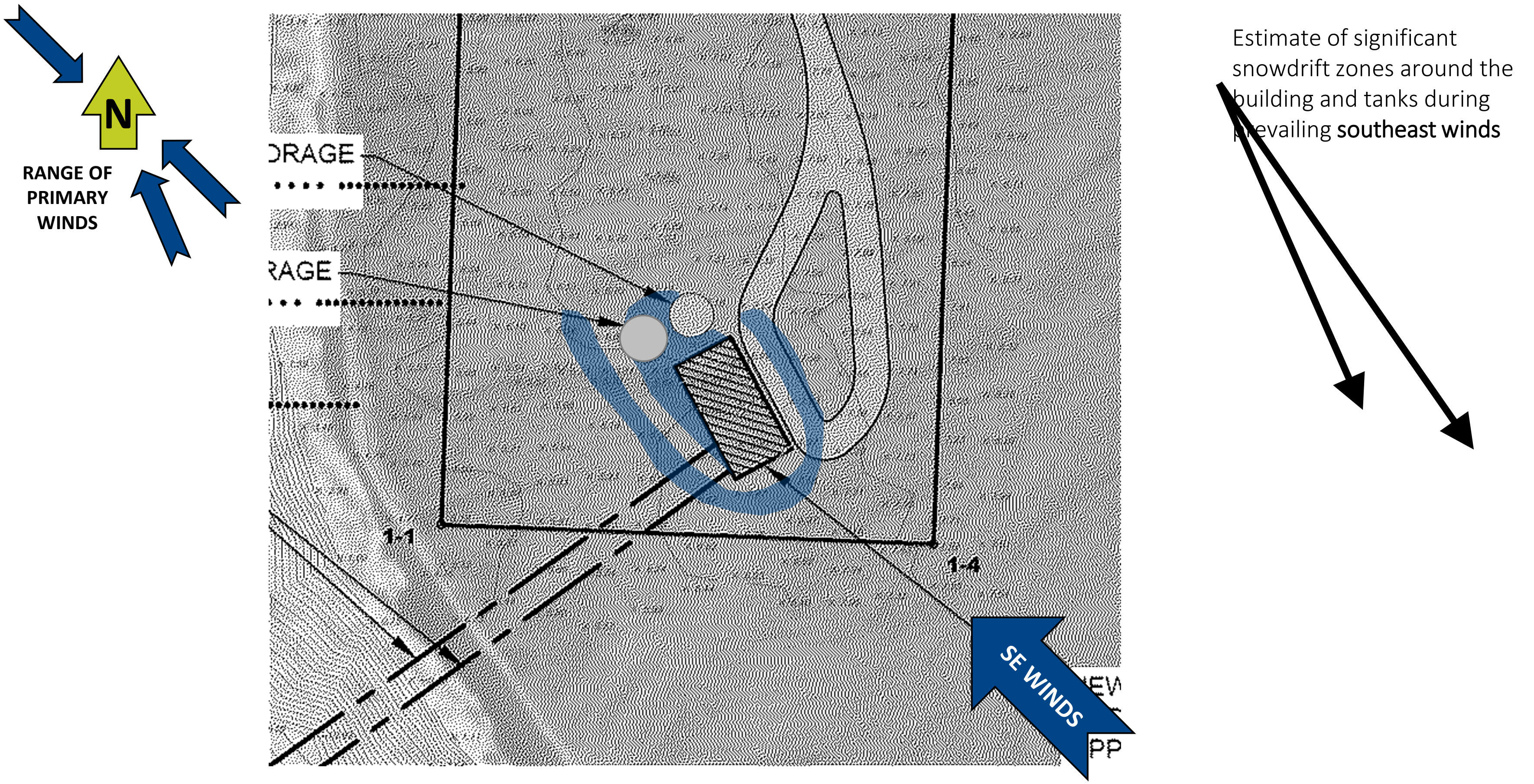


Figure A3a: Site 1 – Anticipated areas of snow accumulation during southeast winds

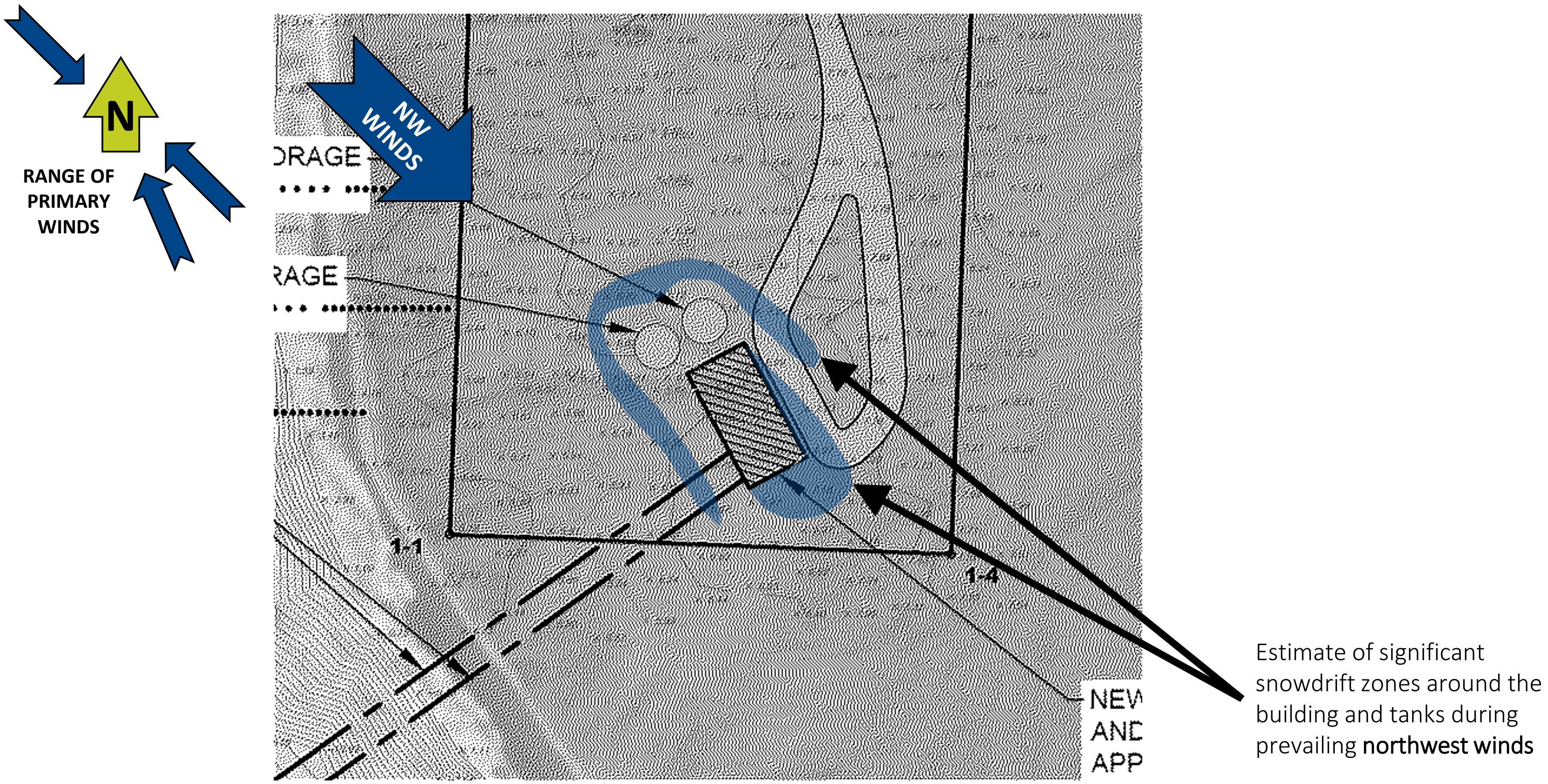


Figure A3b: Site 1 – Anticipated areas of snow accumulation during northwest winds

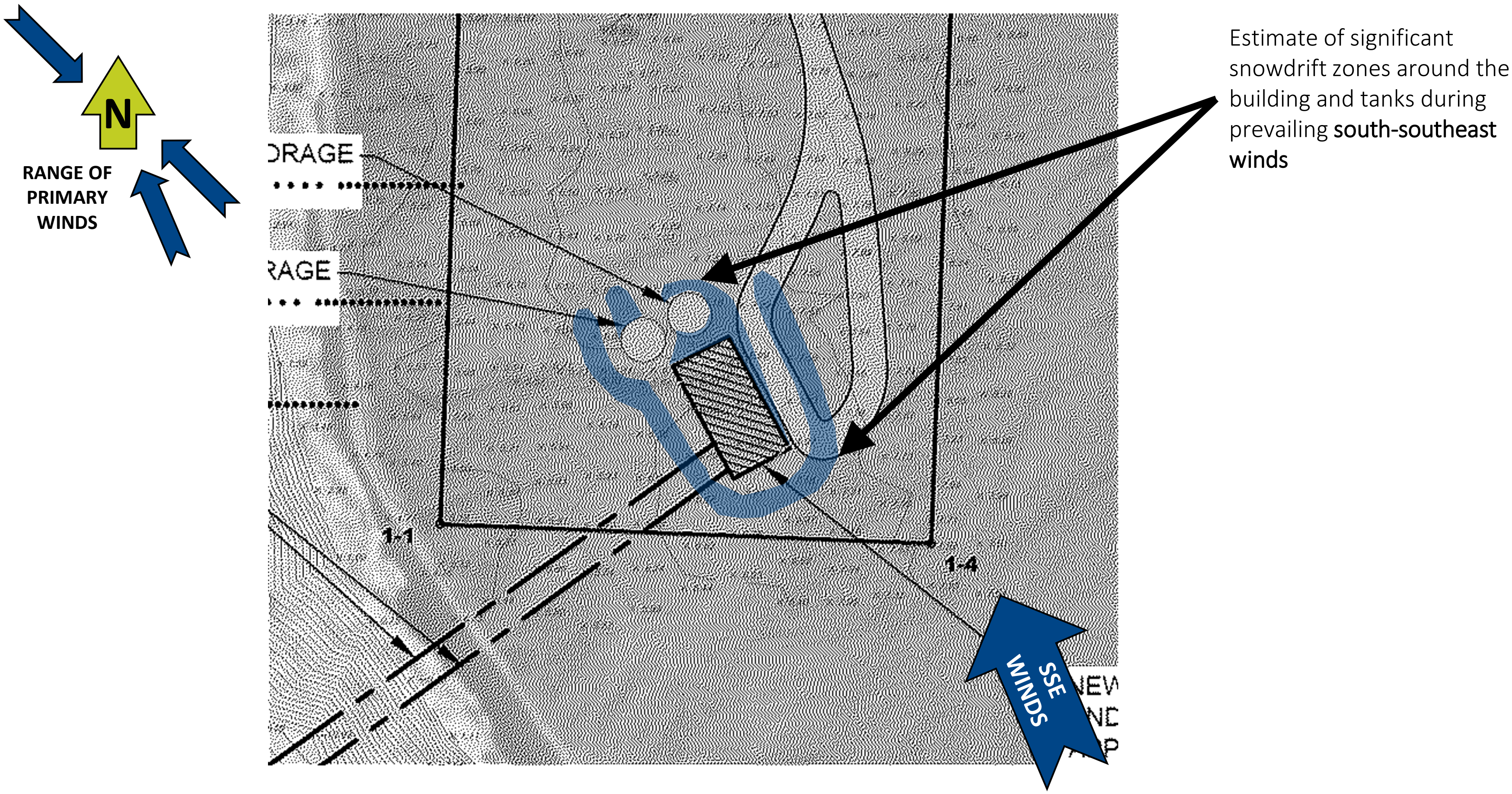


Figure A3c: Site 1 – Anticipated areas of snow accumulation during east-southeast winds

Appendix G – Hydrological and Water Balance Study

1. **Hydrological and Water Balance Study Report (EXP) – Arctic Bay (March 18, 2022)**

High Arctic Water Supply & Treatment

Government of Nunavut

Type of Document:
Hydrological and Water Balance Study Report – Arctic Bay

Project Name:
Business Case for New Water Treatment Facilities and Associated Infrastructures at Arctic Bay

Project Number:
EXP FRN-21016638-A0
GN 21220 00701

Submitted By:
EXP
100-2650 Queensview Drive
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Date Submitted:
2022-03-18

REGISTERED PROFESSIONAL ENGINEER
K.R. JOHNSON
APR 7 2022
NT/NU

Prepared by

Chris Keung, MASc.
Municipal Arctic Designer

Ken Johnson, MASc. RPP, P.Eng.,
Project Manager

Table of Contents

1 Introduction

1.1 Overview

EXP was retained by the Government of Nunavut – Department of Community and Government Services (GN – CGS) to complete a Business Case for New Water Treatment Facilities and Associated Infrastructures at: Pond Inlet, Arctic Bay, and Grise Fiord.

As part of the project scope, a hydrological and water balance study has been completed for Arctic Bay to determine whether the existing water sources and watershed can provide enough water each year to meet the current and future needs of the community over a 20-year horizon. The water sources that were assessed for Arctic Bay include:

- Arctic Bay
  - Marcill Lake (current source – supplied from Marcill Creek)

1.2 Objectives

The objective of this study is to complete a hydrological and water balance study to determine the suitability of the community's existing and potential water sources over a 20-year horizon to the year 2043. The specific tasks of this study include:

- Summary of the hydrologic regime of the system
- Bathymetric survey of water supply ponds in Arctic Bay
- Climate characterization and potential impacts on water supply from climate change
- Water balance study evaluating the watershed of the water source against community requirements
- Recommendations for the current water source and its sustainability for the community over the 20-year horizon including identification of secondary sources as required

2 Previous Investigations

2.1 Hydrological Analysis of Municipal Source Water Availability in the Canadian Arctic Territory of Nunavut (Hayward, J., Johnston, L., Jackson, A. and Jamieson, R., 2020)

A desktop study in 2020 provides a screening level vulnerability assessment of municipal drinking water supplies for the communities in Nunavut with consideration to climate change, population growth, and infrastructure changes. Water balance models were used to predict the annual water yield for each watershed using historical and projected climate data. The study only focuses on the ability of the source watershed to supply annual water volumes and did not include an analysis of storage infrastructure or seasonal water availability. Findings from the study include:

- Based on PCIC datasets, Arctic Bay showed statistically increasing precipitation trends
- Overall increasing trends in evapotranspiration (22 out of 24 communities)
- Based on the worst-case scenario of 50-year return period minimum precipitation and maximum evapotranspiration (ET), the following vulnerability threat levels were identified for historical, 2016-2040 and 2041-2070 timelines:
  - Arctic Bay
    - low level water supply vulnerability threat
    - 13,300 ha (133,000,000 m^2) – watershed area (Marcill Lake)
- Most influential factor regarding water supply vulnerability threat levels appears to be the size of the source watershed

3 Background

3.1 Community and Existing Water Supply System

3.1.1 Arctic Bay

The Hamlet of Arctic Bay, Nunavut is located at 73°02' N latitude and 85°10' W longitude on the northern section of Baffin Island. An aerial view of the community is shown in Figure 3-1 below.

The water supply for the Hamlet of Arctic Bay is Marcill Creek discharging into Marcill Lake, which is 9 km from the community. This freshwater lake sits at sea level and is separated from the ocean by a small ridge – along the south edge of the lake, the width of ridge is approximately 150 m to 350 m. The lake water level is at approximately the same elevation as sea level based on available topographic information. The existing truck fill station is located on the lake. A fleet of water delivery vehicles (three trucks) brings water from the lake and distributes it to Arctic Bay residents. Historically, there have been no notable concerns regarding the quality and quantity of the source water. Chlorination is the only method being used for treatment/disinfection. No reliable secondary sources of water close to the community have been identified – the GN has noted that Marcill Lake will continue to supply drinking water to Arctic Bay into the distant future.

Figure 3-1: Arctic Bay Water Sources

3.2 Methodology

3.2.1 Catchment and Basin Physiography

This study focuses on a coarse-resolution analysis to characterize annual watershed yield versus expected water use of the community and accounts for annual municipal water supply usage, population growth and potential impacts of climate change.

3.2.2 Watershed Delineation

- High Resolution Digital Elevation Models (HRDEM – CanElevation Series) were downloaded from the Natural Resources Canada website and were used to delineate the various watersheds. Digital Surface Model (DSM) datasets were provided at 2 m resolution using the Polar Stereographic North coordinate system referenced to WGS84 horizontal datum or UTM NAD83
- Watersheds were delineated using ERSI ArcGIS Pro. Spatial Analyst Tool (Hydrology Tools) within the ArcGIS Pro software were used to preprocess the DEMs/DSMs prior to analysis. The flow direction, flow accumulation and watershed delineation tools were used to delineate each watershed for a specific extraction point (i.e., the inlets for each water source)

3.2.3 Water Supply Modelling

3.2.3.1 ***Water Balance Formulation***

Water budgets (as volumes) were computed on an annual basis assuming steady conditions with respect to storage WITHIN the watershed. Water volumes are removed (losses) from the watershed through community water usage and evapotranspiration (ET). Water volumes are recharged (inputs) into the watershed through annual precipitation.

The change in annual storage volume equation (water balance) within a watershed is given as:

$$\Delta S = \frac{(P - ET)}{1000} \times Area_w - U$$

Where:

- ΔS = change in annual storage volume (m^3/year)
- P = annual precipitation (mm/year)
- ET = annual evapotranspiration rate (mm/year)
- $Area_w$ = catchment area of the watershed (m^2)
- U = annual water usage of the community (m^3/year)

If $\Delta S > 0$, precipitation (input) exceeds ET and water use (losses) in the watershed and the annual net balance is positive.

If $\Delta S < 0$, precipitation does not exceed ET and water use in the watershed and the annual net balance is negative.

Percolation due to groundwater is assumed to be negligible due to underlain permafrost. The equation above assumes that the entirety of the precipitation entering the watershed experiences evapotranspiration.

Underestimation of precipitation due to snow undercatch and water losses due to sublimation were not accounted for in the calculation. Actual basin snow amounts are usually larger than measured values (at weather stations) which suffer from gauge undercatch and thus the use of snow gauge data was deemed as a conservative approach for this study. Estimates for snow undercatch can range from 10% to 75% depending on gauge type and wind conditions. Sublimation losses have not been characterized. Characterization of these processes requires detailed meteorological data.

3.2.3.2 *Population Projections, Daily Water Consumption and Annual Water Use Rates*

Population projections have been provided using information prepared by the Nunavut Bureau of Statistics (2014).

The 2020 Nunavut Draft Guideline Document "Water Treatment Plant Design" states a minimum per capita average day water consumption rate of 120 litres per capita per day (lpcd) for water treatment plant design for truck fill communities. As a comparison, the GNWT water supply standard is 90 lpcd.

Annual historical water use records were reviewed between 2008-2020 to determine the actual average recorded daily demands. For Arctic Bay, average recorded daily demand between 2008-2020 was 76 lpcd. Actual recorded daily demands are consistent with the design value of 120 lpcd. Thus, the design value of 120 lpcd has been used as a conservative value to estimate the annual water use rates for each community.

Table 3-1: Population Projections and Annual Water Use Rates

	Arctic Bay	
Year	Population	Water Use (m^3/year) *
2021	938	41,091
2043	***1,184***	***51,852***

** Water use based on design value of 120 lpcd*

3.2.3.3 *Meteorology / Precipitation Data*

- Historical data between 1984 and 2020 was downloaded from the Environment and Climate Change Canada website to calculate **annual total precipitation** at a given weather station
    - Total precipitation includes the input of snowfall and rainfall
    - Minimum, maximum, median, average, 3-year low, 5-year low, 10-year low and 3-year high values (mm/year) were calculated for each complete dataset.
    - At many of these weather stations, there are significant gaps in the collected data and concerns about the accuracy of measurements. If a yearly dataset had three or more months of missing data, this dataset was omitted from the water balance analysis.
    - Arctic Bay has only 4 years of complete data. The weather station at Nanisivik, NU (20 km from Arctic Bay) is well-established and provides more continuous weather records compared to the Arctic Bay weather station. As such, the data from Nanisivik has been incorporated in the evaluation to provide a more complete dataset for the meteorology/precipitation conditions in Arctic Bay.
    - 30-year Climate Normal Datasets (1981-2010) are available on the Environment and Climate Change Canada website and have been provided to compare average annual precipitation values for other High Arctic communities. With the exception of Hall Beach (68° N), the listed communities are all north of 70° latitude and provide a snapshot of the range of precipitation values that can be found in similar High Arctic environments:
        - Resolute, NU
        - Alert, NU
        - Hall Beach, NU
        - Alert, NU
        - Pond Inlet, NU

- Nanisivik, NU

Table 3-2: Estimated Annual Precipitation for Study Communities

Annual Precipitation (mm/year)	*Arctic Bay / Nanisivik **	*Pond Inlet*	*Grise Fiord*
Minimum (mm/year)	99	96	87
Maximum (mm/year)	502	476	304
Median (mm/year)	222	191	187
Mean (mm/year)	244	195	197
3-year low average	117	112	124
5-year low average	128	117	132
10-year low average	159	132	145
3-year high average	424	269	291
5-year high average	385	260	281

* Significant data gaps exist for the weather station at Arctic Bay – thus, data from Nanisivik (20 km from Arctic Bay) was used for missed years

For context regarding the distribution of precipitation within a year, average monthly precipitation values for various Nunavut weather stations are summarized in Table 3-3 below.

Table 3-3: Average Monthly Precipitation between 1981-2010 for Nunavut Communities

	Average Monthly Precipitation between 1981-2010 (mm)												*Total (mm)*
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
RESOLUTE	4	4	7	7	9	15	28	34	23	16	10	6	161
ALERT	7	7	8	11	12	12	32	18	22	13	10	7	158
HALL BEACH	6	5	7	12	16	18	26	44	29	24	19	9	215
EUREKA	3	3	2	4	3	8	15	16	10	8	4	4	79
POND INLET	5	4	7	11	9	16	32	39	20	25	14	9	189
NANISIVIK	5	5	8	11	24	25	46	45	38	37	18	7	271

3.2.3.4 *Evapotranspiration*

Evapotranspiration (ET) is the primary mechanism for water loss from a watershed underlain by permafrost. However, sparse data is available regarding actual ET rates for the study community of Arctic Bay. For this assignment, a literature review was completed using past research that investigated annual ET in High Arctic environments in Nunavut (above 70°N latitude) and specifically for intermittent river and ephemeral stream systems. These values have been listed in Table 3-4, below.

Table 3-4: Reported Annual ET Rates (mm/year) in High Arctic Environments

Location	Lat (°N)	Long (°W)	Year	Reported Annual ET Rate (mm/year)	Reference Paper
Resolute, NU	74.7	95.0	1978 (July 1 - Aug 31)	61	1
			1979 (July 1 - Aug 26)	52	
			1976 (May - Sept)	39	
			1978 (May - Sept)	46	
Axel Heiberg Island, NU	79.8	91.3	1969 (June 20 - Aug 31)	85	1
			1970 (June 1 - Aug 14)	86	
			1972 (June 28 - Aug 22)	82	
McMaster River Basin, Cornwallis Island, NU	75.1	95.1	1976-1981	30-51	1
Ellesmere Island, NU	80.8	72.7	1975 (July 6 - Aug 17)	27	1
Heather Creek, Ellesmere Island, NU	80.0	84.5	1990-1991	86	2
Hot Weather Creek, Ellesmere Island, NU	80.0	84.5	1997	56	3
Devon Island, NU	76.0	85.0	1972-1974	81	2
Bathurst Island, NU	75.7	98.7	2008-2010, 2012	103	2
Melville Island, NU	74.9	109.5	2007-2009	81	2
Ross Point, Melville Island, NU	74.0	107.0	1986	43	2

[1] Kane, D.L., Gieck, R.E., & Hinzman, L.D. (1990). Evapotranspiration from a Small Alaskan Arctic Watershed. *Nordic Hydrology, 21, 253-272.*

[2] Young, K.L., Lafrenière, M.J.m Lamoureux, S.F., Abnizova, A. & Miller, E.A. (2015). Recent multi-year streamflow regimes and water budgets of hillslope catchments in the Canadian High Arctic: evaluation and comparison to other small Arctic watershed studies. *Hydrology Research, 46(4), 533-550.*

[3] Young, K.L. & Woo, M.K. (2004). Queen Elizabeth Islands: water balance investigations. *Northern Research Basins Water Balance, 290, 152-163.*

Minimum, maximum, median, average and 3-year high annual ET values for the water balance study have been calculated using these literature values and have been presented in Table 3-5, below.

Table 3-5: Calculated ET Values Used for Water Balance Calculations

ET Parameter	ET (mm/year)
Minimum ET	27
Maximum ET	103
Median ET	61
Average ET	65
3-year high ET	86

As a comparison, wetland treatment studies conducted by Dalhousie University and the Government of Nunavut Community and Government Services (GN-CGS) in 2015-2017 estimated annual ET rates from Sanikiluaq, Cape Dorset and Nauujat to be 91, 63 and 65 mm/year, respectively. All three of these Nunavut communities are south of 70°N latitude – ET rates greatly decrease with increasing latitude because of the decrease of solar irradiance and air temperature. The annual surface irradiance in the High Arctic is approximately 2500 $MJ \bullet m^{-2} yr^{-1}$ which is almost 60% less than communities in the south (Wang et al., 2015). Typically, communities further south (below 70°N latitude) would experience higher ET values, which illustrates that the chosen ET values for the High Arctic communities are appropriate for the conservative approach applied for the purposes of this screening study.

3.2.3.5 ***Water Balance Scenarios***

For the water balance calculations, fifteen (15) scenarios were analyzed. Taking a conservative approach, the fifteen analyzed scenarios use below average values for precipitation and above average values for evapotranspiration (ET). The worst-case would be represented as Scenario 1, with minimum precipitation and maximum ET.

Table 3-6: Scenarios for Water Balance Calculations

Scenario No.	Precipitation Scenario	ET Scenario
1	minimum	maximum
2	minimum	3-year high
3	minimum	average
4	3-year low	maximum
5	3-year low	3-year high
6	3-year low	average
7	5-year low	maximum
8	5-year low	3-year high
9	5-year low	average

10	10-year low	maximum
11	10-year low	3-year high
12	10-year low	average
13	median	maximum
14	median	3-year high
15	median	average

3.2.4 Bathymetry Survey

Field bathymetry surveys using an electric motor-powered boat were completed for the existing reservoirs at Arctic Bay (Marcill Lake) within the period of September 9-17, 2021. Depths and corresponding volumes have been calculated and are presented in the following section.

4 Results

4.1 Arctic Bay

4.1.1 Watershed Delineation

The watershed area for Marcill Lake is shown in Figure 4-1 below. Table 4-1 presents the delineated watershed area for Marcill Lake.

Figure 4-1: Arctic Bay Watershed for Marcil Lake

Table 4-1: Arctic Bay Delineated Watershed Areas

Community	Water Source	Watershed Area (m^2)	Watershed Area (ha)
Arctic Bay	Marcill Lake	126,600,402	12,660

4.1.2 Water Balance and Water Source Assessment

The results showing the amount of potential annual runoff for the community of Arctic Bay are presented in Table 4-2.

Table 4-2: Arctic Bay Potential Runoff Analysis

Scenario No.	Precipitation Scenario	ET Scenario	Precipitation (mm/year)	Estimated ET (mm/year)	Potential Runoff (mm/year)
1	minimum	maximum	99	103	-4
2	minimum	3-year high	99	86	13
3	minimum	average	99	65	34
4	3-year low	maximum	117	103	14
5	3-year low	3-year high	117	86	31
6	3-year low	average	117	65	52
7	5-year low	maximum	128	103	25
8	5-year low	3-year high	128	86	42
9	5-year low	average	128	65	63
10	10-year low	maximum	159	103	56
11	10-year low	3-year high	159	86	73
12	10-year low	average	159	65	94
13	Median	maximum	222	103	119
14	Median	3-year high	222	86	136
15	Median	average	222	65	157

The results of the water balance analysis for Marcill Lake are presented in Table 4-3.

Table 4-3: Arctic Bay Water Balance Analysis

ARCTIC BAY		MARCILL LAKE	
Scenario No.	2043 Water Use (m^3/year)	Runoff (m^3/year)	ΔS > 0
1	51,852	-557,042	NO

2	51,852	1,595,165	YES
3	51,852	4,253,774	YES
4	51,852	1,801,946	YES
5	51,852	3,954,153	YES
6	51,852	6,612,761	YES
7	51,852	3,109,306	YES
8	51,852	5,261,513	YES
9	51,852	7,920,121	YES
10	51,852	7,147,859	YES
11	51,852	9,300,066	YES
12	51,852	11,958,674	YES
13	51,852	15,052,788	YES
14	51,852	17,204,995	YES
15	51,852	19,863,603	YES

If the annual precipitation volume is greater than or equal to the annual losses (annual ET plus community water use), the water supply sufficiently meets the needs of the community. Based on the assessment, the only instance where water supply needs are not met from annual precipitation, is if the community experiences the worst-case scenario (Scenario 1 - minimum recorded precipitation and highest ET).

4.1.3 Bathymetry – Marcill Lake (Existing Reservoir)

Field bathymetry surveys were completed for Marcill Lake (existing reservoir) at Arctic Bay. Depths and corresponding volumes have been calculated and are presented in Table 4-3 below. A bathymetry survey figure for Marcill Lake is provided in Appendix B.

Table 4-3: Marcill Lake Bathymetry Information

Depth (m)	Cumulative Vol. (cu. m)	Comments
-35.00	562	Bottom of reservoir
-34.00	14,688	
-33.00	63,336	
-32.00	142,594	
-31.00	245,701	
-30.00	374,784	
-29.00	531,244	
-28.00	714,616	

-27.00	921,508	
-26.00	1,152,591	
-25.00	1,411,198	
-24.00	1,719,528	
-23.00	2,071,886	
-22.00	2,460,170	
-21.00	2,888,312	
-20.00	3,370,877	Assumed depth of intake
-19.00	3,907,506	
-18.00	4,489,164	
-17.00	5,109,703	
-16.00	5,767,950	
-15.00	6,463,980	
-14.00	7,200,093	
-13.00	7,977,461	
-12.00	8,797,741	
-11.00	9,658,140	
-10.00	10,556,611	
-9.00	11,493,529	
-8.00	12,468,610	
-7.00	13,480,595	
-6.00	14,530,300	
-5.00	15,616,924	
-4.00	16,736,111	
-3.00	17,888,467	Potential depth of ice
-2.00	19,075,267	
-1.00	20,296,724	
0.00	21,556,805	Water surface

5 Discussion

5.1 Hydrologic Regime

Snow constitutes the majority of the total annual precipitation in Arctic Bay. The watershed basins within these communities are associated with snowfall and snowmelt-generated runoff, which characterizes a nival regime streamflow. These nival regimes are characterized by very low or negligible winter flows (typically from October to early May). Evapotranspiration is the main hydrological loss and is apparent for a couple of months after snowmelt until soil moisture declines. Evapotranspiration is greatest following the snowmelt (typically around late June) and decreases substantially throughout the summer.

Runoff ratio, the ratio between runoff and precipitation, are typically high for polar deserts and glacierized basins (Young and Woo, 2004). In the late spring/summer, high solar radiation causes rapid snowmelt where over 80-90% of the annual runoff flow occurs within a few weeks period. Timing and duration of the melt season depends on the weather and end-of-winter snow conditions. After snowmelt, flow generally declines rapidly. The presence of permafrost at shallow depths prevents infiltration.

5.2 Arctic Bay

5.2.1 Water Balance Scenarios

Based on the water balance assessment, the only instance where water supply needs (using Marcill Lake water source) are not met from annual precipitation, is if the community experiences the worst-case scenario (Scenario 1 - minimum recorded precipitation and highest ET).

The catchment area of the Marcill Lake watershed is extremely large at 126,600,402 m^2. Under all but one scenario (worst-case), any net-positive annual runoff will recharge Marcill Lake and provide a sufficient water supply for the community's needs. Based on the large size of the catchment area, a net positive annual runoff of only around 0.4mm is required to meet the 2043 annual water demand for the community in 2043 (51,852 m^3/year)

In a study investigating vulnerability levels of municipal drinking water supplies for the communities in Nunavut, Hayward et al. (2020), it was stated that the most influential factor regarding water supply vulnerability threat levels appears to be the size of the source watershed. The same study noted a low-level water supply vulnerability threat for Arctic Bay based on the worst-case scenario assessment (minimum precipitation and maximum ET scenario) which is consistent with the results from this assessment.

As discussed previously, the maximum ET rate used in the water balance assessment is likely overestimated (conservative) as seasonal recharge caused by snow melt occurs over a short period in the summer and is substantial enough to produce a flowing stream – this short duration of flow reduces the amount of time that the runoff is exposed to evapotranspiration and is represented by the high runoff ratio (ratio between runoff and precipitation) that is seen in polar deserts. During the cold season, precipitation storage is in the form of snow and ice and undergoes negligible evapotranspiration.

5.2.2 Bathymetry and Storage

In rare occurrences where precipitation does not exceed losses from ET and community water use, Marcill Lake has substantial reserve storage volume that is sufficient to meet the needs of the community even in years where annual net recharge is negative (i.e., drought conditions).

Based on the bathymetry survey information, the deepest part of Marcill Lake is approximately 35 m. Assuming a 3 m depth of ice during the winter (to account for lake freeze-up) and an intake depth of 20 m, the operational storage volume of Marcill Lake has been estimated as follows:

$$\boldsymbol{Total\ Winter\ Storage\ Volume} = (Total\ Vol_{Reservoir}) - (Inaccesible\ Vol_{ice\ cover}) - (Inaccessible\ Vol_{depth\ of\ intake})$$

- Total Volume of Reservoir (total depth of reservoir is 35 m) = 21,556,805 m^3
    - Inaccessible Volume due to ice (assuming 3 m depth of ice) = 3,668,338 m^3
    - Inaccessible Volume below intake depth (assuming depth of intake is 20 m) = 3,370,877 m^3
- *Total Winter Storage Volume = 14,517,590 m^3*

The estimated community water demand in 2043 for Arctic Bay is 51,852 m^3/year. Provided that the conservative estimate for available operational storage is 14,517,590 m^3, this would equate to approximately 280 years of available storage from Marcill Lake based on annual water use (assuming no recharge of the lake).

5.2.3 Operational Considerations and Recommendations

Based on the preliminary water balance and bathymetry assessment, the water source of Marcil Lake will be adequate to meet the needs of the community for the 20-year design horizon without supplementary pumping or capacity upgrades to the reservoir.

The size of the Marcil Lake watershed is extremely large at 126,600,402 m^2 and is expected to provide significant volumes of water to recharge Marcil Lake under most climate scenarios. The existing reservoir (Marcil Lake) is large and has an estimated useable operational storage of approximately 14,500,000 m^3 (the equivalent of approximately 280 years of annual water use) which can be used to sustain the community over periods of severe drought conditions (i.e., low precipitation and high ET).

It is recommended to continue using Marcil Lake as the primary water source for the community of Arctic Bay – no additional upgrades to the existing road infrastructure or capacity upgrades to the reservoir are anticipated for this configuration.

One concern that has been identified is potential saline intrusion due to the proximity of the water source (Marcil Lake) to the ocean. The freshwater lake sits at sea level and is separated from the ocean by a small ridge – along the south edge of the lake, the width of the ridge is approximately 150m to 350m (see Figure 5-1 and Figure 5-2). The lake water level is at approximately the same elevation as sea level based on available topographic information. To date there have been no reports of salinity issues or intrusion with Marcil Lake but this could be a potential issue with sea levels anticipated to rise over the coming decades (due to climate change).

Figure 5-1: Marcil Lake (Arctic Bay) Potential Saline Intrusion

Figure 5-2: Marcil Lake (Arctic Bay) Potential Saline Intrusion

6 Limitations of Water Balance Analysis

Results from this analysis should be considered high-level and coarse resolution. This desktop study provides a screening level assessment of the drinking water supplies for the community of Arctic Bay with consideration to climate change, population growth, and existing water infrastructure. This study focuses solely on water quantity and does comment on water quality.

There are a number of limitations based on poor data availability, as well as the questionable quality of the data. If a yearly climate dataset had three or more months of missing data, this climate dataset was omitted from the water balance analysis. For example, between 1984 to 2020, only five complete years of climate data was available for Arctic Bay. Thus, the weather station at Nanisivik (20 km from Arctic Bay) was used to provide a more complete dataset.

Evapotranspiration characteristics of the studied watersheds are also extremely limited – no field data for measured evapotranspiration rates was available at any of the sites. A literature review was completed to estimate evapotranspiration rates in similar High Arctic environments but there is still a high degree of uncertainty in the quality of this historical data. Variations in environmental conditions, plant community composition and micro-topographical features have a significant influence on evapotranspiration rates. There is a large spatial and temporal variability in geomorphic and climatic drivers of evapotranspiration which makes it difficult to predict evapotranspiration rates in the absence of any field data. As precipitation and evapotranspiration are the main sources of water inputs and losses, any variation or error in these values could significantly alter the results of the water modeling assessments.

Underestimation of precipitation due to snow undercatch and water losses due to sublimation were not accounted for in the calculation. Actual basin snow amounts are usually larger than measured values (at weather stations) which suffer from gauge undercatch and thus the use of snow gauge data was deemed as a conservative approach for this study. Estimates for snow undercatch can range from 10% to 75% depending on gauge type and wind conditions. Sublimation losses have not been characterized. Characterization of these processes requires detailed meteorological data.

In general, there is a lack of field studies detailing the hydrological regime and hydrological features that affect recharge (streams, glaciers, flows through the active layer) at all the sites.

To improve the accuracy of future studies, it is recommended to conduct additional field studies to provide more complete and site-specific climate information, evapotranspiration rates and flow rates and water levels for major streams and channels.

7 Conclusions

7.1 Arctic Bay

For the community of Arctic Bay, it is recommended to continue using Marcil Lake as the primary water source with no requirement for supplementary pumping – no additional upgrades to the existing road infrastructure or capacity upgrades to the reservoir are anticipated for this configuration.

The existing reservoir (Marcil Lake) is large and has an estimated useable operational storage of approximately 14,500,000 m^3 which can be used to sustain the community over periods of severe drought conditions.

One concern that has been identified is potential saline intrusion due to the proximity of the water source (Marcil Lake) to the ocean. The freshwater lake sits at sea level and is separated from the ocean by a small ridge. To date there has been no reports of salinity issues or intrusion with Marcil Lake but this could be a potential issue with sea levels anticipated to rise over the coming decades. Supplementary studies are recommended and may include monitoring salinity concentrations at 1m increments for the entire depth of the lake. This would provide insight into the mixing characteristics/temperature profile of the lake and indicate if salt water intrusion is already occurring.

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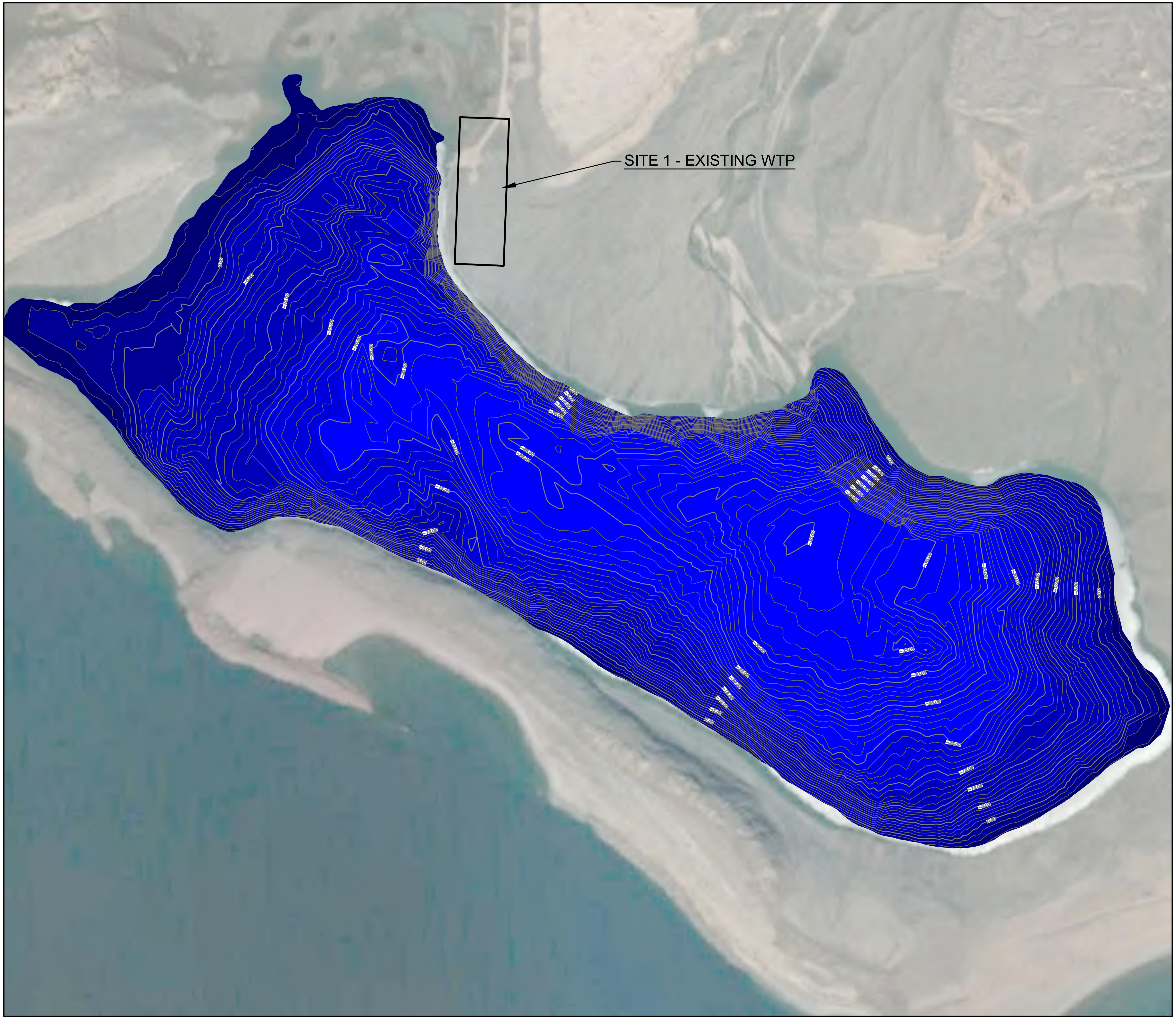
Appendix A – Watershed Delineation Maps

Arctic Bay: Marci Lake Watershed Area

October 2021

Appendix B – Bathymetry Surveys (Arctic Bay)



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No.	Issue	Date

No.	Revision	Date

PRELIMINARY

Drawn By: IB

Dwg Standards Ckd By:

Designed By: CK

Design Checked By:

Scale: 1:7500 — 0 150 300 m

Project Title

HIGH ARCTIC WATER WTP BUSINESS CASE

Dwg. Title

ARCTIC BAY BATHYMETRY SURVEY

Project No. FRN-21016638-A0

Dwg. No. **AB-5**

Rev. No. 0

Arctic Bay Lake Volumes
Project: WTP Arctic Bay
Basin Description: 3D Surface

Elevation (m)	Cumulative Vol. (cu. m)	
-35.00	562	
-34.00	14,688	
-33.00	63,336	
-32.00	142,594	
-31.00	245,701	
-30.00	374,784	
-29.00	531,244	
-28.00	714,616	
-27.00	921,508	
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-24.00	1,719,528	
-23.00	2,071,886	
-22.00	2,460,170	
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-19.00	3,907,506	
-18.00	4,489,164	
-17.00	5,109,703	
-16.00	5,767,950	
-15.00	6,463,980	
-14.00	7,200,093	
-13.00	7,977,461	
-12.00	8,797,741	
-11.00	9,658,140	
-10.00	10,556,611	
-9.00	11,493,529	
-8.00	12,468,610	
-7.00	13,480,595	
-6.00	14,530,300	
-5.00	15,616,924	
-4.00	16,736,111	
-3.00	17,888,467	ice depth
-2.00	19,075,267	
-1.00	20,296,724	
0.00	21,556,805	

Appendix C – Precipitation Data

Compiled Precipitation Data from Environment Canada Historical Records

** data omitted if more than 3 months missing from a year

** Nanisavik data used

Year	Annual Precipitation (mm)		
	Arctic Bay / Nanisavik	Pond Inlet	Grise Fiord
1977			
1978	188.6		
1979	238.8		
1980			
1981	211.6		
1982	211.7		
1983	210.1		
1984	306.5	162.4	
1985	320.6	256.1	270
1986	151.5	191	217.3
1987	236.1	185	
1988	221.9		
1989	216.4	159.5	
1990	136.8	178.1	
1991	319.4	197.8	296.3
1992	149.3	199.8	138.4
1993	235.7	102.2	105.9
1994	227.4		149.1
1995	210.3	247	222.9
1996		252.4	220.7
1997		207	157
1998		247.1	148.5
1999		142.2	87.4
2000	229.6	114.8	141.4
2001	196.3	120.4	193.9
2002	361.4	297.6	235.2
2003	333.3	227.4	179.4
2004	304.7	230	228.6
2005	501.6	225.2	177.2
2006	455.4	192.4	165.9
2007	455.4		
2008		244.2	
2009		155.6	151.1
2010		149.2	303.6
2011		96.4	168.9
2012	114.5	190.7	295.5
2013		124.7	279.9
2014		184.7	126.6
2015		122.8	
2016		194.9	264.7
2017		476.3	
2018	112.1	219.3	167
2019	125.1	188.3	218.7
2020	98.6	133.1	204.5

Annual Precipitation (mm/year)	Arctic Bay / Nanisivik	Pond Inlet	Grise Fiord
Minimum (mm/year)	99	96	87
Maximum (mm/year)	502	476	304
Median (mm/year)	222	191	187
Mean (mm/year)	244	195	197
3-year low average	137	123	143
5-year low average	150	129	146
10-year low average	179	145	156
3-year high average	338	249	272
5-year high average	328	244	256

Longitude (x)	Latitude (y)	Station Name	Climate ID	
-85.01	72.99	ARCTIC BAY CS	2400404	
-82.9	76.42	GRISE FIORD CLIMATE	2402351	
-84.62	72.98	NANISIVIK A	2402730	
-77.96	72.69	POND INLET CLIMATE	2403204	
-77.97	72.69	POND INLET A	2403201	**1975-2007

ARCTIC BAY Historical Precipitation Data

Station Name	Arctic Bay CS
Climate ID	2400404
WMO ID	71592
Latitude	72°59'34.000" N
Longlitude	85°00'44.000" W
Elevation	10.00 m

Year	Annual Precipitation (mm)	Used for Analysis (Y or N)	Comments
1999		N	*11 months missing
2000		N	*275 days missing
2001		N	*365 days missing
2002		N	*365 days missing
2003		N	*11 months missing
2004		N	*11 months missing
2005	113	N	*177 days missing
2006		N	*10 months missing
2007		N	*10 months missing
2008		N	*10 months missing
2009		N	*7 months missing
2010		N	*10 months missing
2011		N	8 months missing
2012	114.5	Y	*53 days missing
2013	139.5	N	*128 days missing
2014		N	*6 months missing
2015		N	*297 days missing
2016		N	*299 days missing
2017		N	*178 days missing
2018	112.1	Y	*26 days missing
2019	125.1	Y	
2020	98.6	Y	

	Total Precip (mm/year)
min	98.6
max	125.1
median	113.3
mean	112.575

NANISIVIK Historical Precipitation Data

Station Name	NANISIVIK A
Climate ID	2402730
WMO ID	
Latitude	72°59'00.000" N
Longlitude	84°37'00.000" W
Elevation	641.90 m

Year	Annual Precipitation (mm)	Used for Analysis (Y or N)	Comments
1977	292.4	N	* 3 months missing
1978	188.6	Y	
1979	238.8	Y	
1980	16.3	N	* 9 months missing
1981	211.6	Y	* 2 months missing
1982	211.7	Y	
1983	210.1	Y	* 1 months missing
1984	306.5	Y	
1985	320.6	Y	* 1 months missing
1986	151.5	Y	* 1 months missing
1987	236.1	Y	
1988	221.9	Y	* 1 months missing
1989	216.4	Y	* 1 months missing
1990	136.8	Y	* 2 months missing
1991	319.4	Y	* 1 months missing
1992	149.3	Y	
1993	235.7	Y	
1994	227.4	Y	* 2 months missing
1995	210.3	Y	* 2 months missing
1996	146.7	N	* 5 months missing
1997	107.8	N	*4 months missing
1998	33	N	* 10 months missing
1999	92.8	N	* 4 months missing
2000	229.6	Y	* 1 months missing
2001	196.3	Y	
2002	361.4	Y	
2003	333.3	Y	
2004	304.7	Y	
2005	501.6	Y	
2006	455.4	Y	
2007	455.4	Y	* 2 months missing
2008	325.8	N	**128 days missing

	Total Precip (mm/year)
min	136.8
max	501.6
median	229.6
mean	265.2

Appendix H – Technology Assessment and Service Conditions Report

1. **Technology Assessment and Service Conditions Report (EXP) – Arctic Bay (March 18, 2022)**

New Water Treatment Facilities & Associated Infrastructure at Pond Inlet, Arctic Bay and Grise Fiord

Technology Assessment and Service Conditions Report

Government of Nunavut

Type of Document:
Technical Report – Technology Assessment – Arctic Bay

Project Name:
Business Case for New Water Treatment Facilities & Associated Infrastructure at Arctic Bay

Project Number:
FRN-21016638-A0

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List of Terms

The following terms are used as acronyms or short forms:

Short Form or Acronym	Reference Document or Term
ACH	Aluminum Chlorohydrate
Alum	Aluminum Sulfate
AO	Aesthetic Objective

AOP	Advanced Oxidation Process
CEB	Chemical Enhanced Backwash
CIP	Clean in Place
CSA	Canadian Standards Association
CSMR	Chloride/Sulfate Mass Ratio (Corrosion Potential)
CT	(Chlorine) Contact Time
DAF	Dissolved Air Flotation
DBPs	Disinfection By-Products
DOC	Dissolved Organic Carbon
EQ	Equalization
GAC	Granular Activated Carbon
GCDWQ	Guidelines for Canadian Drinking Water Quality
GN-CGS	Government of Nunavut – Community and Government Services
Good Engineering Practice Document	Good Engineering Practice for Northern Water and Sewer Systems (2nd Edition), 2017
HAAs	Haloacetic Acids
Lpcd	Litres per capita per day
MAC	Maximum Allowable Concentration
NWT - MACA	Northwest Territories - Municipal and Community Affairs
MCL	Maximum Concentration Limit
MF	Microfiltration
NF	Nanofiltration
NOM	Natural Organic Matter
NWT	Northwest Territories
PACL	Polyaluminum Chloride
RO	Reverse Osmosis
RWU	Residential Water Use
SWTT	Standard Water Treatment Train
SUVA	Specific UV Absorbance
TDS	Total Dissolved Solids
THMs	Trihalomethanes
TTHMs	Total Trihalomethanes
TOC	Total Organic Carbon
TWUC	Total Water Usage per Capita
UF	Ultrafiltration
UVT	UV Transmittance
USEPA	United States Environmental Protection Agency
WTP	Water Treatment Plant

1 Executive Summary

EXP services have been retained by the Department of Community and Government Services, Government of Nunavut to complete the Business Cases for new water treatment plants (WTPs) in Pond Inlet, Arctic Bay and Grise Fiord. In advancing the designs of the proposed WTPs, EXP reviewed the findings of the previous Standard Water Treatment Plant (SWTT) reports (Dillon, 2020) to confirm the WTP treatment trains and service conditions based on each community's existing and forecasted raw water quality over a 20-year design horizon.

The new WTP at Arctic Bay is required to meet the Health Canada Guidelines for Drinking Water Quality (GCDWQ) and the supply needs of the community over the 20-year design horizon. Based on historical water quality, reduction of organics in the raw water is required to ensure treated water is compliant with current and future disinfection by-product regulations (for THMs and HAAs). The proposed WTP will utilize an ultrafiltration membrane process. Membrane manufacturers noted that a DAF for upstream solids removal would not be required for the expected water quality over the design period. All multi-barrier trains are capable of exceeding the 0.1 NTU filtered water turbidity requirements and log removal requirements for viruses (4.0) and protozoa (3.0).

Arctic Bay

The proposed WTP at Arctic Bay will continue to use Marcil Lake as the raw water source. Based on available water quality information, the proposed treatment train at Arctic Bay is:

Screening → Coagulation → Contact Tank → Membranes (UF) → UV → Chlorine

The projected population for Arctic Bay for the year 2043 is estimated at 1,184. This equates to a peak daily water demand of 355.2 m^3/day. It is proposed that the WTP will operate for 12 hours/day at a design flow of 493 L/min. At these demands, it is expected that the community will require 4 trucks (12,000L capacity/truck). Based on capacity and operational considerations, it is proposed to provide 1 truck arm. However, in previous SWTT reports, the GN-CGS noted a preference to have 2 truck arms – this preference to be confirmed with the GN-CGS.

No capacity upgrades to the existing reservoir (Marcil Lake) are expected as the Lake has sufficient volume to meet supply demands over the 20-year design horizon.

Treated water storage for the new WTP is estimated at 394 m^3. Storage requirements will be refined once treatment processes, equipment and storage philosophy are confirmed with the GN-CGS.

Additional Water Sampling

Additional water sampling is recommended and includes:

- *Arctic Bay*
    - To investigate potential saltwater intrusion, an online probe could be used to measure conductivity readings at different depths of the lake
    - Seasonal UVT values for all water sources – sizing and optimization of UV units to ensure disinfection requirements are met throughout the year
    - Corrosion testing at the household level to confirm mitigation actions

2 Introduction

2.1 Objectives

The Government of Nunavut (GN) would like to identify a Water Treatment Plant (WTP) technology process that meets the future needs of the community.

Central to this technology assessment is the evaluation of the appropriateness of the standardized systems identified within the previous Standardized Water Treatment Train (SWTT) reports, in meeting regulatory requirements and community needs from operational and water quality perspectives.

2.2 Scope and Purpose of Current Report

This report will evaluate the appropriateness of the Standard Water Treatment Plant (SWTT) identified by Dillon in their Design Standard for Water Treatment Plants and assess service conditions for the proposed water treatment plant and raw water source for the 20-year design horizon. This report will also discuss the following design criteria and servicing conditions for the new water treatment plant:

- review of existing water quality information
- treatment requirements, water quality requirements and objectives
- review of recommendations provided in previous SWTT reports
- Development of a proposed water treatment process train
- Service conditions including anticipated population growth, demands and regulatory requirements over a 20-year design horizon
    - water treatment plant components including water storage requirements, fire flow requirements, power considerations, etc.

The items discussed in this report will be incorporated into the schematic design. An approach philosophy that considers the challenges of working in a remote environment in the Arctic will be used with the objective of providing simple, robust, and reliable operation while minimizing maintenance activities.

2.3 Background Document Review

We have referenced the following background documentation and research papers. At this stage, Nunavut Public Water Treatment and Design Standards are currently being updated; due to their lack of availability for the purposes of this work, other jurisdictional Standards and Guidelines have also been considered for the purposes of establishing minimum engineering design standards and guidance that are not specified in the Guidelines for Canadian Drinking Water Quality (GCDWQ).

- British Columbia Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia, 2012
- Cold Regions Utilities Monograph, 1996;
- CSA Standards – sewage, drainage;
- Design Standard for Water Treatment Plants (SWTT) Phase 1 to 3 Reports. Dillon, 2020.
- Good Engineering Practice for Northern Water and Sewer Systems (2nd Edition), 2017
- Gora, S.L., Soucie, T.A., McCormick, N.E., Ontiveros, C.C., Herault, V.L, Gavin, M., Trueman, B.F., Campbell, J., Stoddart, A.K., and Gagnon, G.A., 2020. Microbial water quality in a decentralized Arctic drinking water system. Environmental Science: Water Research & Technology, 6, 1855.
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- Guidelines for Canadian Drinking Water Quality, September 2020;
- Guidelines for Canadian Drinking Water Quality, Guideline Technical Document – Manganese. Health Canada, May 2019;
- Guidelines for Canadian Drinking Water Quality, Guideline Technical Document – Trihalomethanes. Health Canada, May 2006;
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- Guidance on Natural Organic Matter in Drinking Water. Health Canada, March 2019.
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- Microfiltration and Ultrafiltration Membranes for Drinking Water, Manual of Water Supply Practices M53, American Water Works Association, 2016
- Nunavut Municipal Infrastructure Capital Standards and Criteria, 2012
- Nunavut Standard Water Treatment Train (SWTT) Project Phase 6: SWTT Schematic Design, October 2020
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- Syvitski, J.P.M. & Andrews, J.T., 1994. Climate Change: Numerical Modelling of Sedimentation and Coastal Processes, Eastern Canadian Arctic. Arctic and Alpine Research, 26(3), 199-212.
- USEPA, Long Term 2 Enhanced Surface Water Treatment Rule Documents, 2005

- USEPA, Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems, 2016
- Water and Sewer Infrastructure in Cold Region Communities (Johnson, 2000)
- Water Treatment Plant Design Nunavut Guideline Document (SWTT) Phase 4, August 2020.

3 Water Quality Review

3.1 General and Findings from the SWTT Report

Available source water quality data for each community is limited and many sampling events did not include a full analysis for all parameters of interest. A review based on all available source water quality data for the community was completed by EXP and compared with the findings stated in the SWTT Phase 2 report. Additional water samples were taken during the September 2021 and October 2021 site visits and will be discussed in the following sections.

Climate forecasts indicate a risk of increased source water turbidity, organics, and microbial pathogens due to increased surface runoff caused by more frequent precipitation events and increasing average temperatures. Based on the limited sampling information, it is not possible to accurately predict the magnitude of seasonal water quality fluctuations as well as potential changes that may occur over the design period of 2020-2040. To account for unknown peak values and potential climate change impacts to the source water quality parameters, Phase 2 of the SWTT report applied a 1.5 factor against the current observed maximum water quality values to use as the design values for the water treatment evaluation. A 1.5 factor was applied to colour, turbidity, DOC, *E. coli* and total coliforms as these parameters are susceptible to projected climate change impacts including increases in surface runoff. pH and TDS design values were established using a factor of 1.0, since these parameters are not expected to increase significantly with changes in surface runoff. As there is large uncertainty in determining peak values and potential changes to these values, this same approach has been used for this assignment.

Limited data is available regarding disinfection by-products (DBPs) in the community to indicate if treatment for dissolved organics is required. The SWTT reports noted that there is a risk of exceeding GCDWQ thresholds for DBPs and thus, they should be incorporated into the minimum water treatment. Subsequent sections will provide additional discussion on DBPs and anticipated DBP treatment objectives.

Based on limited source water data, the Phase 2 SWTT report assumed collective GCDWQ exceedances for the parameters listed below.

- pH
- TDS (salinity)
- Turbidity
- E.coli
- Total Coliforms
- Disinfection by-products (DBPs)

As part of this report, existing and anticipated legislation pertaining to drinking water quality as noted in the GCDWQ was reviewed. Updated water quality information was assessed and compared to the recommendations provided in the SWTT reports.

3.1.1 Arctic Bay Water Quality

The water source for Arctic Bay is Marcil Lake. GN-CGS has noted that Marci Lake will continue to supply drinking water to Arctic Bay into the distant future and will be the only water source evaluated for this assignment. Arctic Bay source water quality for Marcil Lake is summarized in the following table. Exceedances of the GCDWQ maximum allowable concentrations (MAC) or aesthetic objectives (AO) are shown in red.

Table 3-1: Arctic Bay Water Quality (Marci Lake)

Parameter	Units	Number of Samples	Observed Range of Values	Potential Peak Value	Design Value (SWTT)	GCDWQ		Suggested Treatment Objectives
						AO	MAC	
Colour, True	TCU	4	< 2 - 8	12	0	≤ 15	-	-
Conductivity	umhos/cm	4	32 - 38	57	N/A	-	-	-
Hardness	mg/L	4	13 - 14	21	N/A	-	-	80-100 provides balance between corrosion and incrustation
pH	pH Units	4	6.71 - 7.32	-	N/A	-	-	7.0-10.5
TDS	mg/L	11	8 - 29	29	0	≤ 500	-	-
Turbidity	NTU	9	0.3 - 3.3	**5.0**	**3.9**	< 1.0	-	≤ 0.1 (99% of time)
Alkalinity ($CaCO_3$)	mg/L	4	8 - 9	-	N/A	-	-	-
Chloride (Cl)	mg/L	11	2 - 5.5	8.3	N/A	≤ 250	-	-
Sulfate (SO_4)	mg/L	11	1 - 3	4.5	N/A	≤ 500	-	-
CSMR		11	1.03 - 2.50	-	N/A	-	-	< 0.5
DOC	mg/L	11	0.7 - 4	6.0	5.6	-	-	<3 mg/L to reduce DBP formation
TOC	mg/L	3	0.8 - 0.9	1.4	N/A	-	-	
Iron (Fe)	mg/L	11	<0.005 - 0.095	0.14	N/A	≤ 0.3	-	<0.3
Manganese (Mn)	mg/L	11	<0.001 - 0.002	0.00	N/A	≤ 0.02	0.12	<0.02

In general, these results are consistent with the initial source water quality review in the Phase 2 report which noted exceedances for turbidity.

Iron and manganese do not appear to be an issue for Marcil Lake as all water quality samples are below the GCDWQ limits.

Corrosion Considerations

Another potential water quality concern is related to corrosion potential. Chloride (Cl^-) to Sulfate (SO_4) Mass Ratio or CSMR is an indicator of corrosion potential of lead components in copper and brass plumbing and is simply defined as the ratio of chloride to sulfate in mass units. As shown in Table 3-2, the US Geological Survey defines the following categories of corrosion potential based on CSMR. CSMR for the raw water is high and indicates that the water is highly aggressive and has a high corrosion potential (CSMR >0.5 with alkalinity <50 mg/L).

Table 3-2: CSMR and Corrosion Potential Index

CSMR	Corrosion Potential
< 0.2	low
0.2 to 0.5	moderate
> 0.5 with alkalinity > 50 mg/L	moderate
> 0.5 with alkalinity < 50 mg/L	high

In a study conducted by Gora (2020), it was noted that lead release was associated with organic matter (NOM) and iron and manganese compounds in the water and suggests that the presence of these parameters increases the transport of lead through premise plumbing in the system.**. As such, iron and manganese removal and corrosion control treatment should be considered and discussed with GN-CGS to confirm the future WTP water treatment requirements.** Potential options for treatment will be discussed in the subsequent sections.

3.2 Disinfection By-product (DBP) Formation Potential

3.2.1 Current and Anticipated DBP Regulations

Organics in raw water are a concern due to their potential to form disinfection by-products (DBPs) during the disinfection process (typically chlorine). The GCDWQ establishes maximum allowable concentrations for DBPs and guidance from Health Canada is to reduce DBP concentrations to as low as possible. The two categories of regulated DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs, or HAA5 to describe the sum of five haloacetic acids most commonly tested). Both are formed when natural organic matter (NOM) reacts with chlorine. The GCDWQ maximum allowable concentrations for total THMs (TTHMs) and HAA5 are 100 µg/L and 80 µg/L, respectively.

Note that the USEPA according to the Stage 2 Disinfectants and Disinfection By-products Rule states maximum contaminant levels (MCLs) of 80 µg/L and 60 µg/L for TTHMs and HAA5. The USEPA has implemented the 40/30 exemption which allows for less frequent distribution system monitoring for communities that have waters with low levels of TTHMs and HAA5s – the target concentrations for this 40/30 exemption rule are less than less than 50% of the MCLs (half of 80/60). Emerging research and growing concerns about potential health risks related to DBPs in drinking water will likely lead to more stringent rules related to DBPs.

3.2.2 DBP Formation Potential Sampling

Existing THM and HAA information for the three communities is not readily available or may contain unreliable data due to stringent sampling/laboratory requirements for DBPs. To estimate DBP formation potential, raw water samples were collected at the communities during the September/October 2021 site visits. Collected raw water samples were shipped to an external laboratory, spiked with chlorine (2 mg/L) and tested for their respective 7-day THM formation potential. The samples were not analyzed for HAAs. Results are shown in Tables below. Exceedances of the GCDWQ and USEPA TTHM limits are shaded in red and orange, respectively.

Table 3-3: Arctic Bay Water Sources Disinfection Byproduct Formation Potential

Parameter	Units	GCDWQ / USEPA MAC	(1) Marcil Lake THMs
Chloroform	µg/L	-	57-59
Bromodichloromethane	µg/L	-	20
Dibromochloromethane	µg/L	-	<2
Bromoform	µg/L	-	<5
Total Trihalomethanes (TTHMs)	**µg/L**	**100 / 80**	**67-68**

** THM formation potential (µg/L) based on 7-day duration with initial chlorine dose of 2 mg/L*

At Arctic Bay (Marcil Lake), the TTHM formation potential (7-days) was measured at approximately 67 µg/L. This is below the GCDWQ and USPEA TTHM limit but near the upper range of allowable limits. It should be noted that these DBP potential results are based on limited sampling information and real THM concentrations in the water supply is dependent on numerous factors that can vary throughout a system such as water age, organic content, chlorine dose and contact time.

3.2.3 DBP Control and Potential Treatment Options

The samples from the community exceeded the GCDWQ/USEPA TTHM limits or were at the upper range of allowable limits. It is anticipated that DBP regulatory limits will become more stringent including more requirements for comprehensive and frequent monitoring throughout the water supply system. Although the sample size is limited, the results still provide useful insight into the DBP formation potential of the various source waters and indicate that DBP precursors (i.e., NOM) are present in all the source waters. The measured TTHMs are not exceptionally high but there is strong evidence that supports the need to provide a treatment train that contains some form of organic removals process to limit DBP formation.

The GCDWQ does not specify specific treatment objectives for organics and recommends setting objectives based on site-specific raw water monitoring. However, a suggested target noted in the GCDWQ is <2 mg/L for DOC for DBP control. This is similar to the Drinking Water Treatment Standards used for Newfoundland which recommends a treatment objective of <2-3 mg/L for DOC. **As such, in the absence of extensive monitoring and organics information, a reasonable and practical treatment objective of <3mg/L for DOC has been proposed for the treatment train.**

Potential options to reduce organics and control the formation of DBPs include:

- DBP precursor (NOM) removal by optimizing chemical and physical processes prior to disinfection (coagulation + filtration)
- Adjustment of the disinfection strategy
  - Delaying and/or reducing the active chemical disinfect (chlorine) concentration and contact time
  - Use of ultraviolet (UV) light to reduce the required chlorine concentration for primary disinfection

4 Standard Treatment Train Evaluation

4.1 Log Reduction Requirements

The community rely on surface water for their drinking water supply, and thus must meet the minimum treatment requirements as described in the GCDWQ. At a minimum, the GCDWQ states that all surface water must be treated using a multi-barrier approach (at least filtration and disinfection) to achieve a minimum of 3-log reduction (99.9%) of Giardia and Cryptosporidium, and 4-log reduction (99.99%) of viruses.

In Ontario, the drinking water regulations require that the overall treatment process provide a minimum 2-log removal of Cryptosporidium, 3-log reduction of Giardia and 4-log of viruses. The British Columbia Drinking Water Treatment Objectives recommends that water treatment systems should provide, at a minimum, 3-log reduction of Giardia and Cryptosporidium for systems that have a water source considered to have low risk of these protozoa with no known outbreaks. However, higher reductions of Giardia and Cryptosporidium may be required based on baseline levels in the source water. Source water Giardia and Cryptosporidium concentrations should be determined based on actual water sampling and analysis. However, for these communities, comprehensive source water sampling information for Giardia and Cryptosporidium is not available and not feasible to obtain. The GCDWQ does not explicitly state concentration thresholds for Giardia and Cryptosporidium. For example, in Alberta, if no source water data is available for Giardia and Cryptosporidium, the treatment system must meet or exceed the maximum 5.5 log reduction of Giardia and Cryptosporidium and 4-log reduction of viruses. The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR, USEPA 2003) uses a similar approach that can include a maximum 5.5 log reduction of Giardia and Cryptosporidium.

Although Arctic waters are generally 'cleaner' compared to other surface water sources in southern communities due to lack of development/industry, there exists a high level of uncertainty in characterizing the microbial risk of these waters. As such, engineering safety factors or additional treatment reductions should be applied to ensure production of microbiologically safe water. In preliminary discussions with the GN-CGS and initial recommendations provided in the SWTT reports, it is expected that the selected multi-barrier treatment train will meet or exceed the GCDWQ standard of 3-log reduction of Giardia and Cryptosporidium and 4-log reduction of viruses. Minimum log reductions for the proposed treatment trains will be confirmed and discussed in subsequent sections.

4.2 Minimum Treatment Requirements

Based on the discussion above and review of the initial SWTT documents, the following approach has been used for the development of the water treatment train options:

- Required minimum treatment of filtration and disinfection, per GCDWQ
    - The GN (Department of Health) has issued an updated order (GN Turbidity Results Decision Tree – May 13, 2020) noting that filtered water turbidity should consistently be under 1 NTU
- Minimum overall 3-log reduction of Giardia and Cryptosporidium and 4-log reduction of viruses
- Primary disinfection shall include both ultraviolet light (UV) and chlorination
    - Disinfection log removal credits for Giardia and Cryptosporidium shall be achieved by UV
    - Disinfection log removal credits for viruses shall be achieved by chlorination
- Required treatment for reduction of organics (DBP precursors) to meet regulatory and anticipated requirements for DBPs.
- Provision for solids removal/clarification treatment process

- Provision for coagulation treatment process as required
- Provision for corrosion control treatment options – in addition to the initial recommendations provided in the Dillon report, additional sampling has revealed that the water chemistry at the communities is "aggressive" and has a high corrosion potential.

A summary of the water treatment objectives are summarized below:

Table 4-1: Arctic Bay Water Treatment Objectives

Key Parameters	Unit	Source Water	Treatment Objectives	Comments
Turbidity	NTU	1 - 5	≤ 0.1 (99% of time) <0.3 (maximum)	Main Processes (filtration and disinfection) for turbidity, protozoa, virus removals
Protozoa	Log Reduction	-	At least 3-log (up to 5.5 log)	
Viruses	Log Reduction	-	At least 4-log	
TOC/DOC	mg/L	1-10	<3 mg/L to reduce DBP formation	Secondary Processes - Pretreatment or post-filtration processes
TDS	mg/L	8-29	<500	
pH	pH units	6.7 - 7.3	7 - 10.5	
CSMR *	ratio	1.0 - 2.5	< 0.5	
Alkalinity ($CaCO_3$) *	mg//L	8 - 10	$CaCO_3$ > 50 mg/L	

** corrosion control options to be confirmed with the GN-CGS*

4.3 Potential Treatment Technologies

The suitability of treatment technologies is dependent on the source water quality, treatment objectives and operational considerations. A comprehensive review of potential treatment options was completed and submitted in the previous SWTT reports. This current report will only touch on key findings from the previous SWTT reports and will include commentary on additional modifications/recommendations to consider for the updated water treatment trains.

Table 4-4: Review of Potential Treatment Options

Options	Comments for Justification	Preferred Treatment Processes
FILTRATION		
Direct	Not recommended Turbidity and TOC loading thresholds (turbidity < 7-14 NTU, TOC < 3 mg/L) and limited resilience to changes in raw water quality	***Most preferred option is to implement membrane filtration (either UF or hollow-fibre NF)*** In the Phase 2 report, conventional filtration was not recommended due to the high risk of operation related to maintaining proper coagulation chemistry and limited resilience to changes in raw water quality. Membrane filtration is a proven technology that has been successfully used in many cold-climate and Arctic communities (including the NWT) and is the most-preferred technology for this assignment.
Conventional	'rapid sand filtration' – characterized by high filtration rates and no loading thresholds for turbidity or organics. Includes an upstream solids removal process to reduce solids loading to the filters. There are concerns about the required efforts for the coagulation process. Coagulation/flocculation is an essential process and must be optimized to achieve acceptable turbidity removals and to receive log reduction credits. No requirement for pilot testing (as compared to direct filtration or membrane filtration) and thus, is the more conservative option. However, footprint is typically larger.	

Membrane	Membrane filtration provides high quality filtered water using size exclusion and has a small footprint compared with conventional processes. Microfiltration (MF) has larger pore sizes that reject particles between ~0.1-1.0 microns. Ultrafiltration (UF) also rejects particles over the size between ~0.04-0.1 microns. Ultra-filtration was recommended as the membrane standard for the Nunavut SWTT, based on improved filtration performance (including rejection of viruses). A new technology that will be considered and discussed later in this report is hollow-fibre nanofiltration (NF) membranes. Traditional nanofiltration (spiral or tubular) or reverse osmosis membranes which are capable of rejecting dissolved molecules will not be assessed here as these processes are typically used for desalination, softening or specific contaminant removals. Loading thresholds for turbidity was noted in the SWTT as <100 NTU and <2 mg/L for TOC. However, manufacturers can often guarantee higher loading thresholds. Depending on source water quality, a provision for coagulation (targeting dissolved organics removal) and/or upstream solids removal process may be required to minimize excessive backwashing and fouling impacts. Typically, pilot testing for membrane filtration is recommended.	
Cartridge	Not recommended Risk of rapid plugging – cartridges are non-back washable (single use) and are used for pristine water sources – concerns regarding cartridge replacement lifespans	
CLARIFICATION / SOLIDS REMOVAL (Provisional)		
Gravity Settler (clarifier or plate settler)	Not recommended Gravity settling processes are not appropriate due to the large footprint requirement and concerns about Arctic raw water conditions (floc formation potential, cold operating temperatures, low turbidity)	Based on the recommended filtration option (membrane), raw quality information and risk tolerances, the three potential options for membrane filtration are: **(a) A DAF solids-removal step ahead of the membranes.** **(b) An in-line contact tank upstream of the membranes (instead of a DAF)** **(c) No solids removal step – according to various manufacturers, many membrane systems can handle high solids and organic loadings without upstream solids-removal.** These options will be discussed in further detail in subsequent sections.
Dissolved Air Flotation (DAF)	DAF is particularly effective for raw waters that contain low-density particles, low to moderate turbidity (<10 NTU, 10-50 NTU) and algae. DAF performance is affected less by low temperatures making it a good option for cold water regions. DAF is much more efficient in removing low-density particles compared to settling processes. The overall footprint for DAF is smaller compared to settling treatments – smaller floc tanks are required because of shorter flocculation pre-treatment requirements and require a much smaller sedimentation/flotation tank.	
Upstream Contact Tank	In discussions with various membrane manufacturers, depending on the membrane type, the solids-removal step can be substituted with an in-line contact tank. Although this contact tank does not meet the solids removal performance of a DAF or clarifier, it provides the required pre-treatment to	

	reliably operate the membrane system above industry-accepted thresholds (i.e., turbidity > 100 NTU, TOC > 2 mg/L). This configuration has been widely used in the NWT. An in-line cone-bottom contact tank upstream of the membranes is a standard design requirement for all NWT membrane plants.	
No Solids Removal	In discussions with various membrane manufacturers, depending on the membrane type, a solids-removal step may not be required as newer membranes are more robust and can handle higher tolerances of solids and organics. Direct membrane filtration operational limits can likely exceed turbidity >100 NTU and TOC > 40 mg/L)	
ORGANICS REMOVAL (For DBP Precursor Removal)		
Coagulation	Involves injection and mixing of coagulant chemical. Most common approach. For conventional filtration, coagulation is required to achieve log removal credits. For membrane filtration, the GCDWQ does not require coagulation to achieve log removal credits for Giardia, Cryptosporidium and virus. However, for dissolved organic removal using UF, coagulation is required.	Potential options include: **(a) Coagulation pre-treatment (for UF membranes)** **(b) No coagulation pre-treatment (for hollow-fibre NF membranes)** There are concerns about potential DBP formation and exceedances of current or anticipated GCDWQ limits. Thus, a treatment process will be required to reduce DBP precursors prior to disinfection.
No Coagulation (hollow fibre NF)	In discussions with suppliers, hollow-fibre NF suppliers can remove NOM/DOC with minimal pre-treatment steps or chemical addition. This will be discussed in subsequent sections.	
Activated Carbon (Granular activated carbon, GAC)	Not recommended Forms include powdered (PAC) and granular activated carbon (GAC) for absorption of TOC and other DBP precursors, taste and odour causing compounds. PAC is typically dosed upstream while GAC is used as media in gravity or pressure filters. For this assignment considering operational limitations, only GAC will be evaluated. The cycle life of GAC media depends on numerous factors including water quality and frequency and concentration of elements removed in the feed water. Validation typically required through pilot testing as organic removal and life cycle is unknown. Exhausted activated carbon requires disposal or regeneration. Communities would require storing at least one year's worth of activated carbon onsite. GAC media are very porous and can provide application for general turbidity reduction. As GAC has a limited capacity, used as a primary filtration (i.e., upstream of UF), life cycle would be greatly reduced. Based on concerns regarding disposal of exhausted carbon and unknown operational performance, this option is not recommended.	
Biological Filtration	Not recommended Typically requires an ozone treatment to break down larger NOM molecules into smaller molecules that can be consumed within the biofilter. Operating temperatures are expected to be low which is not practical for biological treatments.	
Advanced Oxidation (AOP)	Not recommended Operational and maintenance challenges and energy requirements is not suitable for small systems	

Ion Exchange	Not recommended Operational challenges with regeneration of media, salt consumption, fouling concerns, and creation of an additional waste stream. Not a proven or well-established technology in Arctic environments.	
DISINFECTION		
Chlorination	Chlorine is highly effective for inactivating viruses and bacteria but much less effective against protozoa (Giardia and Cryptosporidium). The project communities are familiar with using either sodium hypochlorite or calcium hypochlorite and the associated equipment for water disinfection.	***Preferred option is to use both chlorination and UV for disinfection.*** According to the SWTT Phase 2 report, the decision to use UV and chlorine for disinfection was made following GN-CGS discussions with the GN-CGS. This multi-barrier system will provide an additional barrier to pathogens and helps limit DBP formation. Chlorine will be used for both primary disinfection of viruses and secondary disinfection (maintaining a minimum free chlorine residual). UV will be used for primary disinfection of Giardia and Cryptosporidium. The implementation of UV disinfection would reduce the size of chlorine contact chambers.
UV	UV is effective for the inactivation of Cryptosporidium and Giardia at economical doses but is much less effective for virus inactivation.	
ADDITIONAL TREATMENT CONSIDERATIONS		
Iron and Manganese	Iron and manganese removal are typically done in conjunction with one another. While special emphasis is placed on manganese removal due to its increased difficulty, in providing sufficient removal for manganese, adequate iron removal is also accomplished. To decrease iron and manganese concentrations, options include: 1. Sourcewater control (in-situ treatment, e.g. lake aeration) 2. oxidation/physical separation (e.g. pre-oxidation/ filtration) 3. adsorption/oxidation (e.g. greensand filter) 4. biological filtration, 5. precipitative softening (e.g. ion exchange)	Processes for iron and manganese removals will be further evaluated following the selection of the main treatment processes and will be discussed in later sections.
Corrosion Control	Appropriate processes to mitigate corrosion risks in the treated water include pH adjustment, addition of orthophosphate, calcite filters and alkalinity adjustments. Corrosion potential is affected by several water parameters such as pH, alkalinity, hardness, dissolved oxygen, chlorine residual, TDS, sulfate concentrations and type and dose of coagulant used	Corrosion control processes will be further evaluated following the selection of the main treatment steps. Similar to iron and manganese treatments, bench-scale testing is highly recommended as the various treatment steps impact the selection of the corrosion control processes. Discussion is required with the GN-CGS about confirming corrosion control objectives.

Fluoridation	Fluoride is often added to drinking water as a public health and dental health initiative. However, the chemicals used for fluoridation (fluorosilicic acid or sodium fluoride salt) are toxic and among the most difficult to handle in a water treatment installation. Sodium fluoride salt is likely more appropriate for Arctic communities as it is less aggressive than fluorosilicic acid and is shipped as solid. Dosing of fluoride during operation of the water treatment plant would require the provision of specialized space within the building to avoid the generation of hydrogen fluoride gas. Suppliers can provide skidded sodium fluoride injection systems which can be added onto the water treatment train as required.	To confirm with GN-CGS if the community requires fluoridation

5 Water Treatment Plant Process Technology Assessment

5.1 Treatment Train Options

As per Phase 2 of the SWTT Report, five standardized treatment trains were short listed for evaluation (Red trains have been eliminated from consideration). Note that we have split Train #3 to include a provision for an in-line contact tank (Train #3a and 3b):

i. Train #1: Direct Filtration

Screening → Coagulation → Pressure Media Filtration → UV → Chlorine

- Eliminated from further evaluation due to turbidity and TOC loading thresholds, limited resilience to changes in water quality, elevated risks in meeting GCDWQ requirements and operational concerns

ii. Train #2: Conventional Filtration

Screening → Coagulation → Gravity Media Filtration → UV → Chlorine

- Eliminated from further evaluation due to large footprint requirements and operational considerations regarding coagulation efforts (turbidity removal for gravity media filtration)

iii. Train # 3a: Membrane Filtration, no solids removal (with contact tank)

Screening → Coagulation → Contact Tank → Membranes (UF) → UV → Chlorine

iv. Train # 3b: Membrane Filtration, no solids removal (without contact tank)

Screening → Coagulation → Membranes (UF) → UV → Chlorine

v. Train # 4: Membrane Filtration with solids removal (DAF)

Screening → Coagulation → Solids Removal (DAF) → Membranes (UF) → UV → Chlorine

vi. Train #5: No Coagulation Option

Screening → Membranes (UF) → Adsorption (GAC) → UV → Chlorine

- Eliminated based on unknown performance of the process, and impracticalities of conducting piloting for performance validation.

Another option that was not discussed in the previous SWTT reports is a hollow-fibre nanofiltration option which is a hybrid between ultrafiltration and traditional nanofiltration. The pore size for these hollow-fibre nanofiltration membranes is smaller than ultrafiltration membranes which eliminates the need for coagulation for DOC removal and slightly larger than traditional (spiral-type) nanofiltration membranes which eliminates the need to re-mineralize the permeate. This option will be called Train #6:

vii. Train #6: Hollow-Fibre Nanofiltration

Screening → Contact Tank → Nanofiltration → UV → Chlorine

As such, treatment trains using ultrafiltration membranes (Trains #3a, #3b and #4) and hollow fibre nanofiltration (Train #6) will be assessed for further consideration.

5.2 Membrane Filtration Technologies (MF, UF, Hollow-Fibre NF)

Membrane Filtration is preferred over conventional media filtration due to small footprint requirements and the ability to produce high quality water. Three potential membrane technologies will be discussed:

- Microfiltration (MF) > 0.10 micron
- Ultrafiltration (UF) < 0.10 micron
- Hollow-Fibre Nanofiltration (Hollow-Fibre NF) < 0.01 micron

MF and UF are often configured as hollow fibre membranes while traditional NF (and RO) units are configured as spiral-wound membranes. As noted in the SWTT report, ultrafiltration (UF) is the preferred and recommended membrane type due to superior filtration performance (compared to microfiltration) and simplified operation and waste stream considerations (compared to desalination technologies such as traditional spiral-wound nanofiltration and reverse osmosis). These considerations were discussed in the previous SWTT reports.

5.2.1 Hollow-Fibre Nanofiltration Technology

There have been great advances in membrane technology over the past decade and one option that was not discussed in the SWTT reports are hollow-fibre nanofiltration which removes NOM/DOC without coagulation. Operationally, the process does not create a concentrated brine solution, does not require re-mineralization of the permeate (as salt retention on the membrane is less than traditional NF/RO) and can operate at much lower operating pressures compared to traditional NF membranes. These hollow-fibre NF membranes are basically a hybrid between UF and traditional NF membranes (pore size has been modified to operate in the range between UF and NF as seen in Figure 4-1). Traditional NF membranes (spiral and tubular) will not be considered due to concerns regarding the production of a concentrated waste stream, high energy consumption and extensive pre-treatment requirements. Although hollow-fibre NF membranes are a relatively new technology with fewer manufacturers (Pentair and NX Filtration), they do merit consideration as there is a great benefit to the reduction of pre-treatment requirements and minimizing chemical addition. Further discussion on hollow-fibre NF membranes is provided in Section 4-6.

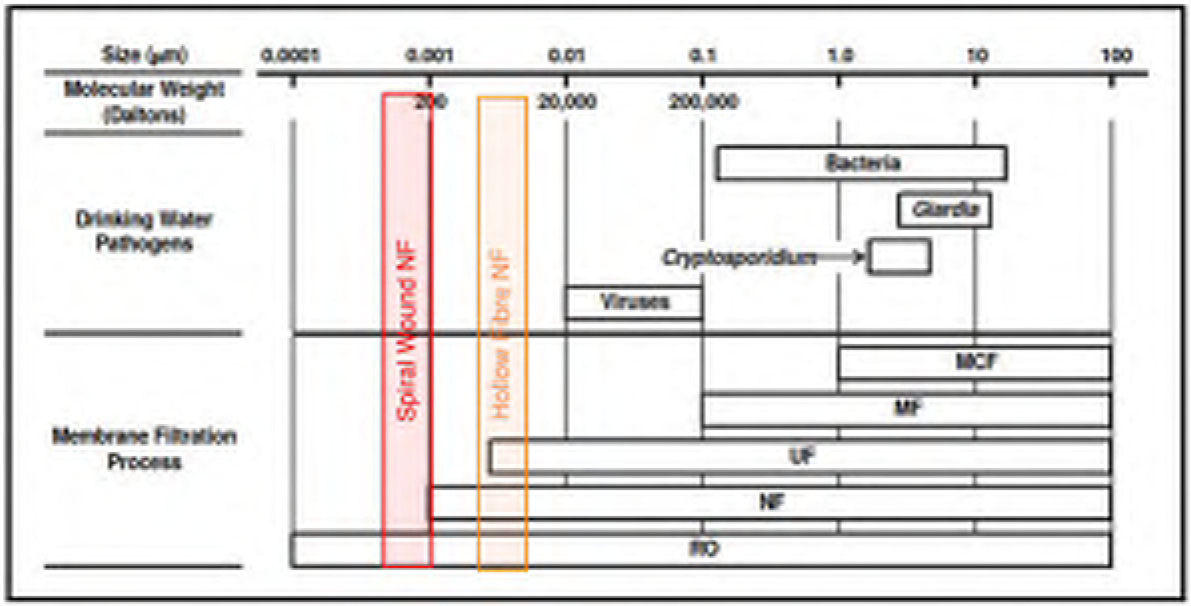

Figure 5-1: Membrane Filtration Spectrum (USEPA) annotated with NF technology pore size ranges

Treatment Trains #3a, #3b, #4 and #6 will be further evaluated, specifically regarding pre-treatment requirements for coagulation and solids removals as minimizing these processes will help simplify operations and chemical consumption. Iron/manganese treatment and corrosion control options will be discussed including how these processes will affect the proposed treatment trains.

5.3 Log Reduction Requirements (as per GCDWQ)

The proposed multi-barrier treatment trains are required to meet a minimum overall 3-log reduction of Giardia and Cryptosporidium (up to 5.5-log reduction), and 4-log reduction of viruses as noted in the GCDWQ. As indicated in the table below, all proposed trains (#3a, #3b, #4 and #6) meet the log removal credits requirements based on individual system processes (at least 5.5-log reductions of Giardia/Cryptosporidium and 4-log reduction of viruses). Conservative values have been used for the log-removal credits and it is expected that higher overall log reductions are achievable and verifiable through challenge testing and direct integrity testing.

Table 5-1: Potential Log Removal Credits for Treatment Trains

Treatment Process	Giardia/Cryptosporidum Credit	Virus Credit
Membrane Filtration	3.0 *	0 **
Coagulation	0	0
Flocculation	0	0
DAF	0	0
Chlorine	0	4.0 [1]
UV	3.0 [2]	0
TOTAL	**6.0 +**	**4.0 +**

* Required to be demonstrated through challenge testing and verified by direct integrity testing – 3 log reductions have been conservatively used for the membrane filtration process. Membrane manufacturers have readily noted log reductions between 4.0 and 6.5.

** Requires to be demonstrated through challenge testing and verified by direct integrity testing. For ultrafiltration/nanofiltration, virus removal is possible with or without coagulation.

[1] Chlorination will be sized for virus inactivation as determined by CT values – log reduction values range from 0 to 4 log for viruses

[2] UV will be sized for protozoa inactivation as determined by UV dose calculations – log reduction values range from 0 to 3 log for protozoa

5.4 Treatment Requirements – Evaluation Method and Screening

5.4.1 Overview

Treatment Trains #3a, #3b, #4 and #6 will be further evaluated, specifically the pre-treatment requirements for coagulation, flocculation and upstream solids removals and their impacts on membrane operations and performance. The main screening topics that will guide the evaluation include:

1. Requirement for upstream solids removal (i.e., DAF)
    a. Membrane capacities for directly handling relatively low turbidity feedwater (<25 NTU) without any upstream solids removal
    b. Membrane capacities for directly handling TOC/DOC in the range of <10 mg/L without any upstream solids removal
2. Membrane Operational Considerations
    a. Coagulation/Flocculation Requirements
3. Iron and Manganese Considerations
4. Corrosion Control Considerations

5.4.2 Screening Topic 1: Requirement for Upstream Solids Removal (DAF)

While membrane filtration is able to accommodate a range of water quality, for effective operation (e.g., to prevent excessive fouling), accepted thresholds for key parameters were considered. As noted in the SWTT report, per Alberta Standards for Municipal Works (2012), source water turbidity for membrane filtration should be less than 100 NTU and Total Organic Carbon (TOC) should be less than 2 mg/L. Based on the source water quality, it is not expected that turbidities will exceed 100 NTU. The new WTPs collect raw water from earthen reservoirs or raw water storage tanks which will help lessen the magnitude of turbidity spikes during the spring runoff. However, source water organic concentrations will likely exceed 2 mg/L. Solely based on this limit (TOC loading < 2 mg/L), the SWTT noted that the community would require an upstream solids/organics removal process such as DAF (Train #4). The implementation of a DAF upstream of the membrane system (Train #4) would require additional pumping equipment, produce an additional waste stream and increase the level of operational complexity.

However, in our review of current membrane research and discussions with suppliers, the use of this noted membrane threshold limit for turbidity and TOC (100 NTU and 2 mg/L) is outdated and most territories/states do not state these maximum threshold limits. In recent years there have been great advances in membrane technology that have led to the improved ability to filter lower quality feed water (higher turbidity and organics), reduction in pre-treatment requirements, smaller footprint requirements, improved membrane fouling resistance and more efficient operations and performance.

Solely based on feedwater characteristics, membrane manufacturers have indicated that much higher loading thresholds (turbidity and organics) are possible and quite typical for recent membrane installations. The AWWA Microfiltration and Ultrafiltration Membranes for Drinking Water Manual M53 (2016) notes that "UF systems results in a consistent filtrate that is independent of feedwater quality"**.** Noted membrane operational feed water characteristics based on discussions with membrane suppliers and AWWA guidelines are included in Table 5-2.

Table 5-2: Membrane Operational Feed Water Characteristics

Feedwater Parameter	Ultrafiltration Membranes* +	Hollow-Fibre Nanofiltration Membranes* ++
Turbidity (NTU)	< 30 - 50, max 100 – 400 (pressurized), max 500 (submerged)	< 100
TOC (mg/L)	< 10, max 40 – 100	< 50
Temperature (°C)	0 - 40	0 - 40
pH	6 – 9, max 2-11	5 - 9
Particle size, µM	< 150, max 300	< 300

**200-500 µM screening pre-treatment required*

[+] *Ultrafiltration membranes – SUEZ, Dupont/Memcor, Toray*

[++] *Hollow-fibre nanofiltration membranes – Pentair and NXFiltration*

All membrane manufacturers noted that a DAF for upstream solids removal would not be required for the expected raw water quality over the design period. **To mitigate risks associated with elevated turbidity or organics in the source water, the membrane system can be designed conservatively using a slightly higher design flow rate and slightly lower design flux as the cost of including additional membrane modules to the treatment train is relatively small compared to the cost of the overall equipment.**

Based on best-available membrane and water quality information, a DAF for upstream solids removal (Train #4) is likely not required to handle the expected water quality (turbidity) over the design period. However, the uncertainty of climate change impacts and potential increases in turbidity events carries some significant risks that need to be confirmed with the GN. Further discussion on potential climate change impacts on water quality are discussed in Section 6.

If it is decided that a DAF is not required, depending on the chemistry of the raw water and pre-treatment requirements, an in-line contact tank (Train 3a) may still be required to provide sufficient contact/flocculation time. Although this contact tank (shown in Figure 5-1 below) does not meet the solids removal performance of a DAF or clarifier, it provides the required pre-treatment and contact/flocculation time to reliably operate the membrane system above the thresholds noted in the SWTT report (i.e., turbidity > 100 NTU, TOC > 2 mg/L). This configuration has been widely used in the NWT. An in-line cone-bottom contact tank upstream of the membranes is a standard design requirement for all NWT membrane plants and is shown in the figure below. **In recent discussions with the NWT, the contact tanks were installed to help deal with seasonal high turbidity (reservoir filling and runoff events) and future changes in raw water quality – to date, most plants do not run the contact tanks on a regular basis as their membrane plants have been operating performing well using direct membrane filtration.**

Figure 5-2: Contact Tank Used in NWT Membrane Plants

Action Items:

- Discussion with the GN regarding risk tolerance for dealing with climate change impacts and uncertainty in determining potential magnitudes of these impacts (elevated turbidity, organics)

5.4.3 Screening Topic 2: Membrane Operational Considerations (Coagulation, Flocculation)

Coagulation Suitability

The two main reasons for implementing coagulation at the proposed WTPs is:

i. For dissolved organic removal using ultrafiltration, a coagulation step is required to effectively remove NOM/DOC to minimize DBP formation.
ii. Additionally, there are applications where pre-treatment/conditioning may be required to enhance membrane system operation. NOM is often cited as one of the most common factors contributing to organic fouling. Coagulation may aid in reducing fouling as the coagulation of smaller (or dissolved) particles into bigger ones can reduce the penetration of materials into the pores of the membrane that cause fouling (AWWA, 2016).

SUVA or specific UV absorbance has been developed as an indicator of humic content (long-chain organics) and the effectiveness of coagulation for NOM removal. A high SUVA value indicates large proportion of humic substances in the water and that NOM will control the dose of coagulant. Humic substances have a tendency to react more readily with disinfectants to form DBPs, thus a high SUVA typically indicates a greater potential to form DBPs. Typically, waters with SUVA values > 2.0 are amenable to coagulation and experience significant drops in organic content after coagulation (Health Canada, March 2019). The opposite occurs with low SUVA values. Low SUVA values indicate lower molecular weight organic compounds that are not easily removed by coagulation.

Additionally, as a general rule, waters with SUVA values >4 may experience issues with membrane fouling. Table 5-3 shows the calculated SUVA values for the three communities based on limited water quality samples collected from the October 2021 site visit. These limited SUVA results indicate that the source waters are likely amenable to a coagulation step and may help with improving membrane operation.

Table 5-3: SUVA Results for Potential Raw Water Sources

Community	***Arctic Bay***	
ID	Sample 1	Sample 2
UVA (cm^{-1})	0.0232	0.0241
DOC (mg/L)	0.8	0.7
SUVA (L/mg/m)	**2.9**	**3.4**

Based on limited sampling information:

- For Arctic Bay, as current DBPs are within acceptable limits, coagulation may not be required for DBP control.
    - However, coagulation may still be beneficial in optimizing membrane performance (reducing membrane fouling) and to meet future DBP regulations.
- It is recommended to include a coagulation injection system in the treatment process– the implementation of the coagulation process can be verified through bench-scale testing and at project commissioning by monitoring system operation and water quality through sampling (DBP formation, DOC removals)

Direct Hollow-Fibre Nanofiltration – Potential Alternative to Coagulation

It has been noted that CGS has concerns about the potential challenges for operating a new water treatment plant, particularly if coagulation is required. The combination of logistics issues and ongoing operational challenges suggest that an alternative approach be considered. Train #6 using hollow-fibre nanofiltration membranes offers a potential train that eliminates the coagulation step. EXP has completed discussions with hollow-fibre NF suppliers – this evaluation between ultrafiltration vs. hollow fibre nanofiltration membranes has been provided in Appendix C.

Following further investigations and discussions with suppliers, we do not see the hollow-fibre NF membranes (Train #6) as an appropriate technology for these High Arctic WTPs. Main considerations for exclusion include:

- Lower recoveries (less than 90%) which would create large volume of wastewater (at least 10% of produced water) – this requires significant disposal efforts and large storage volumes to hold wastewater.
- New and unproven technology – limited track record with cold-water applications
- Lower chemical resistance to chlorine compared to UF membranes
- Higher capital costs for hollow-fibre NF membranes and lower expected life expectancy (~ 3 years)

Coagulation Concerns and Impact on Membrane Operation

a) Considerations regarding direct loading of coagulant on ultrafiltration membranes

Ultrafiltration membranes can likely handle direct loading of coagulant. However, this will depend on coagulant type and required concentrations. This is limited by the amount of coagulant the membrane system can reliably process without undue fouling – a practical upper limit is in the range of 40 mg/L of coagulant (AWWA, 2016). Bench-scale tests are highly recommended to verify appropriate coagulants, approximate dosing rates and reaction times.

b) Requirement for a contact / buffer tank to provide sufficient coagulation/flocculation time

A contact/buffer tank is likely required to provide sufficient coagulation/flocculation time upstream of the membrane process. A reduced flocculation time (and smaller tank) is typical with membrane filtration as the objective is only to create pin-floc that can be filtered by the membrane (vs. conventional coagulation that requires big, settleable floc). However, as water temperatures are low, longer contact times may be required. Piping manifolds (serpentine arrangement or flocculation tubes) that allow for different lengths of piping downstream of coagulant addition may be able to provide sufficient flocculation time. Otherwise, an upstream contact tank or a combination of both will be required. Bench-scale tests are highly recommended to verify the required flocculation times and upstream sizing of pretreatment equipment.

To mitigate risk concerning uncertainty in coagulation/flocculation requirements and limitations in sampling information, it is recommended to provide an upstream contact tank for the ultrafiltration train (Train #3a). Additionally, the contact tank helps provide some buffer volume and some potential upstream solids removal if an upstream DAF process (Train #4) is not included.

An inline static mixer is planned to be used upstream of the contact time to minimize additional mechanical mixing and energy costs. The contact tank design will be dependent on whether a pressurized or submerged ultrafiltration is used. If a pressurized UF unit is preferred, the contact tank will be pressurized from the raw water intake pumps to minimize additional pumping. If a submerged UF unit is preferred, the contact tank can be elevated (and open to atmospheric pressure) to allow gravity-flow into the submerged UF tanks.

5.4.4 Screening Topic 3: Iron and Manganese Considerations

i. Direct loading of iron and manganese on membranes

The iron and manganese will likely cause issues with the membranes if they are not removed/precipitated upstream. This is highly dependent on the form of manganese (dissolved, particulate or colloidal). In general, dissolved and particulate states are manageable as they can either pass through the membranes or are size excluded by the membranes. However, colloidal and partially-oxidized constituents can cause fouling issues if they are not fully oxidized upstream of the membranes. Additionally, dissolved iron and manganese that pass through the filter may cause issues if oxidation occurs post-filtration. For example, if oxidation occurred during the backwash cycle, this would load the foulant directly on the inside of the membrane. Chemical cleanings also present concerns as this process would oxidize any remaining dissolved iron and manganese during the cleaning process. **These noted concerns with iron and manganese can lead to non-reversible fouling and shortened lifespans of the membrane systems. In the absence of pilot testing to confirm the membrane's tolerance to iron and manganese, it is recommended to provide an additional process to reduce iron and manganese concentrations prior to membrane filtration.**

ii. Community- Specific Iron and Manganese Concerns

- *Arctic Bay*

- Concentrations of iron and manganese in the raw water are below levels of concern
- **No additional treatment for iron and/or manganese is required at Arctic Bay**

5.4.5 Screening Topic 4: Corrosion Control Considerations

At Pond Inlet, research by Gora (2020) noted elevated concentrations of copper (> 2000 µg/L) and lead (> 5 µg/L) in water samples at household taps. Corrosion of drinking water systems has not been widely investigated within remote Arctic communities and EXP is not aware of any available information documenting lead and copper levels at a household level at Arctic Bay or Grise Fiord.

Based on available water quality, the community experiences “aggressive”, corrosive water (low CSMR ratio, low alkalinity, pH <7) and from a health perspective, it is recommended to provide some form of corrosion control treatment to reduce potential exposures to heavy metals (lead, copper, zinc).

The USEPA document “Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems” (2016) notes the following options for corrosion control:

i. addition of corrosion inhibitors (phosphate/sulfate-based)
ii. calcite/limestone contactors
iii. pH/alkalinity adjustment – direct chemical addition
iv. full replacement of lead/copper service lines with non-corrosive materials (i.e., plastic)

The additional of corrosion inhibitors will not be considered due to intensive O&M requirements (accurate dosing, difficult pH control, safety concerns, special handling and feed equipment).

An appropriate corrosion control option would include installation of a calcite filter post filtration and post UV (prior to chlorination). A calcite filter is essentially a media filter loaded with calcium carbonate material (crushed calcite housed in a cartridge) which inexpensively neutralizes acidic or low pH to a neutral, less corrosive effluent. As the corrosive water passes through the filter, the calcite dissolves, raising the pH, alkalinity and calcium of the water. Calcite filters are often used for small systems due to their easy operation and self-limiting property (i.e., does not overcorrect the pH). The calcite filter would require periodic backwashing and replacement once the calcite media is consumed. A calcite filter has been installed at Arviat but is not currently in operation.

Typical filtration rates for calcite filters are between 7-14 $m^3/m^2/hr$. Using a conservative loading rate of 8.5 $m^3/m^2/hr$, preliminary calcite filtration sizing is provided in the table below.

Table 5-4: Preliminary Sizing for Calcite Filters

Parameter	***Arctic Bay***
Surface loading rate ($m^3/m^2/hr$)	8.5
WTP flow rate (L/min)	493
Surface Area Required (m^2)	3.46
# of calcite filters *	2

* Individual calcite filters are typically 6ft diameter x 6ft height (surface area = 2.63 m^2/filter)

pH and alkalinity adjustments can also be achieved by the direct addition of various chemicals. As pH adjustment will likely be required as part of the coagulation process, direct chemical addition is also an appropriate option. It is likely more cost-effective than calcite filters but requires more accurate dosing as all the raw waters are low in alkalinity making pH control more challenging.

For smaller communities, it may be more appropriate and economical to consider the replacement of existing lead/copper service lines (plumbing and tanks) in existing homes. New construction should all require PEX or other non-corrosive plumbing materials.

Options for corrosion control are to be discussed with GN-CGS to confirm the requirements for the new WTP water treatment plant.

5.5 Bench-Scale Testing and Additional Sampling

Bench Scale Testing

As noted in the section above, without pilot- or bench-scale testing, pre-treatment requirements (and specifically coagulation and flocculation requirements) are difficult to predict and may lead to an overly conservative or overdesigned treatment system.

As it unlikely that pilot-scale tests will be conducted, it is highly recommended to conduct some bench-scale testing on the raw water sources for the three communities as these tests help confirm membrane performance, operational performance and appropriate sizing of treatment equipment. Typically, it is preferable to complete these tests onsite. However, most membrane manufacturers can provide bench-scale (i.e., jar testing) services at their laboratories. Typically, 15 gallons of water is sufficient to complete these tests.

Bench-scale tests for the three communities are highly recommended as this will help provide information for the following:

- Optimal coagulant type (alum, PACL, ACH, ferric coagulants), estimated coagulant dose and flocculation time
  - Provides insight on associated impacts on membrane operation (flux requirements, membrane fouling, frequency of backwash, chemical cleaning, waste stream characteristics)
    - a practical upper limit for direct coagulant dosing on membranes is in the range of 40 mg/L of coagulant (AWWA, 2016).
  - Confirms sizing requirements of upstream contact tank/DAF
- Target pH for coagulation
  - Confirms if pH adjustment is required
- Impacts on alkalinity and downstream corrosion potential of treated water
  - Confirms if corrosion control measures such as calcite filtration or pH/alkalinity adjustments are required and to what extent
- Impacts of iron and manganese
  - Confirms required oxidation time for iron and manganese and associated impacts on membrane operation.

- Helps assess and optimize oxidant dosing to minimize DBP formation

Additional Water Quality Sampling

Historical water quality sampling is limited and there is not a strong understanding of seasonal water quality and quantity trends. Additional sampling would be beneficial – recommended sampling includes:

- *Arctic Bay*
  - To investigate potential saltwater intrusion, an online probe could be used to measure conductivity readings at different depths of the lake
  - Seasonal UVT values for all water sources – sizing and optimization of UV units to ensure disinfection requirements are met throughout the year
  - Corrosion testing at the household level to confirm mitigation actions

6 Discussion and Treatment Train Recommendations

6.1 NWT/MACA Membrane Experience

A number of communities in the NWT have recently installed ultrafiltration membrane plants. Based on the SWTT reports and recent discussions with the NWT-MACA, some useful commentary on these systems is included below:

- Ultrafiltration is current standard for NWT community water treatment
    - Most samples exceeded the loading threshold noted in the SWTT reports of 2.0 mg/L for organics with no apparent issues.
- Membrane filtration only used for lake or reservoir raw water sources – which reduces the risk of exposure to high turbidity events associated with spring runoff periods
    - More predictable raw water quality and reduce risks for membrane operations – reservoirs are filled during low river turbidity periods
- NWT membrane plants use submerged style membranes (manufactured by Suez), which are contained in a tank where water is fed and pulled through the membranes under vacuum
- NWT uses Suez manufactured membrane packaged systems. The Z-Box systems are the preferred membrane package and the NWT/MACA has not expressed any concerns based on their current experience
    - Suez's ZeeWeed 500/1000 membranes are intended for use in high-solids application without upstream clarification
    - Some older membrane systems manufactured by PALL (pressurized membranes) – the NWT did not indicate any issues with the PALL systems
    - Membrane suppliers are required to provide support and site visits for 2-3 years after the plants were commissioned (typically 3 times per year)
- All NWT plants have the ability for coagulation addition. However, only two of the existing plants use coagulation. These two plants use coagulation solely for DBP control and inject a constant year-round dose.
    - No significant operational issues to note
    - One plant overdosed coagulant, but the membranes were successfully cleaned with no permanent fouling effects
- An in-line cone-bottom contact tank upstream of the membranes is a standard design requirement for all NWT membrane plants – they provide some contact time for flocculation (typically between 10-20 minutes), and solids that settle can be pulled from the tank bottom (although these tanks are not designed for optimal clarification)
    - the contact tanks were installed to help deal with seasonal high turbidity (reservoir filling and runoff events) and future changes in raw water quality – to date, most plants do not run the contact tanks on a regular basis as their membrane plants have been operating performing well using direct filtration.
- Chemical enhanced backwash (CEB) using hypochlorite is not used at NWT plants – only use hydraulic backwash and regular Clean-in-Place (CIP)
    - Cleaning chemicals are added directly to the membrane tank for submerged membranes
    - NWT plants typically perform chemical membrane cleaning 3-4 times a year, and no significant membrane fouling issues have been noted.

- Periodic membrane chemical cleaning (CIP) is not automated – CIP is done using a regional/MACA operator support. CIP normally done 3 or 4 times a year.
- CIP waste streams are de-chlorinated and pH neutralized in a waste tank and then hauled to a lagoon facility

- NWT has a dedicated in-house support team that travels for training and operational support (circuit rider program) – support is most needed for CIP and membrane repairs

6.2 Climate Change Impacts on Water Quality

Potential Impacts on Water Quality

High Arctic freshwater lakes are strongly influenced by the presence of ice cover and permafrost. Arctic regions are undergoing rapid climatic change and models have predicted increased precipitation and temperatures that will alter surface runoff patterns. Models have predicted precipitation increases between 7.5-18.1% in the Arctic, mostly in autumn and winter. Increases in summer temperatures may lead to autumn precipitation falling as rain instead of snow, which may shift the snowmelt patterns that many Arctic communities rely on. Warmer springs will also lead to increased flows during the snowmelt and create more expansive and turbid flows (Roberts et al., 2017).

From a water quality perspective, permafrost thaw has significant effects of the transportation of previously immobile ions in the permafrost layer. In non-permafrost watersheds, sediment transportation is typically related to rainfall and overland surface flows. In Arctic watersheds, the hydrological regime is not the dominant factor of sediment transport – the rate of sediment transportation is largely affected by summer thaw rates in the active layer (Jolivel and Allard, 2017). Additionally, summer rainfall events that occur later in the season may lead to increased sediment transportation as the seasonal thaw is deepest at this time which correlates to the maximum flushing of sediment across a watershed (Roberts et al., 2017). Permafrost degradation may lead to increased erosion events such as slumps or landslides that create a large volume of sediment. This combined with increased precipitation and higher flows during the freshet snowmelt due to increased ambient temperatures can carry large amounts of sediment into downstream lake systems. Syvitski (2002) estimated that for every 2 °C warming there will be a 22 % increase in the amount of sediment carried by rivers. For every 20 % increase in discharge there will be a 10 % increase in sediment load.

Typically, the impact of sediment transportation into lakes is most apparent for smaller lake systems compared to larger systems due to the difference of volumes and turnover. Based on bathymetric information of the existing reservoirs, the communities currently most at risk of increased raw water turbidity would be from highest to lowest, Grise Fiord, Pond Inlet, and Arctic Bay.

Water Treatment Considerations

Although particle/turbidity removal by membrane filtration is independent of raw water quality, operations and productivity can be negatively impacted by increases in raw water turbidity.

Risk mitigation options for high sediment and turbidity events include:

- Using a raw water reservoir (Arctic Bay)
- Designing a more conservative membrane and filtration system
- Adjustments in membrane operation during the high turbidity event including reducing the membrane flux rate (i.e., production rate), increasing the backwash rate and performing more frequent clean-in-place or chemical washes

- Inclusion of an upstream solids-removal step (DAF) or buffer tank

Raw water will be pulled from the reservoir (Marci Lake), which will help reduce high turbidity loading. Additionally, membrane manufacturers have also noted that raw water operational ranges that are capable of handling turbidity peaks in the 100-400 NTU range without detrimental impacts.

It is anticipated that using a more conservative membrane design and adjusting membrane operation without an upstream DAF step during high turbidity events will be sufficient in handling these most-probable events over the design period. The inclusion of a contact tank (in-lieu of the DAF) will help provide some surge volume and may provide some limited upstream solids removal. Based on discussions with the NWT, the contact tank was built using typical polyethylene containers with custom made stands. The capital cost for one of these tanks was under $5,000. Operational adjustments could include reducing the membrane flux rate, increasing the backwash rate and performing more frequent clean-in place or chemical washes. It should be noted that these approaches are typically validated through pilot testing.

However, the uncertainty of climate change and potential magnitude of these impacts carries some significant risks that need to be confirmed with the GN. If it determined that the level of acceptable risk requires some upstream solids removal (DAF), the DAF can be provided in-lieu of the contact tank. The inclusion of the DAF would increase the complexity of the treatment operation and increase the equipment and O&M costs. Based on the SWTT (Phase 6) cost estimate, the budgetary capital cost for a DAF unit (sized for a population of Pond Inlet) would be approximately $275,000.

6.3 Proposed Treatment Trains

6.3.1 Overview

Arctic Bay

Based on the available information, the most preferred treatment train at Arctic Bay is Trains #3a. However, to mitigate uncertainties with potential climate change impacts that include increased turbidity and organics loading, the inclusion of a DAF (Train #4) is also an appropriate option but adds operational complexity and costs.

- *Train # 3a: Membrane Filtration (UF), no solids removal with contact tank*

Screening → Coagulation → Contact Tank → Membranes (UF) → UV → Chlorine

- *Train # 4: Membrane Filtration (UF) with solids removal (DAF)*

Screening → Coagulation → Solids Removal (DAF) → Membranes (UF) → UV → Chlorine

All trains are capable of exceeding the 0.1 NTU filtered water turbidity requirements and log removal requirements for viruses (4.0) and protozoa (3.0).

It is expected that a constant dose of coagulant (established to reduce DBP precursors) will be used. Routine jar testing by operators or optimization of treatment performance during operation of the new WTPs is not expected. **However, as described in the previous sections, bench-scale testing to confirm pre-treatment requirements and impacts on membrane operations is highly recommended.** This will help confirm coagulation/flocculation requirements, optimize the sizing of the upstream equipment and confirm ancillary processes such as pH adjustment and corrosion control measures.

6.3.2 Proposed Treatment Train – Arctic Bay

The most preferred treatment train is Train #3a. However, further discussions with the GN-CGS about including a DAF (Train #4) will be required to confirm acceptable risk-levels. Trains #3a and 4 are essentially the same train with the difference being either the inclusion of an upstream contact/buffer or DAF tank.

The trains include chemical injection points for coagulant, pH adjustment, pre-oxidation (provisional as-required), auto-backwash inlet strainer (200-500 microns), contact zone and tank (or DAF tank), membrane filtration train (UF) with additional spare trains, duty and standby UV reactors, hypochlorite injection, and sufficient treated water reservoir volume to accommodate the required CT for virus inactivation.

Disinfection will be accomplished in two ways. The primary method will be accomplished using Sodium/Calcium Hypochlorite and the secondary will be achieved through Ultraviolet disinfection. The hypochlorite will have two mixing vessels, one for batch mixing and the second to act as a day tank for the blended chemical to be supplied out of. Both small tanks will be equipped with mixers to keep the hypochlorite in suspension. The ultraviolet (UV) configuration will be such that 2x100% treatment will be possible during the highest flow and lowest UVT (based on the worst-case raw water ultraviolet transmittance). The 2 units will have the ability to operate in either series or parallel as this is the most robust approach. It is not recommended to cycle them with a PLC as this overcomplicates the system and does not provide a significant savings in energy costs. As discussed previously, additional sampling throughout the year to characterize seasonal raw water UVT trends is recommended.

As noted in the SWTT, the train will be designed to allow for varying coagulant contact time and mixing using a combination of piping manifolds and a contact tank. An inline static mixer will be used upstream of the contact time to minimize additional mechanical mixing and energy costs. The contact tank design will be dependent on whether a pressurized or submerged ultrafiltration is used. If a pressurized UF unit is preferred, the contact tank will be pressurized from the raw water intake pumps to minimize additional pumping. If a submerged UF unit is preferred, the contact tank can be elevated (and open to atmospheric pressure) to allow gravity-flow into the submerged UF tanks.

Turbidimeters will be provided on the discharge of each membrane module and an online-chlorine analyzer will monitor free chlorine residual in the treated water. The WTP will turn on and off based on water levels in the treated water storage tank. Backwash from the membranes will be sent to a waste holding tank, which will be periodically trucked to a disposal location (lagoon). It is expected that CIP maintenance using sodium bisulfite (SBS) and citric acid will take place at least once every 1-3 months.

The membrane filtration train should be designed to include at least one redundant membrane train (N+1) so that the plant can meet daily production with any one train in backwash or offline. The inclusion of a few additional membrane modules is insignificant to the cost of the overall treatment system. The membrane trains will include differential pressure transmitters and flow meters on the inlet of the filtrate lines. PVDF is the preferred membrane material due to its superior characteristics related to chemical tolerance, fouling resistance and cleanability.

Add-ons for corrosion control (calcite filter or direct chemical addition) and fluoridation skids can be added onto the treatment train as required following discussions with the GN-CGS.

The schematic for the preferred treatment train for Arctic Bay (Train#3a) is shown below.

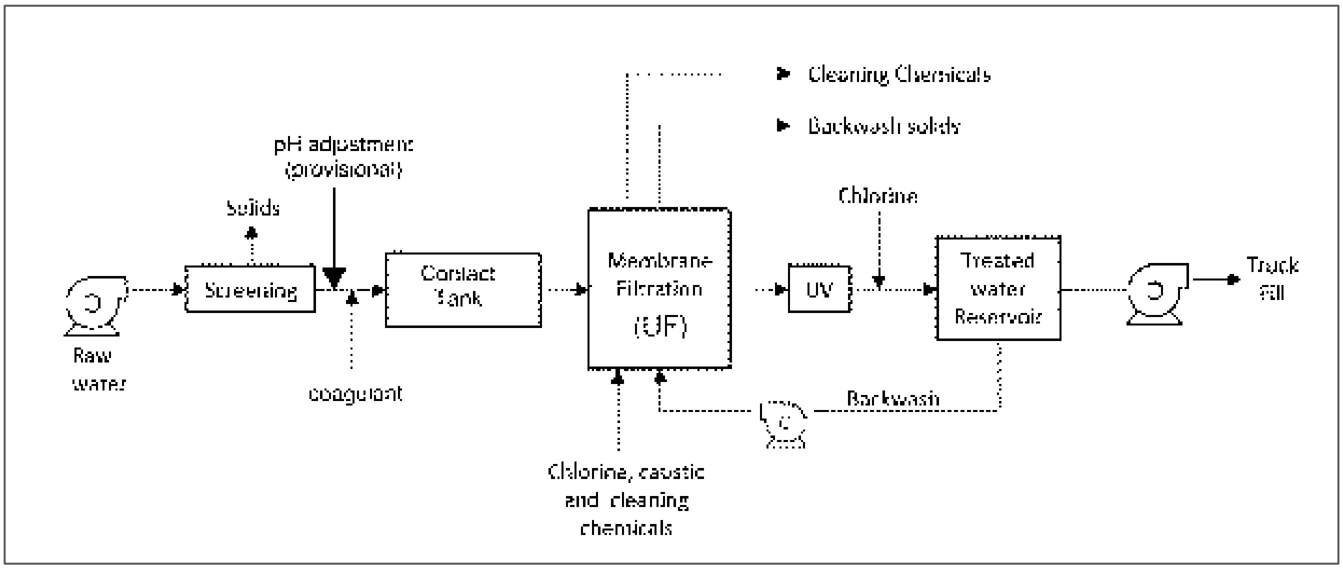

Figure 6-1: Proposed Treatment Train (Arctic Bay)

7 Design and Service Conditions

7.1 Projected Populations, Historical Water Use and Design Water Demands

Population projections have been provided using information prepared by the Nunavut Bureau of Statistics (2014). Non-residential water usage by a community tends to increase with increases in the population. To determine the theorical total community water usage, the Residential Water Usage (RWU) is adjusted based on population to provide a Total Water Usage per Capita (TWUC). The Total Water Usage Per Capita, including residential and non-residential activities is estimated based on the equations in Table 7-1.

Table 7-1 – Theoretical Total Community Water Usage (TWUC) Formula

Community Population	Total Water Use Per Capita (TWUC)
0-2,000	RWU x (1.0 + 0.00023 x Population)
2,000 – 10,000	RWU x [-1.0 + {0.323 x Ln(Population)}]

* RWU assumed to be 90 lpcd as per the Good Engineering Practices guidelines

Annual historical water use records were reviewed between 2008 to 2020 to determine the actual average recorded daily demands. For Arctic Bay average recorded daily demand between 2008-2020 was 77 lpcd. Full theoretical water calculations and historical water use information is provided in Appendix A.

Water use in northern contexts is sensitive to perceptions and reliability of water treatment and delivery – as the current water treatment plants have had challenges with delivery delays and capacity issues, it is likely that residents have consequently moderated their water use. With a new, more efficient system, it is expected that community water use will rise and future projections should take this into consideration.

The 2020 Nunavut Draft Guideline Document "Water Treatment Plant Design" states a minimum per capita average day water consumption rate of 120 litres per capita per day (lpcd) for water treatment plant design for truck fill communities. Table 7-2 compares theoretical TWUC for each community with actual historical water use. From this comparison Table 7-2 also presents the proposed design average demands.

Table 7-2 – Projected Population and Water Demands

Parameter	Arctic Bay
Population (2023) *	956
Theoretical TWUC (2023)	110 lpcd
Population (2043) *	1,184
Theoretical TWUC (2043)	115 lpcd
Actual Water Use (2008-2020)	76
Design Consumption Rate	**120 lpcd**

* *Population projections and projected growth rates based on data and projections from the Nunavut Bureau of Statistics (2014 and 2021), with regression equations extended from 2035 to 2043 as required*

7.2 Peaking Factors

Peak day demands are calculated using the proposed design daily water demand value of 120 lpcd, multiplied by a peaking factor.

Peaking factors can vary community-to-community and trucking patterns can impact the maximum day factor if hauls are not balanced throughout a week. The combined peaking factor will be a combination of the day demand factor times the truck delivery factor – these calculations are shown in Table 7-3 below.

Table 7-3 – Peaking Factor Calculation Based on Truck Delivery Schedule

Trucking Schedule	Day Factor*	Trucking Factor	Combined Peaking Factor
1 day/week	1.5	7/1 = 7	**10.5**
2 day/week	1.5	7/2 = 3.5	**5.3**
3 day/week	1.5	7/3 = 2.33	**3.5**
4 day/week	1.5	7/4= 1.75	**2.6**
5 day/week	1.5	7/5 = 1.4	**2.1**
6 day/week	1.5	7/6 = 1.17	**1.8**
7 day/week	1.5	7/7 = 1	**1.5**

** Day Factor = 1.5, as noted in the Good Engineering Practices (2017) and MACA Water and Sewage Facilities Standards and Criteria (1993)*

The SWTT (Phase 4) noted a peak day peaking factor of 2.5 to determine peak day demand. This is appropriate, assuming that trucking deliveries occur 5 days per week in the community. Even if truck deliveries are more frequent, this conservative factor provides some buffer if higher growth rates are experienced in future years.

7.3 Firefighting Flows and Associated Requirements

Per the Good Engineering Practice guidelines, to provide sufficient water supply for fire flow, either a minimum storage volume of 60 m^3 can be provided for firefighting purposes, or a raw water bypass of the water treatment plant could be used. Likewise, the NWT Fire Marshal requires a minimum firefighting flow of 1000 L/min for 60 minutes. To reduce onsite storage and heating requirements, water used for firefighting purposes will be provided using a bypass of the water treatment plant, so that trucks can be filled through truck fill arms at a minimum rate of 1000 L/min. This eliminates the need for additional onsite firefighting storage.

As such intake pumps will be adequately sized to deliver the emergency bypass rate of 1000 L/min or the peak day design flow for the water treatment plant if it exceeds 1000 L/min. Intake pumps should also have the capability to efficiently run at design flows which are less than 1000 L/min through the use of a variable frequency drive (VFD).

Per the SWTT Phase 4 report, raw water bypassing the water treatment plant for firefighting purposes will be chlorinated. This is consistent with Good Engineering Practice Document (2017) and the approach taken in the NWT, which states that chlorination be maintained in cases where water used for firefighting purposes bypasses the WTP. As such an injection point will be incorporated that will allow chlorination while filling a truck from the bypass.

These approaches are consistent with what is used by the NWT and is deemed as an appropriate for firefighting flows/storage. **However, preference for firefighting requirements are to be confirmed by the GN-CGS.**

Regarding logistics of using the bypass to fill trucks, it has been noted that most communities have a dedicated person on site each day, but not at all hours of the day to monitor and unlock the plant if firefighters need access to the WTP. Thus, it may be beneficial to consider providing firefighters easy access to initiate the bypass such as a button in a locked box (minimal coordination required for WTP operators). Note that firefighting requirements for the community are site-specific and are to be confirmed with the Fire Marshall and/or GN-CGS.

7.4 Peak Demands and Design Flows

Water treatment facilities are to be designed to meet the maximum day demand under the maximum combination of flow and worst raw water quality conditions.

Overall, the treatment process will be a once on a day and once off a day operation, with ~12 hours of continuous run time. A variation of this would be continuously operating the plant (24 hours of run time), with a reduced flow during off-peak hours. This variation would be integrated into the design and could potentially be used during periods of high demand or at the end of the design life. This operational sequence is preferred for chemical addition systems and media filters as they can operate at sustained flowrates for a duration and not have on/off pressure spikes. This will also allow any data to be gathered (i.e., chlorine residuals, turbidity, differential filter pressure, etc.) to be consistent and any changes over time will be noticeable. This is not the operational method for the potable water storage tank operation, as there will be continuous recirculation of the water, continuous heat addition (as required) and continuous free chlorine measurement.

Note that the SWTT (Phase 6) noted that design treated water production must be achieved in no more than 18 hours of service. However, a 12-hr operational time is recommended to reduce treated water storage requirements.

Design flows for the proposed WTP are presented in Table 7-4.

Table 7-4 – WTP Design Flows

Parameter	Arctic Bay
Population (2043)	1,184
Average Daily Demands (lpcd)	120 lpcd
Average Daily Demands (L/day)	142,080 L/day
Peaking Factor	2.5
Peak Daily Demand (L/day)	**355,200 L/day**
WTP Design Flows (L/min) – 12 hr operation day	**493 L/min**
Fire Flow – via bypass (L/min)	1000 L/min
Truckfill Flow (L/min) per Arm	1000 L/min

7.5 Trucking Schedules and Number of Trucks

Based on available information, the current trucking and future trucking demands have been estimated. Calculations have been provided in Appendix D.

Arctic Bay

- 2019 (current trucking schedule)
  - 2 trucks at 12,000 L capacity (1 or 2 duty)
  - 6 days/week, 8 hours/day
  - Approx. 9 total return trips per day
- 2043 (future trucking schedule)
  - Based on 6-day delivery – approx. 14 loads/day
    - **4 trucks (12,000L capacity/truck) are required to meet demands in 2043**

7.6 Number of Truck Arms

According to the Good Engineering Practices, where there are more than two hauling trucks in use, a maximum of 20 minutes between trucks is suggested. Based on capacity and anticipated truck delivery schedules, the number of truck arms required at each community is:

- Arctic Bay – 2 truck arms

At Arctic Bay, based on the size of the community and water demands, it may be more economical to provide only 1 truck arm. However, according to the SWTT report (Phase 5), the GN-CGS has a preference to provide two (2) truck arms to provide additional redundancy and to permit simultaneous loading of two trucks. This preference is to be confirmed with the GN-CGS.

The same number of active (duty) truck fill pumps, plus one for redundancy (standby) should be provided for each truck arm. All truck fill pumps are to be capable of providing pumping rate of at least 1000 L/minute.

7.7 Number of Water Intakes

The NWT recommends single intakes due to fouling in redundant intakes related to sedimentation from lack of consistent operation of the redundant intake. Typically, the NWT found that a single intake with a spare pump and heat tracing equipment on hand is adequate. As per the Good Engineering Practice guidelines, a single intake with a spare pump is sufficient except in cases in which intakes are vulnerable or difficult to access for repairs, or where frequent pump breakdowns are anticipated (such as for sources with high sediment load), or if the facility requires additional firefighting flows.

Per the SWTT Phase 4 report, it was indicated that the GN-CGS preferred dual intakes to provide redundancy and noted past issues with the intakes and intake pumps at Baker Lake, Arviat, and Pond Inlet. With only one intake there is a risk of prolonged water interruptions. Main issue with maintaining dual intakes is sedimentation and keeping both intakes clean and operational. However, this risk can likely be managed by cycling the intakes to manage sedimentation risks and providing spare pumps and additional freeze protection equipment. Additionally, water purge (ability to backflow water down the intake pipe) and air scour/burst systems for screen cleaning and ice mitigation are to be incorporated into the design as these are important process to help manage sedimentation and deep ice/freezing issues with the intakes.

With discussions with the GN-CGS, for a dual intake system, a total of three intake pumps are to be provided (two duty, 1 shelf back) and should have the capability to efficiently run at design flows which are less than 1000 L/min through the use of a variable frequency drive (VFD).

7.8 Intake Freeze Protection

Most northern communities use heat trace for intake freeze protection. Alternatively, some communities use tempered water (25°C) down the carrier pipe for freeze protection. However, the tempered water approach is not recommended as it requires an additional boiler unit with adequate storage and the use of unchlorinated water.

Dual heat trace (duty/standby) on each intake is recommended, along with heat trace controller fault alarms to indicate a failure of the duty heat trace and initiate the standby heat trace if the temperature falls below the setpoint. The addition of an air scour system can help mitigate ice/freezing risks if the intake is susceptible to deep ice. This approach has been used at Rankin Inlet.

7.9 Raw Water Storage Requirements

Raw water storage is required in Nunavut communities to provide a supply of water during the overwinter period (winter, spring breakup or fall freeze up). Based on the Hydrology and Water Balance assessment conducted by EXP (2021), the project will advance on the basis of the following raw water storage methods:

- Arctic Bay
  - Will utilize the existing natural lake (Marcil Lake) for raw water supply over the winter
    - Anticipated total winter storage (2043) estimated at approximately 14,500,000 m^3
  - No capacity upgrades are required to the community needs over the 20-year design horizon

7.10 Treated Water Storage Requirements

Treated water storage is a very important element of this project, as storage permits the activities of truck loading to be separate from treated water production. The separation of these processes will permit the filling of trucks at a rate that is independent of rate of production of treated water. Separation of the processes also provides the opportunity to treat water over the full working day, instead of the practice (used at existing truckfill plants) that entails a start and stop of the treatment process for each truck.

Storage volume requirements and criteria are detailed in Table 7-5 below.

Table 7-5 – Storage Volume Requirements and Criteria

Storage Needs	Storage Requirements
Firefighting storage	Not provided as firefighting flows will be provided via. a separate bypass (at a rate of at least 1000 L/min for 60 minutes). Alternatively or as backup, a fire storage volume of 60 m^3 can be provided. At Grise Fiord, as the raw water annual supply refilling process is a temporary operation that takes place over the span of a few weeks, firefighting flows will be provided in the treated water storage volume (60 m3) and subsequently delivered with the truckfill arms at the GN standard rate of 1000 L/min. The requirement to provide an additional redundant bypass can be further explored in the detailed design phase. Note that firefighting requirements for the community are site-specific and are to be confirmed with the Fire Marshall and GN-CGS.

Equalization (EQ) storage	To allow for fluctuations when demand exceeds supply and in situations where process flow rates are lower than the required truck fill rates. The Good Engineering Practice recommends an equalization storage equal of: (Projected peak daily demand) – (WTP design production for 8 hours)
CT Volume	Chlorine contact time (CT) volumes are provided in a separate tank ahead of the EQ tank. This is a fixed volume which is not to be included in the EQ storage. Requirement for disinfection by chlorine is 4-log virus inactivation with a CT value of 12 mg/L· min at 0.5°C and pH 6-9. A free chlorine residual of 1.0 will be used for CT calculations and assumes that the storage tank will have a baffling factor of 0.1. This yields a CT time of 120 minutes. CT volume will be calculated for peak flows. Note that the SWTT reports noted a tank baffling factor of 0.3. However, based on our experience in the operation and construction of similar tanks, a baffling factor of 0.3 is likely not achievable.
Emergency storage	To provide a continued supply during emergencies or shutdown/maintenance activities. The Good Engineering Practices recommends in-town storage if the water source is >3.2km from the community and a minimum of 30% of average day demand. Emergency storage requirements to be confirmed with the GN-CGS - Arctic Bay – the new WTP will likely be >3.2km from the community. However, the existing WTP is approximately 9km from the community and has a well-maintained road (up to the Airport). Thus, additional emergency storage may not be required. The community council noted that around 2 days are lost a year due to inclement weather. This to be confirmed with GN-CGS.
Plant Use storage	Volume required for treatment plant use such as backwashing filters, chlorine analyzers, turbidity meters and housekeeping uses. This volume should provide a minimum 2 membrane train backwashes. It is recommended that this volume be provided within the main treated water storage tank as a dedicated backwash tank is another asset to maintain and operate. This plant-use storage volume has been conservatively estimated at 10% of WTP design production.
Dead Volume	Volume of the tanks that are not useable or accessible due to elevation and freeboard of the nozzles/drains. The treated water storage tanks will be elevated and outlets will be installed at the bottom of the tank to maximize the useable volume. Thus, no dead volume has been included in the treated storage volumes.

It is proposed that the treatment process will turn on a day and once off a day operation, with approx. 12 hours of continuous run time at the end of the design life (2043) – at the beginning of the design horizon (2023), the plant would run for approx. 7 hours/day to meet the production needs of the community. This operating philosophy is to be confirmed with the GN-CGS.

Table 7-6 –WTP Design Flows and Storage Volume Requirements

Parameter	Arctic Bay
WTP Operational Hours/day	12 hour
Average Daily Demands (L/day)	142,080
Peak Daily Demand (L/day)	355,200
Design WTP Flow (L/min)	493
Truck Arms	**2**
Peak Flow for CT Calculation (L/min)	**2,000**
Firefighting Volume (m^3)*	-
Equalization Volume (m^3) **	**118**
CT Volume (m^3) ***	**240**
Emergency Storage (m^3) $^{+}$	-
Plant Use Storage (m^3) $^{++}$	36

Dead Volume (m^3) +++	-
Total Treated Storage Volume (m^3)	**394**

* *Firefighting volume provided through bypass or 60m³*
** *Good Engineering Practices equalization volume = (projected max daily demand) - (8 hours of WTP design production)*
*** *Contact time = 120 minutes using CT value = 12 mg/L· min, free chlorine residual of 1.0 mg /L, baffling factor of 0.1*
\+ *Assume no emergency storage required*
++ *Assume plant use = 10% of design WTP flow*
+++ *Assume no dead volume*

Note that storage volumes will be refined once treatment processes and equipment have been confirmed. This includes analyzing tank operating levels to confirm daily trends based on required CT times and truck withdrawal rates.

7.11 Process Wastewater Storage

It is recommended to size the working wastewater volume (mainly filter backwash water) to hold a volume of no less than 7 days to account for trucking disruptions. The volume of process wastewater has been conservatively estimated at 10% of the WTP design flow to account for UF membrane backwashing and additional CIP and process upset waste volumes, and provisional calcite filtration processes (periodic backwashing). **Wastewater storage volumes will be refined once treatment processes and equipment have been confirmed.** Preliminary estimates of process wastewater volumes are presented in the table below.

Table 7-7 – Process Wastewater Storage Volume Requirements

Parameter	Arctic Bay
Process Wastewater Storage (m^3) for 7 days	249

7.12 Tank Freeze Protection

All storage tanks will require insulation and heat addition for freeze protection. Freeze protection for tanks may include electrical, hydronic heat tracing or circulation of heated water. As noted in the SWTT reports, the GN-CGS has noted that recirculation is preferred with additional heat tracing on nozzles, vents and piping.

Recirculation will be used as freeze protection for all treated water storage (and raw water at Grise Fiord). Immersion heaters will be used for freeze protection for wastewater tanks.

Appropriate operating levels, freeboard and dead volumes to account for immersion heaters, inlet and outlet elevations are to be considered when confirming the dimensions of the storage tanks.

7.13 Redundancies vs Spares

During the SWTT development, the GN-CGS noted the following preferences regarding redundancies vs spare parts. These items will be incorporated into the schematic design following confirmation from the GN-CGS.

- Duty and standby pumps sized at 100% for reliability, especially for remote communities where long repair times could result in prolonged water shutdowns
    - Intake pumps will be redundant but also recommend shelf spares (one spare for each intake)

- Membrane train – recommendation to include a minimum of one extra fully redundant train (N+1 @100% capacity). For additional redundancy, a N+2 membrane train could be incorporated
- UV system to have 2 units (both @ 100%) that can be configured either in parallel or series
- Inlet basket strainers – 2 units @ 150%
- Contact tank – shelf spare for compressor/aerator equipment
- Chemical feed pumps, recirculation pumps, and domestic pumps should all have redundant units
    - There are up to 3 chlorine injection points (pre-oxidation, filtered water, fire bypass)
    - Recommend having 1 duty + 1 standby for each point
- Truck fills (2 truck fill arms) will have 2 duty + 2 standby truck fill pump
- Intake pumps (2 duty intake pumps, 1 shelf backup)

7.14 Building Components and Ancillary Equipment

Description and footprint allowances for various building components are provided in Table 7-8. These components will be developed in the schematic design.

Table 7-8 – Building Components and Ancillary Equipment

Component	Description
Building Construction	As noted in the SWTT Phase 5 report, GN-CGS prefers the use of a modular (prefabricated) building over a sea container-type building
Power and Backup Supply	Power supply for each WTP to be coordinated with the local electrical supplier. A diesel-powered generator will be included with each WTP and located in a separate, heated enclosure. Fuel tanks provided for day storage and bulk storage of diesel and shall be installed on containment pads to prevent the accidental release of diesel.
Heating Systems	Typically includes boiler, day tank, ducts, vents, piping and instrumentation. As noted in the SWTT Phase 5 report, the GN-CGS has requested that boilers be located in a separate, dedicated room Minimum space allowance: 10 m^2
Chemical (Chlorine Storage Area)	Separate area for mixing and pumping equipment for chlorine and other chemicals. Storage of chemical supply for a minimum of one year. Room to be ventilated and designed to operate under negative pressure, so that atmosphere of the room is exhausted to the outside and will not migrate to other areas of the building Minimum space allowance: 6 m^2
Office / Laboratory	Combined space for office and lab. The space to be separated from the process area with a door and viewing window. Minimum space allowance: 6 m^2
Washroom	The WTP to include a washroom with toilet and sink. Waste from the washroom will be transferred to the main waste tank or to a secondary waste tank. Minimum space allowance: 4 m^2

8 Summary and Conclusions

8.1 General Recommendations for All Communities

A summary of the treatment conclusions and recommendations for next steps include:

- The proposed WTP at Arctic Bay will continue to use Marcil Lake as the raw water source. Based on available water quality information, the proposed treatment train at Arctic Bay is:
    - *Train # 3a: Membrane Filtration (UF), no solids removal with contact tank*

Screening → Coagulation → Contact Tank → Membranes (UF) → UV → Chlorine

- The proposed multi-barrier process train is capable of exceeding the 0.1 NTU filtered water turbidity requirements and log removal requirements for viruses (4.0) and protozoa (3.0).

- All membrane manufacturers noted that a DAF for upstream solids removal would not be required for the expected water quality over the design period.
    - Membrane manufacturers have noted the following operational feed water characteristics for UF membranes

Table 8-1: Membrane Operational Feed Water Characteristics

Feedwater Parameter	Ultrafiltration Membranes +
Turbidity (NTU)	< 30 - 50 , max 100 – 400 (pressurized), max 500 (submerged)
TOC (mg/L)	< 10, max 40 – 100

\+ *Ultrafiltration membranes – SUEZ, Dupont/Memcor, Toray*

-
    - Inclusion of an upstream contact tank is preferred – this tank helps provide the required flocculation/reaction times upstream of the membranes, provides additional buffer volumes, provides some upstream solids settlement, and the mixing (by air) can aid the pre-oxidation process
    - In the NWT, contact tanks were installed to help deal with seasonal high turbidity (reservoir filling and runoff events) and future changes in raw water quality – to date, most NWT plants do not run the contact tanks on a regular basis as their membrane plants have been performing well using direct filtration. The contact tank was built using typical polyethylene containers with custom made stands. The capital cost for one of these tanks was under $5,000
    - However, acceptable risk tolerance for potential climate change impacts (high turbidity) events should be confirmed with the GN-CGS to determine whether a DAF process is required (Train #4). Budgetary capital cost for a DAF unit (based on the SWTT reports, sized for a population similar to a community like Pond Inlet) would be approximately $275,000.
    - The contact tank design will be dependent on whether a pressurized or submerged ultrafiltration is used. If a pressurized UF unit is preferred, the contact tank will be pressurized from the raw water intake pumps to

minimize additional pumping. If a submerged UF unit is preferred, the contact tank can be elevated (and open to atmospheric pressure) to allow gravity-flow into the submerged UF tanks.

- Submerged vs. Pressurized Membranes – The NWT has mentioned the widespread use of submerged UF membranes for their new WTPs. In a submerged system, the membranes are immersed in a tank and the water is drawn through the membrane via a vacuum pump. In a pressurized system, feedwater is forced through the pores with a pressure pump. Both systems produce high-quality water and are both widely used technologies. For UF systems, both submerged and pressurized membranes are available.
    - Based on the community's raw water quality (relatively low turbidity and organics), relatively low production flows, and discussions with membrane suppliers, both submerged and pressurized systems are suitable.
    - An advantage of using a pressurized membrane is that this would minimize additional pumping needs within the treatment plant – submerged membranes would break the pressure as the tanks are in an open tank. For maintenance purposes, additional headspace would be needed to access the membranes for a submerged system (membranes need to be hoisted out of the tank). Further discussion is required with the GN-CGS to confirm membrane preference.
    - Submerged membranes may be able to handle higher peaks of turbidity (<500 NTU) compared to pressurized membranes (<100-400 NTU). Based on historical and expected water quality, turbidities are not expected to exceed 100 NTU.
    - More suppliers provide pressurized membranes and pricing will likely be more competitive for pressurized membrane systems
    - In the previous SWTT reports, the GN-CGS has noted a preference towards the SUEZ ZeeWeed membrane systems (submerged membrane) – this is to be confirmed with the GN-CGS.

- Recommend conducting bench scale to confirm pre-treatment requirements, potential impacts on membrane operation, sizing of pre-treatment equipment, corrosion control measures and iron and manganese removal methods.
    - Helps determine impact on alkalinity and downstream corrosion potential of treated water
        - Confirms appropriate corrosion control measures such as calcite filtration, pH adjustments or alkalinity additions
    - Helps confirm iron and manganese treatment methods
        - Confirms required oxidation time and estimated removal rates for iron and manganese and associated impacts on membrane operation

- Confirmation of additional treatment processes with the GN-CGS
    - Corrosion control processes (calcite filter or direct chemical addition)
    - Fluoridation addition (if required by communities)

8.2 Additional Water Quality Sampling

Additional recommended sampling includes:

- *Arctic Bay*

- To investigate potential saltwater intrusion, an online probe could be used to measure conductivity readings at different depths of the lake
- Seasonal UVT values for all water sources – sizing and optimization of UV units to ensure disinfection requirements are met throughout the year
- Corrosion testing at the household level to confirm mitigation actions

8.3 Arctic Bay – Service Conditions

A summary of the water treatment objectives and service conditions that will be incorporated into the schematic design for Arctic Bay are provided in the following tables.

Note that storage volumes and service conditions will be refined once treatment processes and equipment are confirmed.

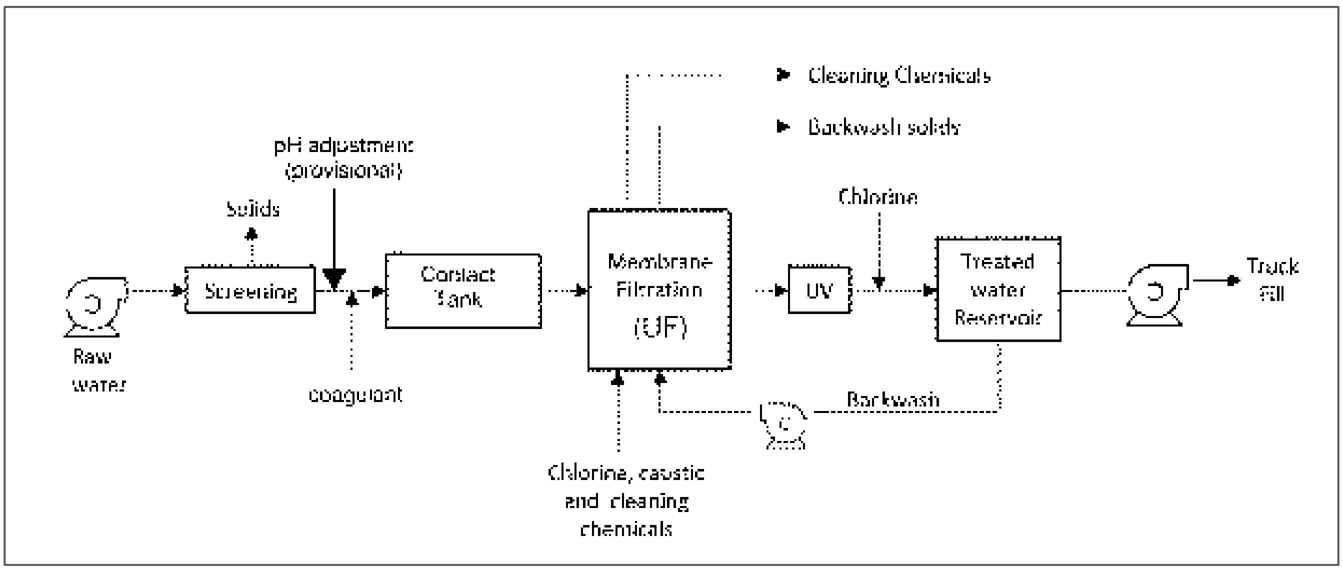

Figure 8-1: Proposed Treatment Train (Arctic Bay)

Table 8-2: Arctic Bay Water Treatment Objectives

Key Parameters	Unit	Source Water	Treatment Objectives
Turbidity	NTU	1 - 5	≤ 0.1 (99% of time) <0.3 (maximum)
Protozoa	Log Reduction	-	At least 3-log (up to 5.5 log)
Viruses	Log Reduction	-	At least 4-log
TOC/DOC	mg/L	1-10	<3 mg/L to reduce DBP formation
TDS	mg/L	8-29	<500
pH	pH units	6.7 - 7.3	7 - 10.5
CSMR*	ratio	1.0 - 2.5	< 0.5
Alkalinity ($CaCO_3$)*	mg//L	8 - 10	$CaCO_3$ > 50 mg/L

** corrosion control requirements to be confirmed with the GN-CGS*

Table 8-3: Arctic Bay WTP Service Conditions

Category	Parameter	Design Input
Population	Population (2023)	956
	Population (2043)	1,184
Demands and Design Flows	Design Consumption Rate	120 lpcd
	Peaking Factor	2.5
	Peak Daily Demand (2043)	355,200 L/day
	WTP Production Time Per Day	12 hours/day
	WTP Design Flow	493 L/min
	Fire Flow Bypass	1000 L/min
	Truckfill Flow (Total for 2 arms)	2 x 1000 = 2000 L/min
Intake	# of Raw Water Intakes	2
	# of Raw Water Pumps	3 (2 duty, 1 spare)
	Intake Freeze Protection	Dual heat trace (duty/standby)
Truck Fill	# of Truck Arms	2
	# of Truckfill Pumps	4 (2 duty, 2 spare)
Contact Tank	Contact Time	10-30 mins depending on required flocculation/coagulation time
Membrane Filtration	# of trains	N+1 or N+2
	Membrane Recovery Rate	>95%
UV	# of UV reactors	2 @ 100% design capacity
Chlorination	CT Time *	120 minutes
Iron and Manganese	Iron and Manganese Treatment	Not required
Corrosion Control	Corrosion Control Treatment	Calcite filter or direct chemical addition 2 duty filters 6ft diameter, 6ft height
Fluoridation	Fluoridation	If required by community
Treated Water Storage	Firefighting Volume	N/A (fire flow provided through bypass)
	Equalization (EQ) Volume	118 m^3
	CT Volume	240 m^3
	Emergency Volume	N/A
	Plant Use Volume	36 m^3
	Dead Volume	-
	Total Treated Water Storage	394 m^3
	Tank Freeze Protection	Recirculation
Wastewater Storage	Wastewater Volume	249 m^3
Raw Water Storage	Type of raw water storage	Existing reservoir (Marcil Lake)
	Capacity upgrade required?	Not required

** Contact Time = 120 minutes using CT value = 12 mg/L· min, free chlorine residual of 1.0 mg /L, baffling factor of 0.1*

9 Legal Notification

This report was prepared by EXP Services Inc. for the account of the Government of Nunavut.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. EXP Services Inc. accepts no responsibility for damages, if any, suffered by any third party because of decisions made or actions based on this project.

Appendix A – Population and Water Demand Projections

1. **Projections for Population and Water Demand**

ARCTIC BAY POPULATION AND WATER DEMANDS

Year	Population	Recorded		Estimated			
		Total Recorded annual demand	Average Recorded Daily demand (lpcd)	RWU (lpcd)	TWU (lpcd)	Estimated daily demand (L/day)	Total Estimated annual demand (L/year)
2009	798	20,982,940	72.0	90	106.5	85,001.8	31,025,672.6
2010	827	21,410,632	70.9	90	107.1	88,587.3	32,334,375.6
2011	868	22,928,176	72.4	90	108.0	93,715.9	34,206,295.0
2012	857	25,145,663	80.4	90	107.7	92,333.1	33,701,579.4
2013	866	27,339,338	86.5	90	107.9	93,464.1	34,114,392.6
2014	864	24,720,907	78.4	90	107.9	93,212.5	34,022,550.5
2015	895	23,678,515	72.5	90	108.5	97,131.2	35,452,894.4
2016	892			90	108.5	96,750.2	35,313,839.4
2017	874	22,673,509	71.1	90	108.1	94,472.2	34,482,365.1
2018	921			90	109.1	100,448.6	36,663,734.9
2019	939	26,793,771	78.2	90	109.4	102,761.6	37,507,993.0
2020	946			90	109.6	103,664.8	37,837,637.8
2021	938			90	109.4	102,653.1	37,468,382.5
2022	947			90	109.6	103,820.0	37,894,292.5
2023	956			90	109.8	105,015.1	38,330,499.5
2024	966			90	110.0	106,193.2	38,760,522.7
2025	976			90	110.2	107,580.8	39,266,975.1
2026	989			90	110.5	109,222.9	39,866,362.2
2027	1,001			90	110.7	110,792.5	40,439,276.5
2028	1,018			90	111.1	113,070.0	41,270,543.5
2029	1,030			90	111.3	114,628.2	41,839,295.8
2030	1,042			90	111.6	116,310.7	42,453,413.3
2031	1,055			90	111.8	117,954.0	43,053,191.8
2032	1,068			90	112.1	119,686.0	43,685,396.3
2033	1,081			90	112.4	121,464.6	44,334,590.1
2034	1,094			90	112.6	123,224.1	44,976,811.1
2035	1,106			90	112.9	124,837.7	45,565,761.7
2036	1,107			90	112.9	125,000.6	45,625,218.1
2037	1,118			90	113.1	126,493.6	46,170,150.5
2038	1,129			90	113.4	127,991.5	46,716,902.4
2039	1,140			90	113.6	129,494.4	47,265,473.8
2040	1,151			90	113.8	131,002.4	47,815,864.6
2041	1,162			90	114.1	132,515.3	48,368,074.9
2042	1,173			90	114.3	134,033.2	48,922,104.6
2043	1,184			90	114.5	135,556.0	49,477,953.8
2044	1,195			90	114.7	137,083.9	50,035,622.5
2045	1,206			90	115.0	138,616.7	50,595,110.7

Appendix B – Water Quality Reporting

1. **Historical Water Quality Summary**
2. **Water Quality Reports for 2021 Sampling**

ARCTIC BAY

HISTORICAL WATER QUALITY SUMMARY

Existing Source (Marcil Lake)

Arctic Bay Water Chemistry								2012	2013	2014	2015		2016	2017		2019	2021	
								August	July	August	February	August	August	March	September	September	September	
Parameters	Units	Canadian Drinking Water Limit (MCL or AO as applicable)	Number of Samples of Raw Water Source	Mean Sample Value	Maximum Sample Value	Minimum Sample Value (for pH)	Design Value (Assuming 1.5 Safety Factor on Max Value, except for pH, UVT and TDS)	Raw Reservoir	Raw Drinking Water	Raw Drinking Water	Raw	Raw	Station DW (ARC-1)	Main Water Source (ARC-1)	Main Water Source	"ARC-1 Raw Water Main Soutce"	Raw Drinking Water (P1 #1)	Raw Drinking Water (P1 #2)
Colour, True	CU	≤15	4	3.75	8		12	8								3	< 2	2
Conductivity	umhos/cm	None	4	34.44	37.75		56.63	37.75								36.00	32.00	32.00
Hardness	mg/L	None	4	13.25	14		21	14								13	13	13
Langelier Index (25C)	No Unit	None	4					-2.62								-3.06	-3.22	-3.23
Langelier Index (60C)	No Unit	None	0															
pH	pH units	7.0-10.5	4	6.905	7.32	6.71	N/A - should be measured in field	7.32								6.87	6.72	6.71
TDS	mg/L	≤500	11	18.409	29		29	18.8	8.0	18.6	29.0	19.0	20.0	23.1	14.0	18.0	17.0	17.0
Transmittance, UV	%T	None	2	94.7	94.8	94.6	94.6										94.8	94.6
Turbidity	NTU	≤1.0	9	1.667	3.3		4.95	2.30			1.40	1.70	3.30	0.30	2.60	0.60	1.50	1.30
Alkalinity ($CaCO_3$)	mg/L	80-100	4	8.75	9		13.5	8								9	9	9
Ammonia (N)	mg/L	N/A	4	0.75333333	2.18		3.27	< 0.01								2.18	0.06	0.02
Bicarbonate (HCO_3)	mg/L	None	2	9	9		13.5										9	9
Bromide (Br)	mg/L	None	2														< 0.4	< 0.4
Carbonate (CO_3)	mg/L	None	2														< 5	< 5
Chloride (Cl)	mg/L	≤250	11	3.482	5.5		8.25	3.70	4.20	2.30	3.90	2.50	2.90	5.00	2.00	5.50	3.10	3.20
Fluoride (F)	mg/L	1.5	11					< 0.1	< 0.1	<0.1	< 0.1	<0.1	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1
Hydroxide (OH)	mg/L	None	0															
Nitrate (N)	mg/L	45	11	0.133	0.2		0.3	0.2	0.2	<0.1	0.100	0.100	0.1000	0.10	<0.1	< 0.1	< 0.1	< 0.1
Nitrite (N)	mg/L	3	5					< 0.1					<0.1		<0.1		< 0.1	< 0.1
Sulfate (SO_4)	mg/L	≤500	11	2.455	3		4.5	3	3	2	3.000	2.000	2.0000	2.00	1.000	3	3	3
Dissolved Inorganic Carbon	mg/L	None	2	3.2	3.2		4.8										3.2	3.2
Dissolved Organic Carbon	mg/L	None	11	1.336	4		6.00	1.00	4.00	1.30	1.30	1.40	1.30	1.20	0.90	0.80	0.80	0.70
Total Carbon	mg/L	None	0															
Total Inorganic Carbon	mg/L	None	0															
Total Organic Carbon	mg/L	None	3	0.833	0.9		1.35									0.9	0.8	0.8
E. coli	MPN/100mL	0	4	4.333	10		15	0								0	10	3
Total Coliforms	MPN/100mL	0	3	13.667	20		30	4									17	20
Aluminum (Al)	mg/L	<0.1	3	0.067	0.09		0.135									0.09	0.05	0.06
Antimony (Sb)	mg/L	0.006	3													< 0.0001	< 0.0001	< 0.0001
Arsenic (As)	mg/L	0.01	8	0.00013	0.0002		0.0003		0.0001	<0.0001	0.0002	<0.0001	<0.0001	0.0001	<0.0001	< 0.0001		
Barium (Ba)	mg/L	2	10	0.030	0.04		0.06		0.031	0.011	0.035	0.028	0.0290	0.0400	0.0160	0.04	0.036	0.036
Beryllium (Be)	mg/L	None	2														< 0.0001	< 0.0001
Bismuth (Bi)	mg/L	None	0															
Boron (B)	mg/L	5	3													< 0.005	< 0.005	< 0.005
Cadmium (Cd)	mg/L	0.007	10						< 0.00002	<0.00002	< 0.00002	<0.00002	<0.00002	<0.00002	<0.000014	< 0.000015	< 0.000015	< 0.000015
Calcium (Ca)	mg/L	N/A	4	2.698	2.92		4.38	2.92								2.62	2.62	2.63
Cesium (Cs)	mg/L	10	0															
Chromium (Cr)	mg/L	0.05	10						< 0.002	<0.002	< 0.002	<0.002	<0.002	<0.002	<0.002	< 0.001	< 0.001	< 0.001
Cobalt (Co)	mg/L	None	2														< 0.0001	< 0.0001
Copper (Cu)	mg/L	≤1.0	7	0.001	0.0015		0.00225	< 0.002					<0.002	<0.002	<0.002	0.0015	0.001	0.001
Iron (Fe)	mg/L	≤0.3	11	0.041	0.095		0.143	0.034	0.063	0.095	0.018	0.028	0.062	<0.005	0.044	0.041	0.029	0.031
Lead (Pb)	mg/L	0.005	10	0.000	0.00175		0.002625		0.00175	0.00003	0.0002	0.00006	<0.00002	0.0000	<0.00002	0.00004	0.00002	< 0.00002
Lithium (Li)	mg/L		0															
Magnesium (Mg)	mg/L	N/A	4	1.608	1.65		2.475	1.58								1.58	1.65	1.62
Manganese (Mn)	mg/L	≤0.02	11	0.001	0.002		0.003	0.002	0.001	<0.001	0.001	0.001	0.002	<0.001	0.001	0.002	0.001	0.002
Molybdenum (Mo)	mg/L		0															
Nickel (Ni)	mg/L		2														< 0.01	< 0.01
Phosphorous (P)	mg/L		0															
Potassium (K)	mg/L		4	0.275	0.3		0.45	0.3								0.20	0.3	0.3
Rubidium (Rb)	mg/L		0															
Selenium (Se)	mg/L	0.05	10						< 0.001	<0.001	< 0.001	<0.001	<0.001	<0.001	<0.001	< 0.001	< 0.001	< 0.001
Silicon (Si)	mg/L		2	0.475	0.48		0.72										0.47	0.48
Silver (Ag)	mg/L	N/A	10						< 0.00002	<0.00002	< 0.00002	<0.00002	<0.00002	<0.00002	<0.00002	< 0.0001	< 0.0001	< 0.0001
Sodium (Na)	mg/L	≤200	4	1.625	1.8		2.7	1.8								1.60	1.5	1.6
Strontium (Sr)	mg/L	7	2	0.006	0.006		0.009										0.005	0.006
Tellurium (Te)	mg/L		0															
Thallium (Tl)	mg/L		2														< 0.00005	< 0.00005
Thorium (Th)	mg/L		0															
Tin (Sn)	mg/L		2														< 0.05	< 0.05
Titanium (Ti)	mg/L		2														< 0.005	< 0.005
Tungsten (W)	mg/L		0															
Uranium (U)	mg/L	0.02	3													< 0.00005	< 0.00005	< 0.00005
Vanadium (V)	mg/L		2	0.0001	0.0001		0.00015										< 0.0001	0.0001
Zinc (Zn)	mg/L	≤5.0	11.0000	0.007	0.007		0.0105	< 0.005	0.007	< 0.005	0.006	<0.005	<0.005	<0.005	<0.005	< 0.005	< 0.005	< 0.005
Zirconium (Zr)	mg/L		0															
Total Dissolved Carbon	mg/L		2	3.95	4		6										4	3.9
Bromodichloromethane	µg/L		2	10	10		15										10	10
Bromoform	µg/L		2														< 5	< 5
Dibromochloromethane	µg/L		2														< 2	< 2
Chloroform	µg/L		2	58	59		88.5										59	57
4-Bromofluorobenzene (SS)	%		1	104	104		156	104										
1,4-Difluorobenzene (SS)	%		0															
Total THMs	µg/L	100	2	67.5	68		102										68	67
Bromochloroacetic Acid	mg/L	0.08	0															
Dibromoacetic Acid	mg/L	0.08	0															
Dichloroacetic Acid	mg/L	0.08	0															
Total Haloacetic Acid	mg/L	0.08	0															
Monobromoacetic Acid	mg/L	0.08	0															
Monochloroacetic Acid	mg/L	0.08	0															
Trichloroacetic Acid	mg/L	0.08	0															
2,3-Dibromopropionic Acid (SS	%		0															

ARCTIC BAY

MARCIL LAKE
SEPT 2021 WATER SAMPLES

CADUCEON ENVIRONMENTAL LABORATORIES
Client committed. Quality assured.

CERTIFICATE OF ANALYSIS

Final Report

C.O.C.: DW 109522 **REPORT No. B21-29978**

Report To:

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Fredericton NB EBB 3Z2 Canada
Attention: Eric Bell

Caduceon Environmental Laboratories
2378 Holly Lane
Ottawa Ontario K1V 7P1
Tel: 613-526-0123
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DATE RECEIVED: 17-Sep-21
DATE REPORTED: 12-Oct-21
SAMPLE MATRIX: Drinking Water

JOB/PROJECT NO.: Arctic Bay
P.O. NUMBER:
WATERWORKS NO.

				Client I.D.	AB-1	AB-2	AB-1-Spike	AB-2-Spike
				Sample I.D.	B21-29978-1	B21-29978-2	B21-29978-3	B21-29978-4
				Date Collected	14-Sep-21	14-Sep-21		
Parameter	**Units**	**R.L.**	**Reference Method**	**Date/Site Analyzed**				
Hardness (as CaCO3)	mg/L	1	SM 3120	20-Sep-21/O	13	13		
Alkalinity(CaCO3) to pH4.5	mg/L	5	SM 2320B	20-Sep-21/O	9	9		
Bicarbonate(as CaCO3)	mg/L	5	SM 2320B	20-Sep-21/O	9	9		
Carbonate (as CaCO3)	mg/L	5	SM 2320B	20-Sep-21/O	< 5	< 5		
pH @25°C	pH Units		SM 4500H	20-Sep-21/O	6.72	6.71		
Conductivity @25°C	µmho/cm	1	SM 2510B	20-Sep-21/O	32	32		
TDS(ion sum calc.)	mg/L	1	Calc.	21-Sep-21/O	17	17		
Colour	TCU	2	SM 2120C	22-Sep-21/O	< 2	2		
Turbidity	NTU	0.1	SM 2130	22-Sep-21/O	1.5	1.3		
UV transmittance	%		SM5910B	24-Sep-21	94.8 [1]	94.6 [1]		
Fluoride	mg/L	0.1	SM4110C	17-Sep-21/O	< 0.1	< 0.1		
Chloride	mg/L	0.5	SM4110C	17-Sep-21/O	3.1	3.2		
Nitrite (N)	mg/L	0.1	SM4110C	17-Sep-21/O	< 0.1	< 0.1		
Nitrate (N)	mg/L	0.1	SM4110C	17-Sep-21/O	< 0.1	< 0.1		
Bromide	mg/L	0.4	SM4110C	17-Sep-21/O	< 0.4	< 0.4		
Sulphate	mg/L	1	SM4110C	17-Sep-21/O	3	3		
Aluminum	mg/L	0.01	SM 3120	20-Sep-21/O	0.05	0.06		
Antimony	mg/L	0.0001	EPA 200.8	24-Sep-21/O	< 0.0001	< 0.0001		
Barium	mg/L	0.001	SM 3120	20-Sep-21/O	0.036	0.036		
Beryllium	mg/L	0.0001	EPA 200.8	24-Sep-21/O	< 0.0001	< 0.0001		
Boron	mg/L	0.005	SM 3120	20-Sep-21/O	< 0.005	< 0.005		
Cadmium	mg/L	).000015	EPA 200.8	24-Sep-21/O	< 0.000015	< 0.000015		
Calcium	mg/L	0.02	SM 3120	20-Sep-21/O	2.62	2.63		
Chromium	mg/L	0.001	EPA 200.8	24-Sep-21/O	< 0.001	< 0.001		
Cobalt	mg/L	0.0001	EPA 200.8	24-Sep-21/O	< 0.0001	< 0.0001		
Copper	mg/L	0.0001	EPA 200.8	24-Sep-21/O	0.0010	0.0010		
Iron	mg/L	0.005	SM 3120	20-Sep-21/O	0.029	0.031		

NOTE: Total Coliform & E. Coli passed acceptable holding time of 48 hours upon arrival at Lab.

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Site Analyzed=K-Kingston,W-Windsor,O-Ottawa,R-Richmond Hill,B-Barrie

Greg Clarkin , BSc., C. Chem
Lab Manager - Ottawa District

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CERTIFICATE OF ANALYSIS

Final Report

C.O.C.: DW 109522 **REPORT No. B21-29978**

Report To:

EXP Services Inc
1133 Regent St., Suite 300
Fredericton NB EBB 3Z2 Canada
Attention: Eric Bell

Caduceon Environmental Laboratories
2378 Holly Lane
Ottawa Ontario K1V 7P1
Tel: 613-526-0123
Fax: 613-526-1244

DATE RECEIVED: 17-Sep-21
DATE REPORTED: 12-Oct-21
SAMPLE MATRIX: Drinking Water

JOB/PROJECT NO.: Arctic Bay
P.O. NUMBER:
WATERWORKS NO.

			Client I.D.		AB-1	AB-2	AB-1-Spike	AB-2-Spike
			Sample I.D.		B21-29978-1	B21-29978-2	B21-29978-3	B21-29978-4
			Date Collected		14-Sep-21	14-Sep-21		
Parameter	**Units**	**R.L.**	**Reference Method**	**Date/Site Analyzed**				
Lead	mg/L	0.00002	EPA 200.8	24-Sep-21/O	0.00002	< 0.00002		
Magnesium	mg/L	0.02	SM 3120	20-Sep-21/O	1.65	1.62		
Manganese	mg/L	0.001	SM 3120	20-Sep-21/O	0.001	0.002		
Nickel	mg/L	0.01	SM 3120	20-Sep-21/O	< 0.01	< 0.01		
Potassium	mg/L	0.1	SM 3120	20-Sep-21/O	0.3	0.3		
Selenium	mg/L	0.001	EPA 200.8	24-Sep-21/O	< 0.001	< 0.001		
Silicon	mg/L	0.01	SM 3120	20-Sep-21/O	0.47	0.48		
Silica	mg/L	0.02	SM 3120	20-Sep-21/O	1.00	1.02		
Silver	mg/L	0.0001	EPA 200.8	24-Sep-21/O	< 0.0001	< 0.0001		
Sodium	mg/L	0.2	SM 3120	20-Sep-21/O	1.5	1.6		
Strontium	mg/L	0.001	SM 3120	20-Sep-21/O	0.005	0.006		
Thallium	mg/L	0.00005	EPA 200.8	24-Sep-21/O	< 0.00005	< 0.00005		
Tin	mg/L	0.05	SM 3120	20-Sep-21/O	< 0.05	< 0.05		
Titanium	mg/L	0.005	SM 3120	20-Sep-21/O	< 0.005	< 0.005		
Uranium	mg/L	0.00005	EPA 200.8	24-Sep-21/O	< 0.00005	< 0.00005		
Vanadium	mg/L	0.0001	EPA 200.8	24-Sep-21/O	< 0.0001	0.0001		
Zinc	mg/L	0.005	SM 3120	20-Sep-21/O	< 0.005	< 0.005		
Ammonia + Ammonium (N)	mg/L	0.01	SM4500-NH3-H	22-Sep-21/K	0.06	0.02		
Dissolved Organic Carbon	mg/L	0.2	EPA 415.2	20-Sep-21/O	0.8	0.7		
Dissolved Inorganic Carbon	mg/L	0.2	EPA 415.2	20-Sep-21/O	3.2	3.2		
Total Organic Carbon	mg/L	0.2	EPA 415.2	20-Sep-21/O	0.8	0.8		
Total Coliform	cfu/100mL	1	MOE E3371	17-Sep-21/O	17	20		
E coli	cfu/100mL	1	MOE E3371	17-Sep-21/O	10	3		
Anion Sum	meq/L		Calc.	21-Sep-21/O	0.324	0.323		
Cation Sum	meq/L		Calc.	21-Sep-21/O	0.341	0.341		
% Difference	%		Calc.	21-Sep-21/O	2.55	2.65		
Ion Ratio	AS/CS		Calc.	21-Sep-21/O	0.950	0.948		

NOTE: Total Coliform & E. Coli passed acceptable holding time of 48 hours upon arrival at Lab.

Greg Clarkin , BSc., C. Chem
Lab Manager - Ottawa District

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JOB/PROJECT NO.: Arctic Bay
P.O. NUMBER:
WATERWORKS NO.

			Client I.D.		AB-1	AB-2	AB-1-Spike	AB-2-Spike
			Sample I.D.		B21-29978-1	B21-29978-2	B21-29978-3	B21-29978-4
			Date Collected		14-Sep-21	14-Sep-21		
Parameter	**Units**	**R.L.**	**Reference Method**	**Date/Site Analyzed**				
Sodium Adsorption Ratio	-		Calc.	21-Sep-21/O	0.181	0.188		
Conductivity (calc.)	µmho/cm		Calc.	21-Sep-21/O	37	37		
TDS(calc.)/EC(actual)	-		Calc.	21-Sep-21/O	0.541	0.542		
EC(calc.)/EC(actual)	-		Calc.	21-Sep-21/O	1.15	1.15		
Langelier Index(25°C)	S.I.		Calc.	21-Sep-21/O	-3.22	-3.23		
Benzene	µg/L	0.5	EPA 8260	23-Sep-21/R	< 0.5	< 0.5		
Toluene	µg/L	0.5	EPA 8260	23-Sep-21/R	< 0.5	< 0.5		
Ethylbenzene	µg/L	0.5	EPA 8260	23-Sep-21/R	< 0.5	< 0.5		
Xylene, m,p-	µg/L	1.0	EPA 8260	23-Sep-21/R	< 1.0	< 1.0		
Xylene, o-	µg/L	0.5	EPA 8260	23-Sep-21/R	< 0.5	< 0.5		
Xylene, m,p,o-	µg/L	1.1	EPA 8260	23-Sep-21/R	< 1.1	< 1.1		
Toluene-d8 (SS)	% rec.		EPA 8260	23-Sep-21/R	104	105		
PHC F1 (C6-C10)	µg/L	25	MOE E3421	23-Sep-21/R	< 25	< 25		
PHC F2 (>C10-C16)	µg/L	50	MOE E3421	21-Sep-21/K	< 50	< 50		
PHC F3 (>C16-C34)	µg/L	400	MOE E3421	21-Sep-21/K	< 400	< 400		
PHC F4 (>C34-C50)	µg/L	400	MOE E3421	21-Sep-21/K	< 400	< 400		
Chloroform	µg/L	1	EPA 8260	08-Oct-21/R			59	57
Bromodichloromethane	µg/L	2	EPA 8260	08-Oct-21/R			10	10
Dibromochloromethane	µg/L	2	EPA 8260	08-Oct-21/R			< 2	< 2
Bromoform	µg/L	5	EPA 8260	08-Oct-21/R			< 5	< 5
Total Trihalomethanes	µg/L	6	EPA 8260	08-Oct-21/R			68	67
Acenaphthene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Acenaphthylene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Anthracene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Benzo(a)anthracene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Benzo(a)pyrene	µg/L	0.01	EPA 8270	22-Sep-21/K	< 0.01	< 0.01		
Benzo(b)fluoranthene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		

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Greg Clarkin , BSc., C. Chem
Lab Manager - Ottawa District

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JOB/PROJECT NO.: Arctic Bay
P.O. NUMBER:
WATERWORKS NO.

				Client I.D.	AB-1	AB-2	AB-1-Spike	AB-2-Spike
				Sample I.D.	B21-29978-1	B21-29978-2	B21-29978-3	B21-29978-4
				Date Collected	14-Sep-21	14-Sep-21		
Parameter	**Units**	**R.L.**	**Reference Method**	**Date/Site Analyzed**				
Benzo(b+k)fluoranthene	µg/L	0.1	EPA 8270	22-Sep-21/K	< 0.1	< 0.1		
Benzo(g,h,i)perylene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Benzo(k)fluoranthene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Chrysene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Dibenzo(a,h)anthracene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Fluoranthene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Fluorene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Indeno(1,2,3,-cd)pyrene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Methylnaphthalene,1-	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Methylnaphthalene,2-	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Methylnaphthalene 2-(1-)	µg/L	1	EPA 8270	22-Sep-21/K	< 1	< 1		
Naphthalene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Phenanthrene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Pyrene	µg/L	0.05	EPA 8270	22-Sep-21/K	< 0.05	< 0.05		
Terphenyl-d14 (SS)	% rec.	10	EPA 8270	22-Sep-21/K	96.0	104		

1 . Subcontracted to Testmark Labs

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Appendix C – Additional Treatment Discussion

1. **Direct Hollow Fibre Nanofiltration Discussion**
2. **Iron and Manganese Discussion**

Hollow-Fibre Nanofiltration vs. Ultrafiltration Comparison

Consideration	Trains #3a, #3b and 4 (Ultrafiltration)	Trains #4 (Hollow-Fibre Nanofiltration)
Pros	- well understood technology with multiple manufacturers and suppliers - backwashable -chlorine resistant - no brine wastes - high recovery rates (typically over 95%)	- chemical free system - does not require coagulation for DOC removal - no brine wastes - backwashable (compared to traditional NF or RO) -minimal salt rejection to maintain salt/mineral balance – selective removals (mono from divalent)
Cons	- requires coagulation for DOC removal	- lower recovery rates (suppliers noted less than 90%) - new treatment with few references and manufacturers - lower chlorine resistance than UF membranes (which may impact pre-oxidization step) - higher investment cost - may still require coagulation/ oxidation step for Mn and Fe removals - lower membrane life expectancy (approx. 3 years)
Can DOC be removed without coagulation?	No	Yes
Can membrane handle direct loading of coagulant?	Likely. However, this will depend on coagulant type and required concentrations. This is limited by the amount of coagulant the membrane system can reliably process without undue fouling – a practical upper limit is in the range of 40 mg/L of coagulant (AWWA, 2016). Bench-scale tests are required to verify appropriate coagulants and approximate dosing rates	n/a (no coagulation required)
Can membrane handle direct loading of precipitated iron and manganese (if required)?	Depends. Unoxidized (or colloidal) Fe and Mn particles may cause fouling or non-reversible fouling issues if they are not properly oxidized upstream of the membranes. Pre-oxidization using chlorine/aeration are the most appropriate oxidants. However, they require long detention times which may not be feasible at the communities. Additional treatment specific for iron and manganese is likely required.	Not conclusive – suppliers noted that their hollow-fibre NF membranes may have limited chlorine resistance

	Bench-scale tests can provide useful insight in verifying these impacts	
Is contact / buffer tank required to provide sufficient coagulation time?	Likely. Piping manifolds (serpentine arrangement or flocculation tubes) that allow for different lengths of piping downstream of coagulant addition may be able to provide sufficient flocculation time. Otherwise, an upstream contact tank or a combination of both will be required. A reduced flocculation time (and tank) is typical with membrane filtration as the objective is to only create pin-floc that can be filtered by the membrane (vs. conventional coagulation that requires big, settleable floc). However, required flocculation time may be governed by the time to oxidize manganese (iron is quicker) upstream of the membrane. Typical times to oxidize manganese is between 10-60 minutes. Bench-scale tests are required to verify the required flocculation times.	May be required for pre-oxidization of Fe and Mn. Same considerations as UF membranes.

Iron and Manganese Treatment Discussion including Oxidant Comparison

Iron and manganese removal are typically done in conjunction with one another. While special emphasis is placed on manganese removal due to its increased difficulty, in providing sufficient removal for manganese, adequate iron removal is also accomplished.

To decrease iron and manganese concentrations, options include:

1. Sourcewater control
2. oxidation/physical separation,
3. adsorption/oxidation,
4. biological filtration,
5. precipitative softening

Among these options, given site conditions and other considerations such as the desire to minimize unit processes, preference is given towards oxidation/physical separation. To promote oxidation of manganese, the following oxidants are considered:

1. Permanganate
2. Chlorine dioxide
3. Ozone
4. Chlorine and oxygen

Using permanganate, oxidation can occur rapidly within a wide range of pH (>5.5) and temperature (>5 degrees Celsius). Oxidation takes longer if there is a lower initial concentration of manganese (II). Oxidation also takes longer if higher levels of organics are present and requires that higher concentrations of permanganate be applied. Dosing of permanganate must be optimized, with sufficient dosage to completely oxidize manganese without leaving discoloured water, either with pink water from excess permanganate or discoloured water from manganese oxide (MnO_x) precipitates forming downstream. One means of controlling chemical dosing amidst varying feed water quality is through the use of ORP (oxidation reduction potential) controlled dosing rather than simply flow-controlled chemical addition. It is also important that the required contact time for oxidation be provided, particularly if membrane filtration is applied downstream since precipitates created from oxidation can damage the membrane structure if formed within the membrane pores.

Similar to permanganate, chlorine dioxide can be used for oxidation to occur rapidly within a range of conditions, with low temperature and low pH both reducing oxidant efficiency. The use of chlorine dioxide has the complication of the potential for formation of chlorate ion downstream within secondary disinfection chlorination processes. In order to prevent this, Health Canada recommends not using a maximum dose of 1.2 mg/L. For effective oxidation, a higher oxidant dose is required if higher levels of organics are present, so chlorine dioxide is not recommended for feed waters with high levels of organics. Another downside of chlorine dioxide is it must be prepared onsite due to its high reactivity. While chlorine dioxide is considered the most effective oxidant for feed water containing low levels of manganese (II), its significant drawbacks make it not suitable for the High Arctic communities in consideration.

Ozone is likewise a strong oxidant, however it is considered less effective than the previous two options considered in limiting manganese levels to low residual levels (e.g., below 0.02 mg/L). High levels of organics significantly inhibit ozone's oxidation of manganese unless alkalinity is also high. When applying the high doses of ozone which may be needed for effective oxidation of manganese, manganese (VII) may be formed and water may become discoloured.

Oxidation using chlorine and oxygen is not typically used due to the extremely long contact times required when alkaline pH conditions aren't present. In addition to a high pH (>8) being required for effective oxidation, reaction times are also significantly increased by lowered temperatures and higher concentrations of organics. As well, in light of the additional contact time provided by prechlorination in addition to downstream chlorination and secondary chlorination, increased downstream formation of manganese oxide (MnO_x) precipitates can result, and associated discoloured water.

Jar testing is recommended to determine dosing requirements and which oxidants are most effective. This is particularly important with chlorine given its potential to require extremely high doses which may not be pragmatic, considering the remoteness of the treatment plants. Jar testing may also provide insight for the outgoing concentration of manganese to be expected in cases in which the objective is not met within a reasonable time limit, particularly amidst conditions less favourable for oxidation.

In general manganese oxidation is increased with:

1. increased temperature,
2. increased pH, particularly if using oxygen or chlorine as oxidant,
3. increased dose of oxidant,
4. increased contact time,
5. lessened competitive oxidant demands, such as organics,
6. increased alkalinity, if using ozone as oxidant
7. higher initial concentration of manganese (II), if using permanganate as oxidant

While jar testing is highly recommended, data from studies of manganese (II) removal using various oxidants provided initial insights, particularly relating to reaction time required. A compilation of data provided in "Guidelines for Canadian Drinking Water Quality: Guideline Technical Document - Manganese" (Health Canada, 2019) is consolidated in Table 1, below.

While oxidation/physical separation has primarily been considered to minimize the number of unit processes, given the challenges associated with each oxidant identified, it is recommended that adsorption/oxidation alternatives (such as manganese greensand) be considered which require lower oxidant dosing requirements and shorter reaction times.

*Table 1 - Manganese oxidation data from "Guidelines for Canadian Drinking Water Quality: Guideline Technical Document - Manganese" (Health Canada, 2019)**

Mn (II) to be treated (mg/L)	Oxidant	Chemical Formula	Oxidant Dosage (mg/L unless specified)	pH	Temperature (°C)	DOC (mg/L) unless specified	Reaction Time	Source referenced by "Guidelines for Canadian Drinking Water Quality: Guideline Technical Document - Manganese"
0.25	Potassium Permanganate	$KMnO_4$	0.50	5.5-9.0	25	<1	<60s	Knocke et al. (1990a)
0.25	Potassium Permanganate	$KMnO_4$	0.50	7	25	10	1-2min	Knocke et al. (1990a)
0.06	Potassium Permanganate	$KMnO_4$	0.34	7	9	3.4	20min	Gregory and Carlson (2003)
1	Potassium Permanganate	$KMnO_4$	not provided	7	9	3.4	<200s	Gregory and Carlson (2003)
0.25	Chlorine dioxide	ClO_2	1-1.5	unknown	unknown	<2.5	unknown	Knocke et al. (1987)
0.25	Chlorine dioxide	ClO_2	>3	unknown	unknown	8-10	unknown	Knocke et al. (1987)
0.06	Chlorine dioxide	ClO_2	0.29	7	9	TOC=3.4mg/L	<300s	Gregory and Carlson (2003)
0.2	Chlorine dioxide	ClO_2	0.98	7	9	TOC=3.4mg/L	75s	Gregory and Carlson (2003)
	Ozone	O_3 (aq)	0.5-2	5.63-7	9-25	1-3.4	30-60s	Knocke et al. (1990a) and Carlson and Gregory (2003)
1	Chlorine (Hypochlorous Acid)	HOCl	5.2	7	25	unknown	3h	Knocke et al. (1990a)
1	Chlorine (Hypochlorous Acid)	HOCl	5.2	9	25	unknown	<1h	Knocke et al. (1990a)

*This document did not specify reaction times for dissolved oxygen, however, similar to chlorine, dissolved oxygen requires high contact times, on the order of hours, unless high pH (>9) conditions are present.

References:

Guidelines for Canadian Drinking Water Quality, Guideline Technical Document – Manganese. Health Canada, May 2019

Appendix D – Calculations

1. **Trucking Delivery Calculations**
2. **Calcite Sizing Calculations**

ARCTIC BAY TRUCKING SCHEDULE

ARCTIC BAY - REPORTED TOTAL WATER USE VOLUMES (MONTHLY)

Month	2012	2013	2014	2015	2017	2019
January	1,942,759	2,505,163	2,377,075	2,239,267	2,238,908	2,417,044
February	1,634,576	2,180,575	1,950,872	1,940,538	1,673,509	2,221,685
March	2,290,661	2,352,715	2,155,887	2,055,612	1,823,650	2,281,909
April	2,295,236	2,262,524	1,933,408	1,881,284	1,703,189	2,491,610
May	2,103,621	2,356,124	2,196,099	1,769,018	1,882,832	2,524,589
June	1,858,028	2,193,722	1,764,161	1,716,195	1,813,234	2,138,900
July	1,991,245	2,290,254	1,628,034	1,887,353	1,880,447	2,385,722
August	2,155,561	2,110,609	2,160,428	1,850,860	2,219,070	2,254,352
September	2,130,990	2,314,020	2,118,484	1,910,657	1,887,224	2,266,909
October	2,263,760	2,489,969	2,301,681	2,162,963	1,910,599	2,145,085
November	2,107,746	2,276,846	2,002,646	2,175,515	1,787,258	1,756,197
December	2,371,479	2,006,818	2,132,132	2,089,254	1,853,591	1,909,770
Total	**25,145,663**	**27,339,338**	**24,720,907**	**23,678,515**	**22,673,509**	**26,793,771**

ARCTIC BAY - % ANNUAL WATER USE BY MONTH

Month	2012	2013	2014	2015	2017	2019	
January	8%	9%	10%	9%	10%	9%	
February	7%	8%	8%	8%	7%	8%	
March	9%	9%	9%	9%	8%	9%	
April	9%	8%	8%	8%	8%	9%	
May	8%	9%	9%	7%	8%	9%	
June	7%	8%	7%	7%	8%	8%	
July	8%	8%	7%	8%	8%	9%	
August	9%	8%	9%	8%	10%	8%	
September	8%	8%	9%	8%	8%	8%	
October	9%	9%	9%	9%	8%	8%	
November	8%	8%	8%	9%	8%	7%	
December	9%	7%	9%	9%	8%	7%	** consumption throughout year is consistent

ARCTIC BAY - CURRENT TRUCKING REQUIREMENTS (2019)

Truck Schedule Assumptions

Population (2019) =	939.00	persons
Actual Daily water use per capita (2019)=	78.2	lpcd
Water Truck volume =	12,000.00	L
Truck Schedule - 6 days/week, 8 hours/day		

Month (2020)	Trips/month	Trips/week (4 weeks/ month)	Trips/day (6 days/ week)	**Trips/day (rounded up)**	**Trips per truck/day** (with 1 trucks)	**Trips per truck/day** (with 2 trucks)
January	201.4	50.4	8.4	9	8.4	4.2
February	185.1	46.3	7.7	8	7.7	3.9
March	190.2	47.5	7.9	8	7.9	4.0
April	207.6	51.9	8.7	9	8.7	4.3
May	210.4	52.6	8.8	9	8.8	4.4
June	178.2	44.6	7.4	8	7.4	3.7
July	198.8	49.7	8.3	9	8.3	4.1
August	187.9	47.0	7.8	8	7.8	3.9
September	188.9	47.2	7.9	8	7.9	3.9
October	178.8	44.7	7.4	8	7.4	3.7
November	146.3	36.6	6.1	7	6.1	3.0
December	159.1	39.8	6.6	7	6.6	3.3
Total	2232.8	-	-	-	-	-

	Trip length (1 trucks)	**Trip length (2 trucks)**
	57.2	114.4
	62.2	124.4
	60.6	121.2
	55.5	111.0
	54.8	109.5
	64.6	129.3
	57.9	115.9
	61.3	122.6
	61.0	122.0
	64.4	128.9
	78.7	157.4
	72.4	144.8
average trip length (mins)	62.6	125.1

ARCTIC BAY - FUTURE WATER PRODUCTION RATE REQUIREMENT (2043)

WTP and Trucking Delivery - Cycle Times

Volume per Truck	12,000	l/truck	
Truck Fill Rate (WTP)	1,000	l/min	
Truck Fill Time (including hookup and disconnect)	15	min	** 3 min to connect/disconnect
Average Travel Time to Community	12	min	**8km @ 40 km/hr
Average Travel Time back to WTP	12	min	**8km @ 40 km/hr
Number of household fiills per truck	8	stops	** assume 1,500L (400 gal) per household tank
Time unloading at each stop	12	mins/stop	
Time unloading within community	96	min	
Total Cycle Time per truck load	**135**	**min**	** (i)+(ii)+(iii)+(iv)

Calculation for Required Trucks in 2043

Population (2043)	1,184	persons	
Per Capita Water Usage	120	lpcd	
Weekly water volume to provide	994,560	l	
BASED ON SEVEN (7) DAY WATER DELIVERY			
Daily volume of water to deliver	142,080	L/day	** weekly volume provided over 7 days
Number of truck loads per day	12	loads/day	* 12,000L/truckload
Total Time for 3 trucks to complete cycles	533	min	*3 trucks
	8.9	hours	
Total Time for 4 trucks to complete cycles	400	min	*4 trucks
	6.7	hours	
Total Time for 5 trucks to complete cycles	320	min	*5 trucks
	5.3	hours	
BASED ON SIX (6) DAY WATER DELIVERY			
Daily volume of water to deliver	165,760	L/day	** weekly volume provided over 6 days
Number of truck loads per day	14	loads/day	* 12,000L/truckload
Total Time for 7 trucks to complete cycles	622	min	*3 trucks
	10.4	hours	
Total Time for 8 trucks to complete cycles	466	min	*4 trucks
	7.8	hours	
Total Time for 9 trucks to complete cycles	373	min	*5 trucks
	6.2	hours	
BASED ON FIVE (5) DAY WATER DELIVERY			
Daily volume of water to deliver	198,912	L/day	** weekly volume provided over 5 days
Number of truck loads per day	17	loads/day	* 12,000L/truckload
Total Time for 7 trucks to complete cycles	746	min	*3 trucks
	12.4	hours	
Total Time for 8 trucks to complete cycles	559	min	*4 trucks
	9.3	hours	
Total Time for 9 trucks to complete cycles	448	min	*5 trucks
	7.5	hours	

CALCITE FILTER - SIZING CALCULATION

	Unit	*Pond Inlet - Calcite*	*Arctic Bay - Calcite*	*Grise Fiord - Calcite*
Filtration rate	gpm/ft2	3.5	3.5	3.5
Filtration rate	m/hr	8.54	8.54	8.54
WTP Flow Rate	L/min	1058	493	83
WTP Flow Rate	m3/hr	63.48	29.58	4.98
TOTAL Surface Area Req.	m2	7.43	3.46	0.58
Surface area for 1 filter	m2	2.63	2.63	2.63
# filters required	#	3	2	1

**Calcite cut sheet notes rates = 3-6 gpm/ft2

** filters are typically 6 ft diameter (1.83m)

** # of duty required

Notes

**backwash rate 8-12 gpm/ft2

Backwash bed expansion = 12% minimum

Bed Depth = 24-30 inches (~800mm)

Freeboard = 50% of bed depth (minimum)

Appendix I – Climate Risk Screening – Saline Intrusion Report

1. **Climate Risk Screening – Saline Intrusion – Arctic Bay Community Water Source (EXP) – (October 31, 2022)**

High Arctic Water Supply & Treatment

Government of Nunavut

Type of Document:
Climate Risk Screening – Arctic Bay Community Water Source
(*supplemental report to Hydrological and Water Balance Study Report – Arctic Bay*)

Project Name:
Business Case for New Water Treatment Facilities and Associated Infrastructures at Arctic Bay

Project Number:
EXP FRN-21016638-A0
GN 21220 00701

Prepared by:

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Date Submitted:
2022-10-31

Table of Contents

Executive Summary

A high level climate change risk assessment of the potential for saltwater impacts on the Hamlet of Arctic Bay's Marcil Lake potable water supply was completed. Marcil Lake is the community's only available water supply and is located near the ocean. The lake is interpreted to be protected from saltwater intrusion by a natural perimeter ridge of variable elevation. The main climate change risks interpreted included:

- Direct saltwater impacts by lateral migration of seawater into the lake;
- Sea level rise/ storm surge overtopping or breaching the existing barrier ridge; and
- Permafrost thaw leading to ridge erosion or release of relic saline porewater from watershed sediments of marine depositional origin.

Results of the screening suggest that for the "normal" (i.e. median) projections of most climate change scenarios (Shared Socioeconomic Pathways, SSPs) presented in the recent United Nations Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (IIPCC AR6, 2021), that site conditions provide for adequate buffer with low risk of saltwater intrusion up until at least 2100. However, for a scenario of more extreme climate change (e.g. SSP5-8.5 *low confidence* scenario) there is significant potential for climate change to impact the lake by overtopping and/ or breaching of the lower lying lake outfall area located along the northwest portion of the ridge that separates Marcil Lake from Arctic Bay (Figure A).

Figure A: Northwest portion of ridge separating Marcil Lake from Arctic Bay

Regarding the five (5) main illustrative SSPs adopted by IPCC AR6 to contrast future climate scenarios it is understood that currently the most likely climate scenario that will be realized outward to 2100 is SSP2-4.5. Under this scenario the median sea level rise is projected to be 0.06 in 2050 and 0.13 m by 2100; the upper 83rd percentile of simulations within which there is a 66 % probability of the actual outcome occurring is 0.33 m by 2050 and 0.74 m by 2100. This magnitude of sea level rise is not expected to overtop the interpreted 4.5 m "critical" elevation representative of the lower maximum ridge elevation along Marcil Lake's perimeter. SSP2-4.5 assumed extreme sea level (ESL) events associated with high tide and storm surge are expected to increase the potential for impact with the possibility of marginal exceedances by 2050 and increasing through to 2100 and beyond. However, for the range of SSP2-4.5 scenarios (and most other scenarios) considered it is anticipated that the risk of overtopping could be mitigated through construction of coastal defences such as an earthen berm constructed from local aggregate sources.

In addition to direct impact from lateral intrusion of seawater, permafrost thaw may increase this risk in the event of erosion of the barrier ridge particularly where present as glacial veneer deposits in low lying sections (e.g. lake outflow area). Permafrost thaw also has the potential to impact lake water quality by melting watershed sediments releasing previously frozen saline porewater and/or possible other naturally occurring parameters of concern. With increased warming in the region impacts due to permafrost could become the principal concern regarding potential for saline or other impacts to the overall freshwater quality of the Marcil Lake raw water source.

Recommendations to facilitate planning and address suspected or actual potential water quality impacts include:

- Enhanced site assessment
- Development and implementation of a regular and consistent raw water monitoring program
- Establishment of a community based Arctic Bay Climate Change Committee is also recommended to support site assessment initiatives that can be considered (e.g. geotechnical and geomorphologic characterization of the Marcil Lake barrier shoreline; tide, storm surge and sea level rise monitoring/ characterization; permafrost and active layer monitoring; and raw water and watershed inflow monitoring).This information could be reviewed by the Arctic Bay Climate Change Committee supported by outside technical specialists and used to guide adaptation and possible mitigation measures that may be warranted should future climate change conditions suggest the lake water quality will be impacted.

1 Introduction

1.1 Overview

EXP Services Inc. (EXP) was retained by the Government of Nunavut – Department of Community and Government Services (GN – CGS) to complete a climate risk screening of potential saltwater impacts on the Hamlet of Arctic Bay's Marcil Lake communal potable water source. The work was completed as a supplemental study to the project entitled "*Business Case for New Water Treatment Facilities and Associated Infrastructures at: Pond Inlet, Arctic Bay, and Grise Fiord*" (EXP file FRN-21016638-A0; GN-CGS file 21220 00701) whose project scope included the completion of a hydrological and water balance study for the Arctic Bay communal water source.

The hydrogeology and water balance report (EXP, 2022a) focused on determining whether Arctic Bay's existing water source (Marcil Lake) and related watershed can provide enough water each year to meet the current and future needs of the community over a 20-year horizon. Based on that assessment, it was concluded the only instance where water supply needs are not met from annual precipitation is if the community experiences a "worst case" scenario (Scenario 1 minimum recorded precipitation and highest evapotranspiration). The report also identified the possibility of climate risks associated with the Marcil Lake water source; in particular the potential for saltwater intrusion to impact the Marcil Lake due its proximity to the Arctic Ocean present as Arctic Bay to the northeast, and Adam Sound to the south. The community location and related water bodies are indicated in Figure 1-1.

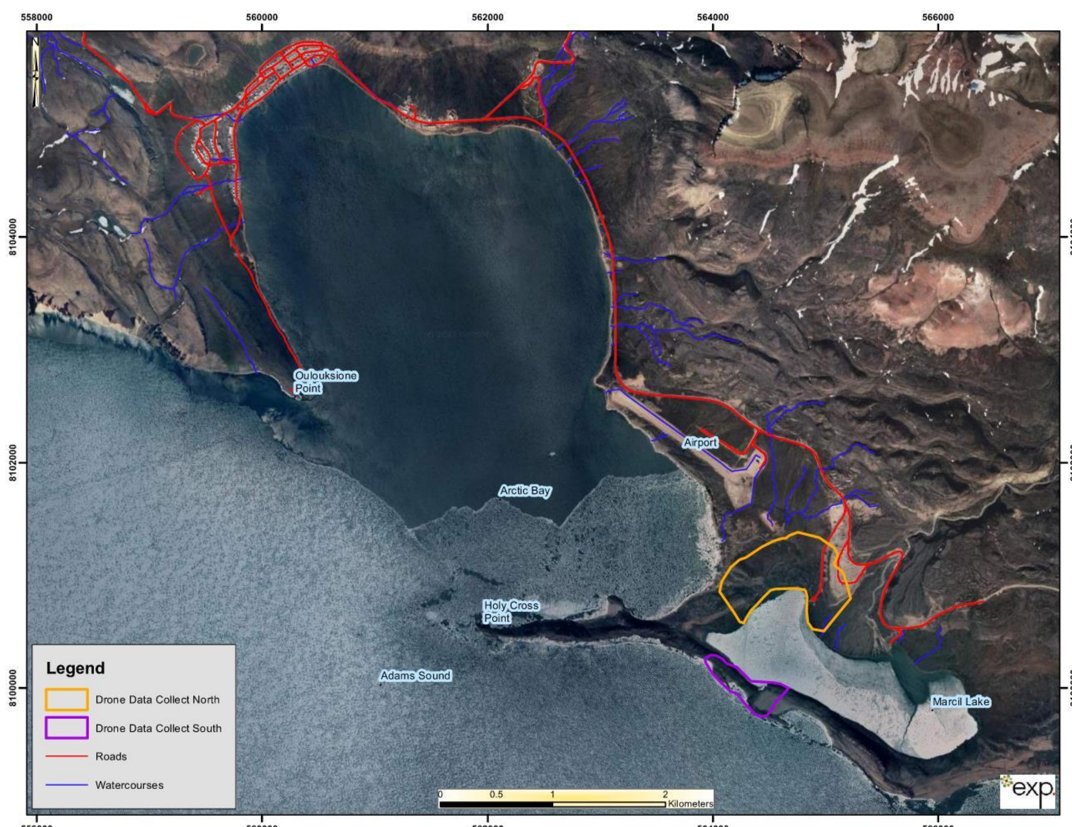


Figure 1-1 Site Location Plan

1.2 Objectives

Marcil Lake is the community of Arctic Bay's only identified drinking water source. The freshwater lake sits close to sea level and is separated from the ocean by a natural perimeter protective ridge along its south and northwest edges as shown in Figure 1-2. The width of the ridge around the perimeter of the lake varies from approximately 150m to 350m. Along the length of the ridge, maximum elevations range from approximately 4 to 80 m above sea level. Based upon recent drone survey, the lake level is approximately 4m above sea level.

Figure 1-2 Perspective photograph looking west at Marcil Lake

To date it is understood that there have been no reports of salinity issues or saline intrusion associated with Marcil Lake but this could be a potential issue associated of anticipated climate change processes such as sea level rise, storm surge, permafrost thaw and related erosion of the ridge. As part of the GN-CGS's request for additional investigations, EXP was retained to complete a screening level Climate Risk Assessment Desktop Study to assess the vulnerability of the drinking water source (Marcil Lake) to the following risks:

i) Risk of saline intrusion

ii) Vulnerability to sea level rise/ storm surges

iii) Permafrost degradation

The following report provides a summary of the work completed.

1.3 Methodology

Methodology for the study was as follows:

1) Collection and review of readily available background information on topography, geology, available high resolution ortho-imagery, and projected climate change conditions;
2) Review of Surficial Geology (desktop) based on available mapping from and contact with government sources;
3) Screening Level Risk Assessment of "most likely" climate risks;

4) Develop recommendations for field assessment and monitoring programs and identify "high-level" potential mitigation strategies.

Initially, two sources of elevation data were used during the analysis: (1) A Digital Surface Model (DSM) sourced from the National Geospatial-Intelligence Agency (NGA) and National Science Foundation (NSF) ArcticDEM project (Porter et al.), (2) a bathymetric model sourced from the hydrogeology and water balance report (EXP, 2022a).

The ArcticDEM elevation data is derived photogrammetrically from high resolution satellite imagery (0.5m) stereo pairs as a Digital Surface Mode (DSM). A Digital Surface Model differs from a Digital Terrain Model in that the elevation values are representative of surface objects such as vegetation canopy, buildings, and other structures. However, in this region there is little vegetation so the elevation values are believed to reflect the topographic surface. The ArcticDEM data was downloaded from the Polar Geospatial Centre servers in Geotiff format and reprojected from WGS 84 / NSIDC Sea Ice Polar Stereographic North coordinates to UTM Zone17 NAD83CSRS coordinates. The Arctic DEM elevation data is available in 50 by 50 km tiles at a 2m grid cell resolution. The data are provided without ground control points and absolute accuracy is approximately 4 meters in horizontal and vertical planes. Accuracy of the data varies as a function of location, satellite data source, and image quality. An in-house accuracy assessment conducted using ground based survey data yielded a vertical error of 0.29 m RMS. Horizontal accuracy is more difficult to assess without a more rigorous assessment procedure. Given the error calculated in the vertical accuracy assessment it is estimated based on EXP's experience that the horizontal accuracy is in the range of 2m RMS. The satellite stereo pairs used in the photogrammetric processing were from 2009 so some error may be due to the temporal differences. The study area was extracted from the DSM tile and added to the project geospatial database.

The bathymetric dataset was available as contours (1m contour interval). The data was acquired using a small boat. The bathymetric data was of marginal value in the shoreline areas because of the limitation of boat and sensor in shallow water.

During progress of the work, it was determined that site specific drone survey was warranted to confirm two low lying areas along the perimeter ridge, one along the south ridge area and more importantly the second area along the lake's low lying outflow area located at its northwest corner. A Digital Terrain Model was generated from the high resolution drone aerial photography. The DTMs were generated at a grid resolution of 1m and projected to UTM Zone 16 WGS84 coordinates and using the CGVD2013 Vertical Datum.

Select plans and sections of the Marcil Lake study area were generated using ArcGIS. Based on the data and profile plots, for the purpose of this report an elevation of 4.5 m geodetic was used as the "critical" elevation wherein sea level rise and or extreme storm tide events could lead to overtopping or inundation of Marcil Lake by the adjacent ocean waters. This elevation was selected as it essentially represents the "high" point along each of the two interpreted outflow streams draining Marcil Lake to Arctic Bay and is also the approximate perimeter protective ridge maximum elevation along the approximately 600 m length of the low lying lake outflow area.

2 Background

2.1 Community and Existing Water Supply System

2.1.1 Arctic Bay

The Hamlet of Arctic Bay, Nunavut is located at 73°02' N latitude and 85°10' W longitude on the northern section of Baffin Island. The water supply for Arctic Bay is the Marcil Creek watershed that discharges into Marcil Lake. The community of Arctic Bay is located approximately 9 km to the west and is serviced by an existing potable water truck fill station located on the north side of the lake. A fleet of water delivery vehicles (three trucks) brings water from the lake and distributes it to Arctic Bay residents. Historically, there have been reported concerns regarding the quality and quantity of the source water. Chlorination is the only method being used for treatment/disinfection. No reliable secondary sources of water close to the community have been identified – the GN has noted that Marcil Lake will continue to supply drinking water to Arctic Bay into the distant future

As noted above, Marcil Lake sits near sea level and is separated from the ocean (present as Adam Sound along the south shoreline and Arctic Bay along the west shoreline) by a small ridge (Appendix A). Along the south edge of the lake, the width of ridge is approximately 150 m to 350 m. Elevations along the perimeter of the lake are understood to range from 0 to 18 m on the south/ southwest and south/southeast portions of the ridge. Similar elevations are present along the first half of the ridge bounding the northwest shoreline but the ridge is understood to drop along the remainder of this section to a range of 0 to 5 m elevation. This lower area to the northwest is understood to be the discharge area where Marcil Lake flows into Arctic Bay. The lake water level has been reported to be at approximately the same elevation as sea level, although an important distinction based on available topography (e.g. lake bathymetric survey (EXP, 2022a); recent drone acquired lidar survey to supplement this saltwater intrusion study) is that the lake level is at approximately 4 m above sea level.

The outflow area located along the northwest shoreline of the lake is approximately 600 m in width. Within this area, based on review of high resolution aerial photography, two separate outflow streams are observed; one in the south portion flowing essentially from the lake to the northwest and into Arctic Bay, and one in the north portion flowing initially north from the lake then meandering northwest and flowing subsequently into Arctic Bay. Between and bounding these interpreted outflow stream is a low lying ridge between the shorelines of Arctic Bay and Marcil Lake which rises from sea level to a height of approximately 5 m. Detailed site plans including the overall lake area, cross sections, interpreted alignment of the outflow streams and selected profiles along the outflow streams and related low lying portion of the perimeter protective ridge are provided in Appendix A. As noted above, based on the profile plots, an elevation 4.5 m was interpreted as the "critical" elevation for overtopping of the perimeter ridge by ocean waters.

2.1.2 Geology

Bedrock in the Arctic Bay region is composed of undivided sedimentary rocks and Cambrian-Ordivician carbonate and siliclastic rocks (EXP, 2022a). Regional scale bedrock geology mapping at 1:3,500,000 (deKemp et al., 2006) indicates Paleozoic Era Cambrian-Ordicician carbonate and siliclastic rocks dominate the western portion and Mesoproterozoic undivided sedimentary rocks dominate the eastern portion of the Arctic Bay area/ peninsula.

Turner (2022) differentiates in more detail the bedrock geological units of the area (reproduced as Figure 2-1). This more detailed mapping further differentiates the bedrock units in the area of Marcil Lake as Adams Sound Formation to the east consisting of *"…crossbedded quartz arenite with minor conglomerate and siltstone intervals.."*, and the younger Arctic Bay Formation on the west consisting of a *"…fining-upward sandsone-to-shale succession up to 800 m thick that sharply, but conformably overlies the Adams Sound Formation*". In addition to these main bedrock units, there are a series of mafic dykes (igneous rocks) in the area; of particular note is the mapped presence of a mafic dyke bounding and forming the south and southwest shoreline separating Marcil Lake from Adams Sound.

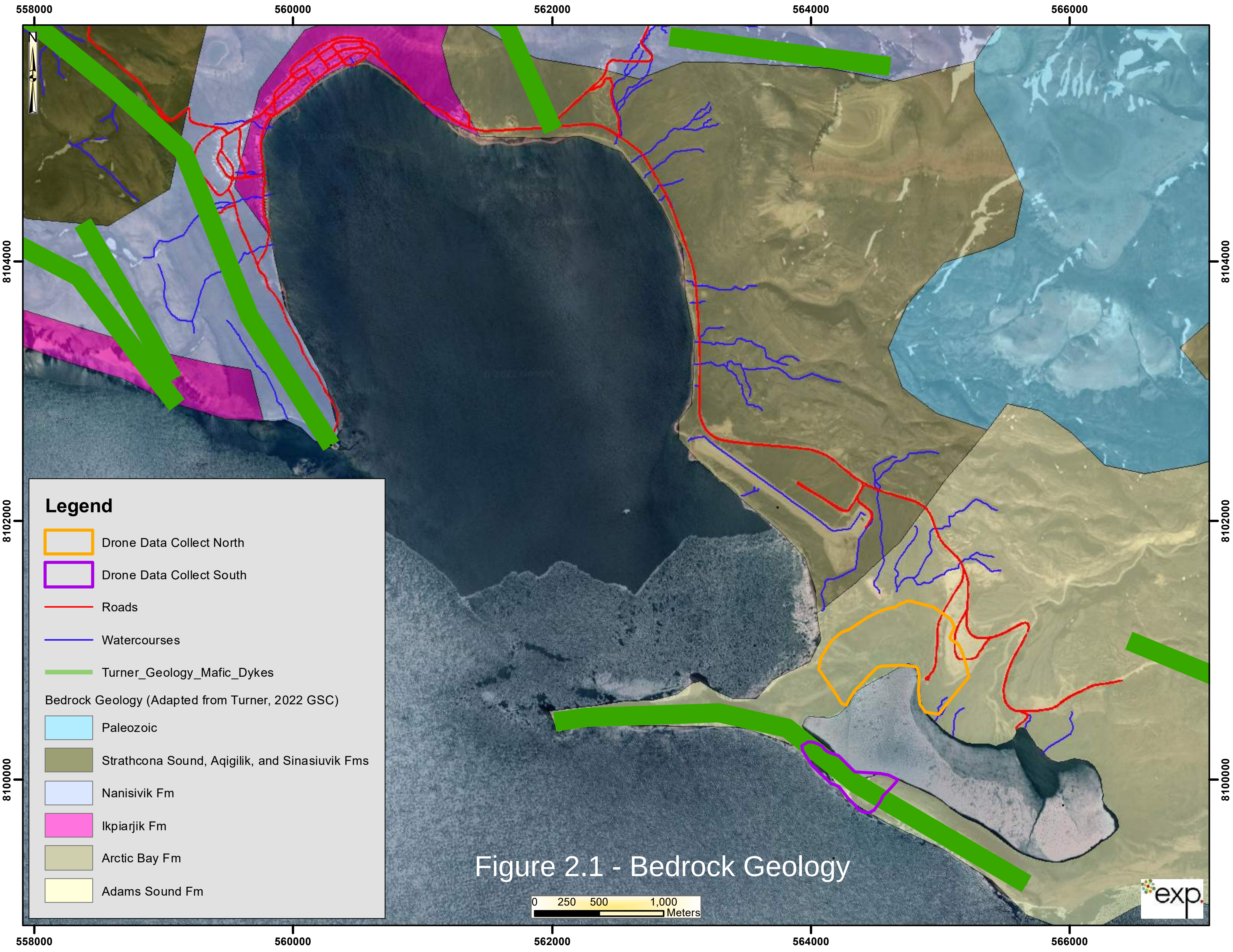
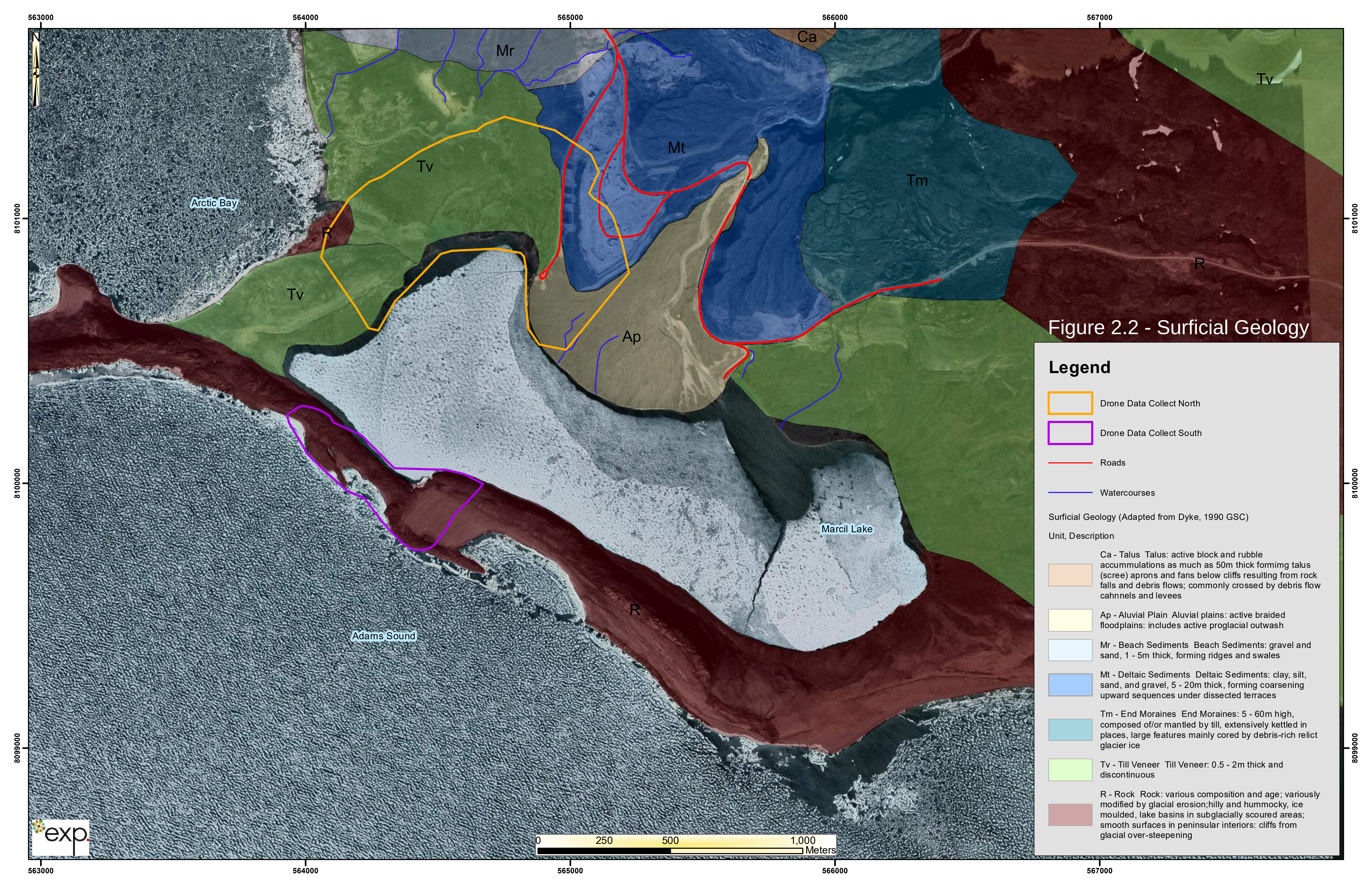


Figure 2.1 - Bedrock Geology

Surficial geology (Figure 2-2) is comprised of a complex of glacial deposits of varying types including till veneer, marine sediments and alluvial fan deposits. As discussed in subsequent sections below, of particular relevance regarding the potential for saltwater impacts on Marcil Lake is the presence of glacial till veneer deposits in the low lying outflow area outflow area between Marcil Lake and Arctic Bay, and marine terrace deposits bounding the area where the Marcil Creek drains into Marcil Lake.



563000
564000
565000
566000
567000
8101000
8100000
8099000
Mr
Ca
Mt
Tm
Tv
Arctic Bay
R
Ap
Marcil Lake
Adams Sound
Figure 2.2 - Surficial Geology
Legend
Drone Data Collect North
Drone Data Collect South
Roads
Watercourses
Surficial Geology (Adapted from Dyke, 1990 GSC)
Unit, Description
Ca - Talus Talus: active block and rubble accummulations as much as 50m thick formimg talus (scree) aprons and fans below cliffs resulting from rock falls and debris flows; commonly crossed by debris flow cahnnels and levees
Ap - Aluvial Plain Aluvial plains: active braided floodplains: includes active proglacial outwash
Mr - Beach Sediments Beach Sediments: gravel and sand, 1 - 5m thick, forming ridges and swales
Mt - Deltaic Sediments Deltaic Sediments: clay, silt, sand, and gravel, 5 - 20m thick, forming coarsening upward sequences under dissected terraces
Tm - End Moraines End Moraines: 5 - 60m high, composed of/or mantled by till, extensively kettled in places, large features mainly cored by debris-rich relict glacier ice
Tv - Till Veneer Till Veneer: 0.5 - 2m thick and discontinuous
R - Rock Rock: various composition and age; variously modified by glacial erosion;hilly and hummocky, ice moulded, lake basins in subglacially scoured areas; smooth surfaces in peninsular interiors: cliffs from glacial over-steepening
0 250 500 1,000
Meters
exp.

The nature of the bedrock and surficial deposits is anticipated to be one of the primary factors governing the potential for, and mitigation of, possible saltwater impacts on the Marcil Lake water quality. In the case of bedrock, where present and at sufficient elevation, these units would be expected to provide for higher resistance to erosion and in this sense serve as a significant barrier to lateral intrusion of saltwater (overtopping or breaching). For example, mapping provided by Turner (2019) indicates that the south side of the lake is separated from Adam's Sound by a significant mafic dyke which forms a bedrock ridge. This ridge is anticipated to be highly resistant to erosion and breach by the sea.

In contrast to the bedrock, the surficial deposits are anticipated to be comparatively less protective, and factors such as their relative location to the shoreline, thickness, sediment type and presence as permafrost and/or active layer would to a significant extent dictate their protective nature. For example, given their low lying nature and proximity to the shoreline of Arctic Bay the till veneer deposits in the lake outflow area are expected to be much more susceptible to erosion and overtopping particularly in the event of permafrost melting and increased sea level and storm surge associated with climate change. As discussed in Section 3.3 below, depending on their depositional environment, the surficial deposits upstream in the watershed could also have the potential to cause saline impacts to the Marcil Lake water quality due to erosion and/or thawing and release of previously frozen brackish pore water (if present).

2.2 Saltwater Intrusion

2.2.1 Saltwater Intrusion

Traditionally, saltwater intrusion is defined as the movement of saline water into freshwater aquifers, which can lead to groundwater quality degradation, including drinking water sources, and other consequences. Saltwater intrusion can occur naturally or be induced (e.g. by overpumping/ withdrawal) in coastal areas and aquifers, owing to the hydraulic connection between groundwater and seawater.

Under natural conditions, the seaward movement of freshwater prevents saltwater from encroaching on freshwater coastal aquifers. This interface between freshwater and saltwater is maintained near the coast or far below the land surface. The interface actually is a diffuse zone where freshwater and saltwater mix. This zone is referred to as the zone of dispersion or the zone of transition (Figure 2-3).

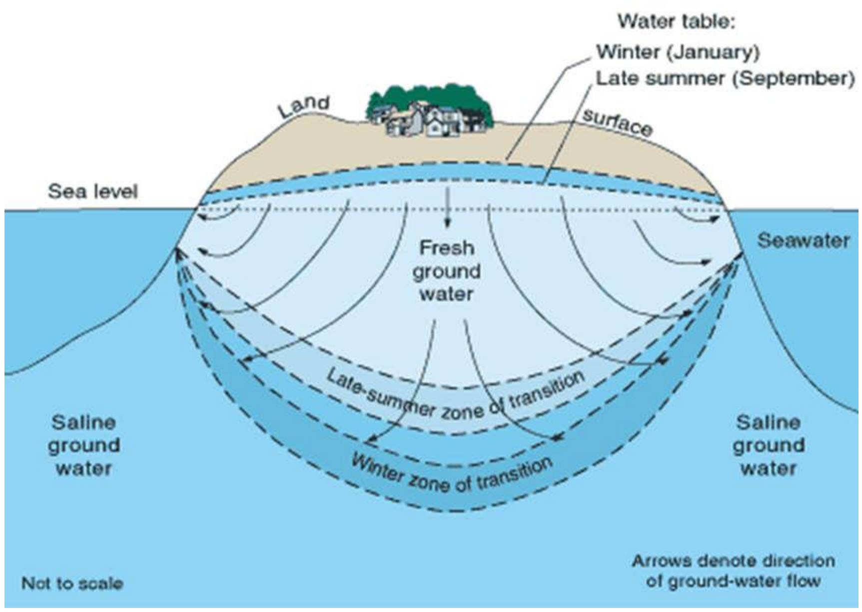


Figure 2.3 - Saltwater intrusion

Groundwater pumping can reduce freshwater flow toward coastal areas and cause saltwater to be drawn toward the freshwater zones of the aquifer. Saltwater intrusion decreases freshwater storage in the aquifers, and, in extreme cases, can result in the abandonment of wells. Saltwater intrusion occurs by many ways, including lateral encroachment from coastal waters and vertical movement ("up coning") of saltwater near discharging wells. The intrusion of saltwater caused by withdrawals of freshwater from the groundwater system can make the resource unsuitable for use.

The Ghyben-Herzberg relation describes the relation between the height of the groundwater above the sea level and the depth under it. Simplified it is: $z = 40h$, where "z" is the depth to groundwater and "h" is the head of freshwater above sea level (Figure 2-4). For example, the Ghyben-Herzberg Relation (Saltwater Intrusion) ratio states that for every foot of fresh water in an unconfined aquifer above sea level, there will be forty feet of fresh water in the aquifer below sea level.

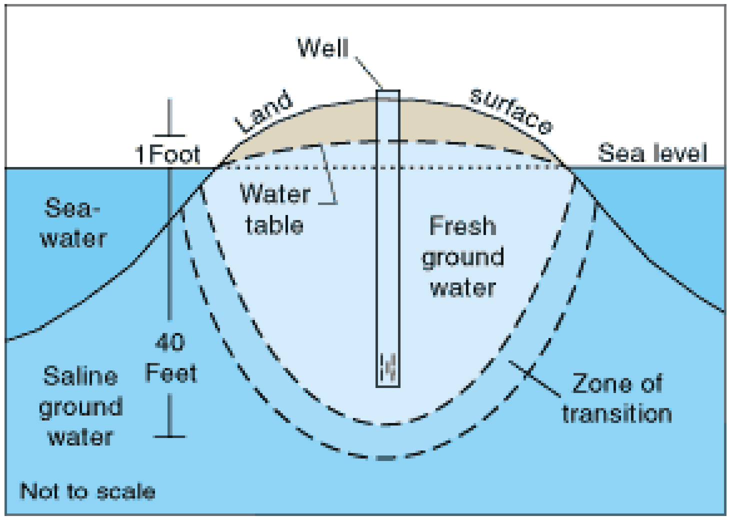


Figure 2.4 - Ghyben-Hertzberg Depth to Saltwater

As noted, the concept of saltwater intrusion is generally thought of in terms of coastal groundwater aquifer systems which are not frozen. However, it is suggested that the general concepts are also of relevance to the Arctic Bay Marcil Lake communal water source given the proximity of the lake to the sea (Arctic Bay to the west and northwest, and Adam Sound/ Strathcona Sound to the south and southwest).

It is understood that to date there has been no evidence of saline/ saltwater impacts on Marcil Lake. In the context of saltwater intrusion mechanisms the following are suggested as the main reasons:

1) the water level elevation in Marcil Lake is on the order of 4 to 5 m above sea level. Under this scenario, even in the absence of frozen ground (permafrost conditions), the Gyben-Herzberg depth to saltwater equation would suggest that there is adequate water level elevation ("hydraulic head") in the lake to "push" the potential brackish water intrusion wedge seaward. (In simple theoretical terms, assuming say and average 3 m of head difference between the lake and the ocean tidal waters, the depth to the saltwater interface would be on the order of 120 m (z = 40 x 3 m = 120 m) in the lake); and,

2) "permafrost" conditions are anticipated to provide further mitigation to minimize the potential of lateral migration through the underlying ground into the lake. This is based on the assumption that the active layer in the permafrost is relatively shallow, and that any subsurface permeable features such as fractures/ jointing in the perimeter ridge bedrock or intergranular porosity in the surficial sediments are frozen thereby eliminating the potential for lateral migration into the lake.

2.3 Climate Change Projections

In recent years society and governments have become increasingly aware of changes to the climate resulting in extreme weather events and their potential for impacts. It is generally recognized that low lying coastal communities including those in the Arctic region will be particularly at risk. As a result, significant effort has been expended within the scientific community to predict changing climate conditions and their potential impacts. One of the main tools for this work is the continuing development and refinement of Global Climate Models that can be used to create simulations of day-to-day weather over many years. These models are not meant to be used to predict what the weather is expected to be in the future on any particular day or sequence of days. Instead their purpose is produce daily simulations that are interpreted statistically, resulting in statements about the probability of particular weather conditions being observed in the future. The climate models effectively combine many simulations of possible weather to produce the accumulated story of what average and extreme conditions might happen under various assumptions/ scenarios; as such the models do not produce weather forecasts; they produce *climate projections* (https://climateatlas.ca/climate-change-projections).

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks. As part of this effort, the IPCC surveys and distills scientific literature and provides consensus projections of climate change outcomes across the globe under a range of possible future scenarios. The goal of working with scenarios is not to predict the future but to better understand uncertainties and alternative futures, in order to consider how robust different decisions or options may be under a wide range of possible future.

One of the more recent iterations of the IPCC's ongoing climate change assessment work, the 6th Assessment Report from Working Group I, was released on August 9th, 2021. This report provides climate change projections covering the time-period from 2020 to 2150 for various future scenarios termed ***shared socioeconomic pathways (SSPs)***. The SSPs are IPCC's latest iteration in climate change storyline and scenario hypotheses and are the evolution of the SRES developed in 2000 for use in the IPCC's Third Assessment Report (*Special Report on Emissions Scenarios - SRES*), and the RCPs (representative concentration pathways) developed circa 2007 and used as the basis for the IPCC's AR4 and AR5 reports as time-dependent projections of atmospheric greenhouse gas (GHG) concentrations and radiative forcing outcomes (i.e. a measure of the amount by which the planet will warm).

The current SSPs scenarios used in IPCC AR6 are based on five narratives describing broad socioeconomic trends that could shape future society. These are intended to span the range of plausible futures. Similar to the RCPs used in the IPCC AR5 report the various SSPs (SSP1-SSP5) scenarios are combined with the expected level of radiative forcing which represents a measure of the extent of global warming in the year 2100 (in the range 1.9 to 8.5 W/m depending on the respective SSP scenario). The main differences between SSPs come from their assumptions on global population growth, access to education, urbanization, economic growth, resources availability, technology developments and drivers of demand, such as lifestyle changes. (https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/)

The IPCC AR6 main SSP scenarios include:

- a world of sustainability-focused growth and equality (**SSP1-1.9 and SSP1-2.9**) – this envisions a relatively optimistic trend for human development, with "substantial investments in education and health, rapid economic growth, and well-functioning institutions", with an increasing shift toward sustainable practices;
- a "middle of the road" world where trends broadly follow their historical patterns (**SSP2-4.5**) - SSP2 represents a "middle of the road" scenario where historical patterns of development are continued throughout the 21st century;

- a fragmented world of "resurgent nationalism" (**SSP3-7.0**) - SSP3 assumes a more pessimistic scenario of future economic and social development, with little investment in education or health in poorer countries coupled with a fast-growing population and increasing inequalities. A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues;
- a world of ever-increasing inequality (**SSP4-3.4 and SSP4-6.0**) – SSP4, like SSP3 also assumes a more pessimistic path in future economic and social development. Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries;
- a world of rapid and unconstrained growth in economic output and energy use (**SSP5-8.5**) – similar to SSP1, SSP5 envisions a relatively optimistic trend for human development but differs in that SSP5 assumes this will be driven by an energy-intensive, fossil fuel-based economy, while in SSP1 there is an increasing shift toward sustainable practices;
- **SSP5-8.5 *low confidence*** scenario – this is a low-likelihood, high impact scenario for possible global mean sea level rise based on large part on possible widespread loss from the Antarctic ice sheet. This storyline should be interpreted as possible futures whose probability of occurrence is low or not well known, but if they did happen they could have a significant impact on society or ecosystems. This means that they can't be ruled out and need to be considered as part of climate risk assessment and coastal decision-making. For projections to 2100, the low-likelihood, high impact storyline could lead to an additional metre of global mean sea level rise and is associated with loss from both the Greenland and Antarctic ice sheets. For projections to 2300, the low likelihood, high impact scenario could lead to global mean sea level rise of up to 15m or greater compared to a much smaller sea level rise of approximately 3 m for the SSP2-2.6 scenario.

The main scenarios used by IPCC AR6 to compare and contrast climate projections are SSP1-1.9 and SSP1-2.9; SSP2-4.5; SSP3-7.0; and SSP5-8.5, with corresponding best estimates of global climate temperature increase by year 2100 ranging 1.4°C for SSP1-1.9 to 4.4°C for the SSP5-8.5 scenario. Regarding the more optimistic SSP1 storyline it is possible that the current objectives to minimize global warming to 1.5 degrees Celsius by 2100 (e.g. Paris Climate Agreement target) remains within reach, and that conceivably the SSP1 lower global warming level impact scenarios might be reached. However, SSP2-4.5 is reported to be more consistent with government climate policies that are currently in place (https://yaleclimateconnections.org/2021/08/the-new-ipcc-report-includes-get-this-good-news/). Although the IPCC AR6 report did not estimate the likelihoods of the scenarios a 2020 commentary described SSP5-8.5 as highly unlikely, SSP3-7.0 as unlikely, and SSP2-4.5 as likely. The SSP2-4.5 scenario envisions global carbon emissions increasing another 10% over the next decade before reaching a plateau that's maintained until carbon pollution slowly begins to decline starting in the 2050s. Global carbon emissions approach but do not reach zero by the end of the century. Even in this unambitious scenario, the very worst climate change impacts might be averted, although the resulting climate impacts would be severe. Under intermediate and high GHG emissions scenarios, the Arctic is projected to be practically ice-free near mid-century.

The IPCC AR6 report from Working Group I released on August 9th, 2021 includes results developed from Global Climate Models for global and regional sea level projections. The projections cover the time-period from 2020 to 2150 and are provided for the various future scenario shared socioeconomic pathways (SSPs) adopted for IPCC AR6. Projections for individual processes that cause sea level to change, globally averaged projections, regional projections on a regular global grid, and local projections at individual tide gauge locations are provided. For the Arctic Bay Marcil Lake climate risks discussed in this report, the IPCC AR6 projections for sea level rise were used. As noted above, global climate model results are interpreted statistically resulting in statements about the probability of particular weather conditions being observed in the future. In this context the IPCC AR6 sea level rise outputs are expressed for each particular SSP scenario outcomes as a median value with the 17th and 83rd percentiles. The 17th and 83rd percentiles represent the range in which there is a 66 % probability that a particular scenario's outcome will fall.

3 Climate Risk Screening (Saltwater Intrusion)

3.1 Saltwater Intrusion and Current Setting

There are two main general mechanisms that saltwater intrusion can impact fresh water sources in coastal environments; vertical "up-coning", and lateral migration of saline water from the sea.

3.1.1 Vertical Up-coning

Saltwater up-coning, a term typically applied to groundwater wells pumping near the coast, can be defined as the region around a pumping well within which a significant rise in the saltwater-freshwater interface occurs. In general vertical "up-coning" is most common where groundwater wells pump and induce an excessive cone of influence/ drawdown in the water table near the pumping well(s). If over pumping occurs, the confining head of freshwater below the pumping well(s) is reduced such that the hydraulic head of the underlying brackish/ saline water is sufficient to reverse vertical gradients with the result that the saline water migrates upward and impacts the freshwater source.

In the context of the Marcil Lake reservoir system there are no active pumping wells, the closest analogy being the freshwater intake that is understood to be at approximately 20 m below surface. In simple theoretical terms, assuming a lake water level of 4 m above sea level, the Gyben-Hertberg relationship suggests that the saltwater-freshwater interface (if present) would be on the order of 160 m below sea level. Given this scenario, aside from the likelihood of mitigative conditions from impermeable ground (permafrost), the risk for saltwater up-coning to impact the reservoir under current conditions is considered minimal (if any).

3.1.2 Lateral Migration

3.1.2.1 Sea Level and High Tide

Within coastal settings lateral migration of seawater can occur due to a number of factors, e.g. overpumping of wells near the shoreline, high tides inducing a driving force for migration of the saltwater-freshwater interface landward or overtopping of low elevation areas, and erosion of protective barriers (e.g. coastal dunes, cliffs).

Regarding the potential for high tides to impact Marcil Lake, under current conditions, it is understood that the tidal range in the Arctic Bay region is on the order of 2.3 m relative to chart datum. Chart Datum (CD) is measured relative to the lowest level the tide would be expected to fall under average meteorological conditions. In comparison, Geodetic Datum (GD) is understood to normally represent "*average (mean) sea level*". If it is assumed that the difference between chart datum and geodetic is approximately one half the range in tidal fluctuation (2.3 m total), then the geodetic elevation of a "normal" Arctic Bay high tide would be 1.2 m geodetic (i.e. high tide at 2.3 m chart datum = 1.2 m geodetic datum).

Based on available topographic mapping the perimeter ridge separating Marcil Lake from the sea can reach heights of 18 m or more particularly along the Adams Sound shoreline (lowest elevation along this section is 10 m geodetic) and to a lesser degree along the Arctic Bay/ Marcil Lake shoreline. Given these relatively high elevations, under current and reasonably foreseeable conditions, the potential for high tides to induce lateral migration into Marcil Lake along most of the shoreline is expected to be negligible.

In the area of the lake discharge to the northwest (along the Arctic/ Marcil Lake section), the geodetic elevation range is much lower and understood to be in the range 0 to 5 m. Although this provides for less buffer than the dominant bedrock ridge present as mafic dyke around much of the lake's south and southwest perimeter, assuming a 1.2 m geodetic high tide, the potential for lateral migration of seawater through this much lower area is also expected to be negligible. The fact that the water source is located in a zone of essentially permanent permafrost is expected to provide significant additional mitigative conditions; i.e. impermeable frozen ground other than for a relatively thin seasonal active layer thaw understood to be on the order of from surface to 1.2 m depth, EXP (2022b).

3.1.2.2 Extreme Sea Levels (ESLs) / Storm Surge

It is important to recognize that storm surge incidents combined with increased wave heights will add additional height to the assumed high tide. Storm surge (https://sealevel.nasa.gov/glossary/#item_207) is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge should not be confused with storm tide. Storm surge is produced by water being pushed toward the shore by the force of the winds moving cyclonically around the storm; storm tide is defined as the water level rise due to the combination of storm surge and the astronomical tide. Such incidents can be referred to as "*extreme sea levels, or ESLs*" (e.g. IPCC AR6, 2021) and can result in extreme flooding and erosion in coastal areas, particularly when storm surge coincides with normal high tide resulting in storm tides reaching up to 6 m or more in some cases.

Under current conditions, it is understood that severe storm surge in Canadian regions can be on the order of 2 to 3 m (https://open.canada.ca/data/en/dataset/de1a9911-8893-11e0-82c2-6cf049291510). More locally for the Arctic region, a relatively dated paper by Harper et al. (1987) reported a local surge maximum occurred at Tuktoyaktuk of approximately 2.4 m above mean sea level (MSL); lower maximum surge elevations (2 m above MSL) were documented to the north and west of Tuktoyaktuk. Although that paper reported there was no evidence that higher surges had occurred during the last 100 years, it is generally accepted that reduction in sea ice, a highly likely occurrence with continued climate warming of the Arctic (e.g., IPCC AR6, 2021), will result in increase in storm surge with time and the increasing frequency and severity of ESL events. Under all five illustrative SSPs used in IPCC AR6, the Arctic is likely to be practically sea ice-free in September 31 at least once before 2050 (IPCC, 2021b; bullet B.2.5) with more frequent occurrences for higher warming levels.

Regarding Marcil Lake, for consideration of current and near term conditions, recognizing that Arctic Bay may have some natural attributes (e.g. perimeter ridge separating the lake from the adjacent ocean water; possibility of the local/ regional area landmass/ shoreline configuration to limit wave fetch) that may mitigate the magnitude of storm surge, assuming a 2.5 m storm surge event coupled with a relatively high tide (e.g. 2.3 m chart datum or approximately 1.2 m geodetic), the height of the storm surge for current conditions would be 3.7 m geodetic. Under these conditions, this assumed ESL/storm surge scenario (other than wave spray) would approach but not be expected to overtop the lower 4.5 m elevation of Marcil Lake's perimeter ridge. However, as discussed below, climate change effects such as sea level rise and reduction in ice cover combined with the projected increasing intensity and frequency of extreme events such as storm surge, can reasonably be expected to significantly increase the risk of seawater to impact Marcil Lake water quality.

3.2 Sea Level Rise (Future Conditions)

3.2.1 Sea Level Rise

Of the many threats posed by climate change, for coastal communities and infrastructure, sea level rise and ESLs are likely the most significant in terms of near and long term impacts. The two main factors causing sea level rise the melting of ice over land, and the oceans warming causing seawater to expand and take up more space in the ocean basin. Other contributing processes/ phenomenon include changes in land water storage and vertical land motion related to isostatic rebound or subsidence of the earth's crust resulting from glacial unloading or tectonic activity. Regarding the latter, it is understood that isostatic rebound in Arctic regions may be one factor that will contribute significantly to mitigating sea level rise; i.e. as sea level rises the vertical rise of the earth's crust due to glacial unloading will compensate in part for rising sea levels.

According to the National Ocean and Atmospheric Administration (NOAA) (https://oceanservice.noaa.gov/facts/sealevelclimate.html) global tidal records from 1900 to 1990 show an estimated 10 to 12.7 cm rise in global mean sea level (0.11 to 0.14 cm/year), rising to 7.6 cm (0.30 cm/year) in the 25 years from 1990 to 2015. Currently, sea level is rising about 0.32 cm/year with the rate of rise projected to increase in the future. By the end of the century (2100) median sea level rise projections according to IPCC AR5 ranged from 0.15 m for a low-end global warming scenario to 0.6 m for a high-end scenario (compared to the average sea level from 1986-2005). These estimates come with a large degree of uncertainty, which pushed the top bound of likely sea-level rise above 0.75 m; other estimates including the more recent IPCC AR6 have suggested the rise could be much higher (e.g. 2.4 m or more).

The NASA Sea Level Projection Tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool) allows users to visualize and download the sea level projection data from the IPCC 6th Assessment Report (AR6). The goal of this tool is to provide easy and improved access and visualization to the consensus projections found in the IPCC's AR6 sea level rise projection datasets for the five (5) SSP scenarios, relative to a baseline of 1995-2014, in meters.

For the current Arctic Bay Marcil Lake study, the NASA Sea Level Projection Tool was used to access the regional projections for the Arctic Bay area and the downloaded data is provided in Appendix B. Individual contributions of the various processes causing sea level rise are shown for the year 2100. Median values and likely ranges (17^{th} and 83^{rd} percentiles which are understood to define the range in which there is a 66 % probability that the projected outcome will occur) are shown. Average rates for total sea-level change are shown in mm yr-1. The SSP5-8.5 *low confidence* column incorporates a representation of the potential effect of low-likelihood, high-impact ice sheet processes that cannot be ruled out. In particular, this column shows the 17th-83rd percentile range factoring into account information from structured expert judgement and from a model incorporating Marine Ice Cliff Instability a hypothesis that Antarctic ice sheets with ice cliffs taller than a critical height (~90 m) will undergo structural collapse, initiating runaway retreat in ice-sheet models (Clerc et al., 2019).

The Arctic Bay area sea level rise projection results (Appendix B) for the years 2030, 2050, 2100 and 2150 are summarized in **Table 3-1.** The range of sea level rise projections median values for the various SSPs (excluding the SSP5-8.5 *low confidence* scenario) and year 2100 varied from 0.05 m to 0.25 m; and for year 2150, -0.12 m to 0.27 m. The range of upper bound projections (83^{rd} percentile) was 0.63 m to 0.93 m for year 2100; and for year 2150, 0.80 m to 1.43 m. When compared to global average projections the Arctic Bay region sea level rise values are understood to be lower and in large part attributable to the regional isostatic rebound (raising) of the land surface due to ice/ glacier unloading.

Table 3 1 - Summary of Sea Level Rise

Year		SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 Low Confidence
Total (2030)	Median	0.06	0.04	0.04	0.04	0.04	0.03
	17th , 83rd	(-0.09, 0.21)	(-0.12, 0.19)	(-0.11, 0.19)	(-0.11 ,0.19)	(-0.12,0.19)	(-0.14,0.19)
Total (2050)	Median	0.08	0.06	0.06	0.06	0.07	0.06
	17th , 83rd	(-0.19, 0.35)	(-0.21, 0.33)	(-0.21 ,0.33)	(-0.22,0.34)	(-0.21 ,0.35	(-0.26,0.35)
Total (2100)	Median	0.05	0.06	0.13	0.1	0.25	0.30
	17th , 83rd	(-0.51 ,0.63)	(-0.52,0.64)	(-0.46,0.74)	(-0.44,0.81)	(-0.39,0.93)	(-0.56,1 .09)
Total (2150)	Median	-0.02	-0.12	0.05	0.17	0.27	0.91
	17th , 83rd	(-0.89,0.88)	(0.12,0.80)	(-0.90,1 .05)	(-0.81 ,1 .24)	(-0.78,1 .43)	(-0.79,4.24)

Using the upper values of sea level rise projection (i.e. 83rd percentile) and assuming an additional 1.2 m for high tide would give ocean levels as shown in **Table 3-2**; in year 2100 a high tide level of 2.13 m , and 2.63 m in year 2150 (excluding SSR5-8.5 *low confidence* scenario). Therefore, assuming the IPCC AR6 sea level rise projections are representative of future conditions, for most of the SSP scenarios the median values (and range) of sea level rise projections for the near (2050), intermediate (e.g. 2100), and longer (2150) terms is anticipated to pose minimal risk of overtopping or inducing lateral saltwater intrusion into Marcil Lake. This assumes that the perimeter ridge will remain intact and will not be compromised due to permafrost thaw or erosion.

Table 3 2 - Summary of High Tide Elevations (geodetic) High Tide (1.2 m above geodetic)

Year		SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 Low Confidence
Total (2030)	Median	1.26	1.24	1.24	1.24	1.24	1.23
	17th , 83rd	(1.11, 1.41)	(1.08,1.39)	(1.09,1.39)	(1.09,1.39)	(1.08,1.39)	(1.06,1.39)
Total (2050)	Median	1.28	1.26	1.26	1.26	1.27	1.26
	17th , 83rd	(1.01,1.55)	(0.99,1.53)	(0.99 ,1.53)	(0.98,1.54)	(0.99,1.55)	(0.94,1.55)
Total (2100)	Median	1.25	1.26	1.33	1.37	1.45	1.50
	17th , 83rd	(0.69,1.83)	(0.68,1.84)	0.74,1.94)	(0.76,2.01)	(0.81,2.13)	(0.64,2.29)
Total (2150)	Median	1.18	1.08	1.25	1.37	1.47	2.11
	17th , 83rd	(0.31,2.08),	(1.32,2.00)	(0.30,2.25)	(0.39,2.44)	(0.42,2.63)	(0.41,5.44)

***NOTE - Yellow highlight indicates exceedance above assumed 4.5 m “critical” elevation for overtopping of perimeter ridge.**

3.2.2 Extreme Sea Levels (ESLs) - Future

As noted above, storm surge and related phenomenon (extreme high tides, wave action) combine to form the potential of extreme sea level events (ESLs). With climate change, it is generally accepted that there will be increasing intensity and frequency of storm surge and related ESLs and that these will increase risk particularly in low lying coastal settings. Even without an extreme event, recent work in the Grise Fiord, NU community by researchers (https://rbr-global.com/grise-fiord-coastline-changes/) has shown that wave action can lead to enhanced permafrost erosion, and that even small waves can have impacts. These more intense events have even led some communities in the Arctic Region to relocate (https://nunatsiaq.com/stories/article/65674high_waves_batter_nunavuts_most_northern_community/).

To assess the potential of climate change ESLs to impact Marcil Lake, the sea level rise projections for the years 2030, 2050, 2100 and 2150 provided in Appendix B were combined with an assumed ESL event that included a 1.2 m high tide above geodetic datum and an additional 3 m to account for storm surge (i.e. resulting in a storm tide ESL of 4.2 m). The calculated/ projected results under these assumptions are provided in **Table 3-3** for the respective SSPs and timelines.

Table 3 3 - Summary Extreme High Tide (ESL) Elevations (geodetic) ESL (High Tide + 3 m Storm Surge= 4.2 m)

Year		SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 Low Confidence
Total (2030)	Median	4.26	4.24	4.24	4.24	4.24	4.23
	17th , 83rd	(4.11, 4.41)	(4.08-4.39)	(4.09,4.39)	(4.09,4.39)	(4.08,4.39)	(4.06,4.39)
Total (2050)	Median	4.28	4.26	4.26	4.26	4.27	4.26
	17th , 83rd	(4.01,4.55)	(3.99,4.53)	(3.99 ,4.53)	(3.98,4.54)	(3.99,4.55)	(3.94,4.55)
Total (2100)	Median	4.25	4.26	4.33	4.37	4.45	4.50
	17th , 83rd	(3.69,4.83)	(3.68,4.84)	(3.74,4.94)	(3.76,5.01)	(3.81,5.13)	(3.64,5.29)
Total (2150)	Median	4.18	4.08	4.25	4.37	4.47	5.11
	17th , 83rd	(3.31,5.08),	(4.32,5.00)	(3.30,5.25)	(3.39,5.44)	(3.42,5.63)	(3.41,8.44)

***NOTE - Yellow highlight indicates exceedance above assumed 4.5 m "critical" elevation for overtopping of perimeter ridge.**

Based on the tabulated data, extreme sea level events would begin to marginally exceed a 4.5 m ridge elevation around 2050 for a few of the higher upper bound sea level projections (e.g. SSP1-1.9, SSP5-8.5 and the more extreme SSP5-8.5 *low confidence* scenario). However, these are generally marginal exceedances of 0.05 m. For the year 2100, exceedances are present for the upper bound sea level rise/ ESL values (83rd percentile values) for all scenarios exceeding the assumed 4.5 m overtopping elevation by 0.33 to 0.63 m for all but the "worst case" SSP5-8.5 *low confidence* scenario. By year 2150 the exceedances are all greater than 0.50 m and in the case of the SSP5-8.5 *low confidence* scenario upper bound sea level rise (83rd percentile = 4.24 m) the ESL height is 8.44 m, i.e. on the order of 4 m higher than the assumed critical 4.5 m ridge elevation. Under this last scenario it is expected that Marcil Lake would be seriously impacted by saltwater.

An important aspect in consideration of future ESLs regards frequency of occurrence, IPCC AR6 (2021) suggests that continued retreat of sea ice cover in the Arctic will lead to more energetic wind-wave conditions, and that even small to moderate changes in mean relative sea level (RSL) will lead to potentially significant increases in the frequencies with which certain thresholds are exceeded. The concept of increased frequency of currently rare ESL events is discussed further by Cai (2019) who notes that if the one in one hundred year (1 in 100) extreme sea level occurrence is thought of in terms of the recent past, it can be referred to as a *Historical Centennial Event* or HCE. With climate change and rising sea levels, HCEs can be expected to become annual events; i.e. what in the recent past happened once every 100 years will happen once every year or even multiple times per year in future at many locations.

From a "global average" perspective of ESL events, according to IPCC AR6, by 2050, a historical (1995–2014) 1% annual probability ESL will have increased to a 19–30% annual probability. By 2050, the 1% historical annual probability event is expected to become an annual event at 19–31% of the 634 tidal stations studied, and at over 50% of stations by 2100.

Information provided by Cai (2019) suggests that the timeline for this phenomenon of more frequent ESL occurrence will be most acute in areas near and in proximity to the equator where hurricanes, cyclones and typhoons originate. For example, in select Caribbean areas along parts of the southwest and southeastern coasts of the United States, the HCE may occur annually within a timeline of 2030 to 2060. However, even though IPCC AR6 reports that these extreme weather phenomenon are moving toward the poles, for Arctic regions information provided by Cai (2019) suggests that this phenomenon will not occur until at least 2100 and beyond.

3.2.3 Summary and Discussion – Future SLR and ESLs

The results of the future sea levels and calculated extreme sea levels outlined above, subject to the related assumptions, suggest that for most SSPs considered by IPCC AR6, that the risk for overtopping the Marcil Lake barrier ridge should be low until sometime between 2100 and 2150. Within this timeline, although there are potential incidents where ocean side water levels (particularly for ESL events) could reach or exceed the assumed 4.5 m overtopping elevation, for the most part the exceedances are marginal.

In the case of marginal exceedances for ESLs, it is speculated that these would be of relatively short duration and that freshwater watershed inflow from snowmelt, runoff and precipitation combined with say an assumed 4 m water level elevation head difference retained in Marcil Lake would be sufficient to "flush out" sea water that might overtop the ridge and mix with the lake's freshwater. In addition, the sea level rise and ESL water level elevation exceedances are generally considered within the range in which relatively "low tech" mitigation could be considered and implemented such as construction of an earthen berm and shoreline armoring to protect against the upper limits of projected high tides and most extreme storm tides/ ESLs. For example, in the event current or future conditions were suspected to overtop or erode the existing low lying ridge, the ridge could be built up along its approximately 600 m low lying outflow area width. It is suggested that this would be a manageable undertaking given the assumed readily available aggregate resources in the immediate area.

It must be appreciated that the sea level rise (SLR) and related ESL projections are subject to a great deal of uncertainty due to the number of variables involved, and ultimately what future climate storyline/ SSP will govern and outcomes actually realized. As noted, for most of the SSP scenarios the median values (and range) of sea level rise would be anticipated to pose relatively low risk of saltwater impacts on Marcil Lake. If it is assumed as suggested by IPCC AR6 that SSP2-4.5 is representative of the likely climate change scenario/ outcome realized, then all other factors being equal (e.g. minimal permafrost thawing, retention of limited active permafrost layer) maintaining acceptable water quality in Marcil Lake should be manageable. For example, under the assumed conditions of high tide and storm surge, the median and maximum ESLs for SSP2-4.5 in year 2100 are 4.33 m and 4.94 m, the latter marginally exceeding (by 0.44 m) the 4.5 m overtopping elevation. However, at the extreme range of sea level rise projections and related ESLs (e.g. 4.24 m sea level rise by 2150 for SSP5-8.5 *low confidence* scenario, Appendix B) there would be significant risk and high probability of overtopping and inundating Marcil Lake by as early as 2100 and more acutely by 2150.

In the extreme case, looking beyond 2150, IPCC AR6 reports (IPCC AR6, 2021b: Figure SPM.8, reproduced in Appendix B) that the SSP5-8.5 *low confidence* scenario could lead to sea level rise of 15 m and possibly more by 2300. If such projections were to be realized it is expected that the Arctic Bay community would have to retreat/ relocate from the shoreline, and that an alternate water source would need to be developed or the current Marcil Lake watershed reservoir and withdrawal relocated and significantly modified (e.g. dam further upstream).

3.3 Permafrost Thaw

An expected result of climate change that could impact the Marcil Lake freshwater source quantity and quality is potential for impacts related to permafrost thaw. Under current conditions it is understood that Arctic Bay/ Marcil Lake falls within a zone of continuous permafrost with an active layer estimated to be on the order of surface to 1.2 m depth (EXP, 2022b). Near the shoreline it has been suggested (e.g. EXP, 2022b) that there is potential for the warmer nearby ocean waters to influence or alter the nature and depth of the permafrost and active layer thickness near the shoreline even for current conditions. Climate change and the related loss of sea ice could further significantly alter the permafrost regime particularly near warming ocean waters.

Potential processes, related risks, and a general qualitative assessment of the relative risk to the Marcil Lake's freshwater quality and quantity due to potential permafrost thaw are identified to include:

a) thawing of existing permafrost such that the active zone was to increase/ deepen and open currently frozen (i.e. impermeable) subsurface/ porosity flow features (e.g. intergranular porosity in overburden soils; fracture/ jointing/ bedding planes in the bedrock). Under these conditions it is conceivable that the presumably impermeable frozen permeability features in the perimeter ridge could result in "leakage" loss from the lake into the sea or even sudden lake drainage, and/or enhanced potential for lateral intrusion landward due to extreme sea level events.

   Regarding the potential for sudden lake drainage, Canada-Nunavut Geoscience Office (CNGO, 2022) noted that permafrost thaw has been documented in Siberia and the western Arctic of North America, and that some studies suggested that such drainage could decrease the number of lakes and their total surface area over the long term. However, CNGO (2022) noted that at the time of writing they were not aware of any sudden draining of lakes or ponds occurring in Nunavut that could be attributed to permafrost degradation but this could change in the future under higher greenhouse gas emissions scenarios.

   Regarding Marcil Lake, it is EXP's opinion that for current and near term conditions, and likely into the foreseeable future (e.g. 40 to 50 years hence), that the risk of this aspect of permafrost thaw causing potential drainage of Marcil Lake is low. The rationale for this assessment is based in part on the geothermal modelling completed recently as part of the geotechnical investigation (EXP, 2022b) for the proposed Marcil Lake Water Treatment Plant (WTP). This modelling study suggested relatively minimal change in the depth of permafrost thaw within at least the next 40 years. However, it must be appreciated that predictions of climate change induced permafrost thaw will be strongly dependent on the rate of climate warming. Therefore, the potential for lake drainage cannot be completely discounted and site conditions should be regularly monitored to assess risk and determine if potential mitigative options are warranted.

b) thawing of permafrost causing or enhancing erosion due to processes such as wave action (ocean and lake sides), sea level rise, storm surge, and slumping resulting in impacts to or removal of portions of the existing barrier ridge separating the lake from the seawater. It is suspected the most critical/ susceptible area would be the till veneer currently mapped along the lake's perimeter and in particular within the low lying outflow area located at the lake's northwest corner. Thawing of this material and resulting erosion could compromise the integrity of the ridge and possibly result in its complete loss.

Since the depth of the till veneer is not currently known, in the event of its loss or partial loss, it is uncertain as to what level of protection the underlying bedrock could provide. For example, even removal of 1 or 2 m of overburden could significantly increase the risk of overtopping given there is little buffer between the anticipated elevation of high tide plus storm surge and wave action (ESL events) and the lower maximum ridge elevations (e.g. 4.5 m) of the ridge. However, regarding this risk it is EXP's preliminary opinion that for the near and the reasonably foreseeable (e.g. 40 years hence) that the risk is low. Rationale for this is similar to that above regarding potential for lake drainage; that is under current climate warming projections it is assumed that no significant melting/ alteration of the permafrost will occur. However, it is recommended that the protective ridge particularly where present as overburden (e.g. till veneer) at the northwest outflow area be observed on a regular basis including after storm surges to document and provide for a continuous record of ridge conditions and response to extreme events and seasonal thaws. To assist in this task, it is suggested that local community members could be trained to complete high level "geomorphological/ erosion" screenings and document their findings (e.g. erosion measurements, photographs). In addition, it is suggested that boreholes could be completed to assess the thickness and type of sediments in the lake outflow area.

c) thawing of permafrost within the watershed and release of relic porewater containing seawater contaminants such as chloride and sodium or other potential parameters that could impact water quality. A screening level investigation of community water quality across Nunavut, CGNO (2022), noted the following:

> "…..Climate change is also driving direct changes to surface water quality through increased chemical reaction rates in warming waters, as well as indirectly through changes to thermal stratification, lake mixing (Mueller et al., 2009) and many other interconnected biogeochemical processes (Rouse et al., 1997;Williamson et al., 2009; Roberts et al., 2017; Benateau et al., 2019). For example, permafrost thaw and slumping increase the transport of organic matter and associated metals and nutrients into the water column (Louiseize et al., 2014; Fouché et al., 2020; Miner et al., 2021), which can in turn stimulate primary productivity and drive further biogeochemical change (Brubaker et al., 2010; Vincent et al.,2013). There is a scarcity of published data on baseline water quality and biogeochemical conditions in Nunavut (Chiasson-Poirier et al., 2019), making it difficult to know what climate impacts may be occurring now, and how current conditions are likely to change. This information is key to the ability of communities to adapt to climate change, specifically with respect to ensuring long-term water security (Rouse et al., 1997; Mueller et al., 2009)."

Using preliminary findings by EXP (2016) supplemented by additional water analyses, CGNO (2022), presented a case study for the community of Sanikiluaq located on Belcher Island in southeastern Hudson Bay. EXP (2016) had reported an increase in the concentration of saltwater indicator parameters (e.g. chloride, sodium, conductivity) in the community potable water source in 2009. By March 2014 the chloride levels had risen to 654 mg/L which is well in excess of the Health Canada aesthetic drinking water objective (250 mg/L or lower). Community members reported issues with taste throughout the year but most noticeable during the spring freshet.

Based on the fact that EXP (2016) mentioned no field evidence was found to link the source of the saline parameters to road salt, saltwater or salt spray, CGNO (2022) hypothesized that:

> *"…the source of the salts may have been from thawing of permafrost in fine grained marine sediments. These sediments were estimated to comprise an estimated 10 – 30 % of the watershed* sediments *which were deposited when the island was submerged by the sea following deglaciation approximately 8,700 years ago. When the sea retreated from the elevation of the reservoir about 800 years ago, seawater was trapped in the sediments. The recent climate warming of about 1.2°C*

> *observed between 1990 and 2010 likely progressively warmed the permafrost and consequently deepened the active layer, as observed in nearby communities. The warming may have thawed a thin upper salt rich layer in the fine-grained marine sediments. The thawing would cause the gradual release of salty water into the overlying watershed and ultimately into the drinking water source."*

From this case study, CGNO concluded:

> Adequate data on primary and alternate drinking water sources is key to determining how quickly communities are able to adapt and identify safe alternative supplies or implement new technologies. This case also highlights the need for more holistic and routine data collection in primary and alternative source watersheds to anticipate and adapt more quickly to changes in water quality or quantity. In addition to improving the collection of water quality data, a better understanding of local permafrost characteristics (ice richness, total depth, salinity and active layer depth) is needed.

It is EXP's opinion that the CGNO's (2022) Sanikiluaq case study and conclusions are equally relevant to the Marcil Lake watershed its potable water reservoir given that local surficial geology mapping combined with preliminary interpretation of geomorphological features based on topography suggest relic shorelines within the watershed at higher elevations, and that near the inflow to the lake a large unit mapped as "marine terrace" sediments is shown. This would suggest a high probability for frozen relic seawater to be present within at least some of the Marcil Lake watershed sediments, and as such potential for saline impacts on water quality in the event of increase in permafrost thaw. It is acknowledged that this could be somewhat offset by the relatively large amount of watershed scale seasonal/ spring thaw snowmelt runoff that would tend to dilute melting sediment porewater.

Taliks and Methane "Lakes" – Regarding permafrost thaw and its potential for impact on Marcil Lake, although suspected as remote, the concepts of taliks and the recent increasing reports of methane release from lakes in Arctic regions are noted.

A talik is a layer of year-round unfrozen ground that lies in permafrost areas. They can occur underneath lakes and rivers, where the deep water does not freeze in winter and thus the soil underneath does not freeze either. Some permafrost regions may also develop an unfrozen layer between the seasonally thawing and freezing top layer and the permafrost. This layer is called a supra-permafrost ("above the permafrost") talik; it is different from traditional taliks, which are usually associated with water bodies, in that a supra-permafrost talik occurs because the ground that thawed in the summer does not completely refreeze in the winter. Calculations show that climate warming induces supra-permafrost taliks in intermediately cold regions (https://en.wikipedia.org/wiki/Talik).

Regarding methane, in some areas of the Arctic massive wedges of actual ice can be present within permafrost. When that ice melts, the ground surface collapses and forms a sinkhole that can fill with water resulting in the formation of a thermokarst lake. Two things can happen as the permafrost layer thaws beneath lakes: microbial activity increases and pathways form in the permafrost. Microbial activity can digest dead plants and other organic matter in the previously frozen soil in a process that produces carbon dioxide and methane. More rarely, permafrost thaw can form 'chimneys' under lakes that allow methane and other gases – previously trapped deep underground – to escape. This release of 'geologic' methane is known to be happening in certain areas of the Arctic and it's occurrence is expected to increase with climate change. (https://blogs.nasa.gov/earthexpeditions/2022/09/22/alaskas-newest-lakes-are-belching-methane/).

For the current study, because of various factors (e.g. Arctic Bay being located relatively far north and within an area of continuous permafrost; site geology), the potential for talik conditions and methane "belching" lake formation for current conditions is assumed by EXP to be remote. However, with increased climate change warming, it is suggested that over the longer term these aspects of Arctic hydrology be included in the continued consideration and assessment of risks to Marcil Lake (see Section 4, below). For example, the possible presence or development of talik-like conditions could lead to development of a more traditional (i.e. unfrozen) oceanwater/ freshwater interface within the subsurface. In the case of thermokarst lake formation, if such features were to develop due to thawing of possible ice-rich sediments within the watershed, their formation and potential for methane off-gassing could have possible implications to Marcil Lake freshwater quality.

4 Monitoring and Mitigation/ Adaptation

Based on the preliminary saltwater intrusion/ saline impacts climate screening assessment outlined above, the near (e.g. 2030 – 2050) and medium to intermediate term (e.g. 2050 to 2100) risk of saline impacts to the Marcil Lake fresh potable water source is interpreted to be low. However, it is evident that predictions of potential climate change impacts are subject to a number of variables and uncertainty. In particular, sea level rise and the expected increase in intensity and frequency of ESL/storm surge events for coastal communities such as Arctic Bay vary widely and will be strongly dependent on the vagaries of nature coupled with the actual shared socioeconomic pathway (SSP) and corresponding climate change pathway (e.g. low versus high greenhouse gas emissions) that unfolds to the end of year 2100 and beyond. Given these uncertainties and the general lack of site specific information available for Arctic Bay in general, and the Marcil Lake water source in particular, the following monitoring, assessment and general mitigation aspects are presented for consideration to enhance monitoring and long term adaptation planning.

4.1 Monitoring and Assessment

Near Term (0 to 10 years):

- Establish an Arctic Bay Climate Change Committee staffed with local community members. This group would oversee proposed monitoring, assessment and potential adaptation/ mitigation plans related to Marcil Lake. Members of the group could also assist in coordinating community individuals who could support outside technical resources in data collection, sampling station maintenance, and the sampling and monitoring work recommended below.
- Develop and implement a Watershed Protection Plan for Marcil Lake and its watershed area and incorporate the protected area into municipal or regional government as a regulated protected surface watershed;
- Water Quality Monitoring/ Assessment
    - Develop and implement a regular raw water quality monitoring program. This work should include sampling and analysis of general chemistry and trace metals parameters that will track potential water quality changes over time. Suggested sampling locations would include Marcil Lake and a station at the inflow to the lake to document runoff/ recharge water entering the lake from the watershed. It is recognized that the relatively remote nature of the Arctic Bay will complicate analysis of samples by a fully equipped and accredited laboratory. Given this, it will perhaps be only practical to have full general chemistry and trace metals scans completed on a once or twice per year basis. However a "field" testing program using well developed field testing equipment (e.g. Hach water quality test kit, conductivity datalogger) could be used to supplement more detailed laboratory analyses.
    - Install a lake level monitoring gauge to document seasonal and yearly water levels in Marcil Lake.
    - Install a conductivity meter at the water source to establish a "real" time and continuous record of water quality regarding conductivity which is a fundamental parameter to monitor for potential saline water impact. It is understood that a new water treatment plant is being considered for the community and if so the facility should be equipped a conductivity monitoring probe/ datalogger (and other low cost monitoring probes such as turbidity). In the interim, a water level and conductivity probe could be installed and configured at the Marcil Lake extraction point/ intake to record conductivity (e.g. Solinst or similar water level, temperature and conductivity probe; (https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/ltc-

levelogger/) (Note that the conductivity probe is typically configured to measure water level and temperature; the water level function could be used to supplement the lake level gauging measurement station).

- Develop and implement a conductivity profiling protocol for Marcil Lake. This would consist of measuring water conductivity as a function of lake depth to assess whether there is currently any evidence of saline water or conductivity stratification with depth. The protocol and initial screening should be developed and implemented to establish baseline conditions, and a consistent approach to permit a direct comparison to future repeat conductivity profiling survey(s).

As noted in the hydrogeological and water balance report (EXP, 2022a), the Marcil Lake reservoir and related watershed drainage basin is associated with snowfall and snowmelt-generated runoff where rapid snowmelt results in over 80-90% of the annual runoff flow occuring within a few week period during late spring. Therefore, timing and duration of the melt season depends on the weather and end-of-winter snow conditions. Water quality monitoring and assessment should incorporate consideration of these seasonal conditions.

- Marcil Lake Geotechnical Assessment
    - Given the interpreted importance of the perimeter ridge separating Marcil Lake from the open sea (Arctic Bay and Adams Sound), a geotechnical screening of the coastline is recommended with emphasis on characterization of the nature of the lake's outflow area. Suggested elements of this assessment should include:
        - A site walkover by a qualified coastal geomorphologist/geologist to map the Marcil Lake perimeter shoreline. This work would characterize:
            - the nature of the bedrock ridge (e.g. rock type, nature of fracturing/ bedding/ jointing);
            - the location and nature of the glacial till veneer present along the lake shoreline and in particular in the lake outflow area;
            - location of coastal sediments along the shoreline; and,
            - document coastal dynamics including interpretation of high tide and storm surge lines/ elevations along the shoreline.
        - Complete a geotechnical borehole program to characterize the nature and depth of surficial deposits along the shoreline. The priority area for this work would be to assess the nature (soil type, thickness, ice content) of the till veneer that is present at the outflow area of the lake. Supplemental work could be considered for other areas along the ridgeline that separates Marcil Lake from the sea to assess areas of overburden (or fractured bedrock) that may be observed during the initial geomorphology walkover.
        - Complete select boreholes as monitoring wells to allow for collection of porewater samples to assess parameters indicative of potential saline impacts (e.g. chloride, conductivity) and assess hydraulic conductivity.
        - Complete select boreholes with thermistors to allow ground temperature profiles to be documented and monitored to establish existing conditions and provide for future monitoring

        - Supplement permafrost assessment and monitoring work with other research and initiatives directed toward long term monitoring and assessment of Arctic Bay area permafrost thaw (e.g. https://permafrostthaw.org/).

- Arctic Bay/ Adam Sound Coastal Dynamics Assessment
    - Consult with other Nunavut area communities (e.g. Grise Fiord and their related outside researchers) to review the findings and work in progress at that community regarding existing conditions related to wave action and risks to coastal geomorphology and infrastructure, and assess how their findings of current wave dynamics studies may pertain to Arctic Bay and Marcil Lake;
    - There appears to be a tide gauge station in the immediate vicinity of Marcil Lake on the shore of Arctic Bay (Station 5865, Latitude = 72.993, Longitude = 85.062).
        - Adapt information from the existing Arctic Bay tidal gauge station into the Marcil Lake risk monitoring and review work and document evolution of near, intermediate and long term tidal range and storm surge/ESLs in the immediate area of the lake shoreline;
    - Consider development and implementation of a wave/ storm surge characterization program. This program would include installation of wave height monitoring stations and equipment to assess seasonal variations and conditions including storm surge along the Arctic Bay and Adam Sound shorelines where they border Marcil Lake.

Medium and Long Term (10 years – ongoing):

- Implement through the Arctic Bay Climate Change Committee regular monitoring and review of the climate change literature and related evolution and projections with focus on Arctic Region impacts. Aspects of primary interest should include sea level rise, storm surge and ESL levels and projections; permafrost conditions; rate and depth of permafrost thaw and its implications to water quality and coastal erosion.
- Develop and continue to refine alternate water supply and water treatment options in the event of saline/ saltwater intrusion into Marcil Lake and related degradation of water quality.

4.2 Mitigation/ Adaptation

In the event "worst case" climate conditions were to result in salt/ saline water quality impacts on Marcil Lake from sea level rise, storm surge, and/ or permafrost thaw and related erosion either by lateral migration, breaching of the perimeter ridge or significant release of seawater from previously frozen watershed sediments potential mitigation/ adaptation strategies could include:

- Construction of coastal defences (e.g. seawall in low lying areas) to protect against sea level rise and storm surge. One possible approach could be to install an earthen berm and armoring supplemented (if warranted) with concrete structure(s) across the outflow stream(s) that drain Marcil Lake into Arctic Bay; an example alignment is included in Appendix B. The intent would be to enhance isolation and impoundment of the lake water (e.g. dam low lying outflow stream and ridge sections to create a sufficient continuous barrier);
- Construction of additional water treatment plant infrastructure such as a reverse osmosis system to lower salinity, or in the extreme, construct a desalination plant to treat ocean/ saline water either pumped from the lake or directly from Arctic Bay;
- Consider an alternate reservoir system at a higher elevation and further "upstream" within the Marcil Lake watershed. For example, a dam could be constructed upstream of the alluvial fan area currently present where Marcil Creek flows into Marcil Lake;

- In the event of a "catastrophic scenario" (e.g. SSP5-8.5 *low confidence*, year 2300 sea level rise of 15m or more), the only likely option may be to relocate the community.

5 Limitations of Climate Change (Saltwater Intrusion) Screening

Similar to the hydrologic and water balance study (EXP, 2022a) results from this review of potential saltwater/ saline impacts on the Marcil Lake fresh water supply should be considered high-level and coarse resolution. This desktop study provides a screening level assessment of the potential for saltwater/ salinity impacts on the drinking water supply for the community of Arctic Bay with consideration to information on climate change readily available in the literature. This study focuses solely on the potential for climate induced impacts related mainly to potential saltwater/ saline impacts on water quality; regarding quantity the reader is referred to the hydrologic and water balance study (EXP, 2022a).

There are a number of limitations based on generally poor site specific data availability, as well as the uncertainty associated with the number of variables and differences in climate change scenarios (i.e. SSPs) which are used as the basis for projecting near, intermediate and long term (e.g. to year 2150 and beyond) potential climate change effects. To address these uncertainties recommendations including site specific assessment (e.g. geotechnical assessment of the barrier ridge; assessment of tide, wave and storm surge conditions), and development and implementation of a regular raw water source and watershed monitoring program has been provided.

In general, there is a lack of field studies and site specific information detailing the hydrological regime and hydrological features that currently provide protection from saltwater and saline impacts on Marcil Lake from the adjacent saltwater bodies (Arctic Bay and Adam Sound). In addition factors that are anticipated to potentially affect the water quality and quantity of freshwater recharge (e.g. permafrost thaw with release of possible contaminants from porewater, change in flow through the active layer; changes in watershed flow) within the Marcil Lake watershed are generally poorly understood.

To improve the accuracy of future studies and provide for information to guide near, intermediate and long term planning, it is recommended to conduct additional field studies to provide more complete and site-specific information on aspects such as temporal and spatial water quality; geotechnical conditions including bedrock assessment, and depth and susceptibility of overburden/ glacial deposits to thaw and erosion along the barrier coastline; and ocean conditions (e.g. tidal and storm surge levels, wave heights and intensity).

Limitations of climate projections - Regarding climate change projections, the IPCC AR6 Sea-Level Rise Projections are licensed by the IPCC authors under a Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/). EXP Services Inc. and the data producers and data providers make no warranty, either express or implied, including, but not limited to, warranties of merchantability and fitness for a particular purpose. All liabilities arising from the supply and interpretation of the information (including any liability arising in negligence) from the authors, or the use of this information by EXP for the purpose of preparing this assessment for the Government of Nunavut, are excluded to the fullest extent permitted by law.

6 Conclusions

A high-level climate change screening assessment of the potential for saltwater/ saline impacts on the Arctic Bay Marcil Lake potable water supply was completed. The main climate change risks interpreted included:

- Direct saltwater impacts by lateral migration of seawater into the lake;
- Sea level rise/ storm surge overtopping or breaching the existing barrier ridge; and
- Permafrost thaw leading to ridge erosion or release of relic saline porewater from watershed sediments of marine depositional origin.

Results of the screening suggest that for the "normal" (i.e. median) projections of most climate change scenarios (SSPs) presented in the IPCC AR6 report, site conditions provide for adequate buffer and that there is low risk of saltwater intrusion up until at least 2100. For most SSPs considered by IPCC AR6, the risk for overtopping the Marcil Lake barrier ridge is considered low until sometime between 2100 and 2150. Within this timeline, although there are potential incidents where ocean side water levels (particularly for ESL events) could reach or exceed the assumed 4.5 m overtopping elevation, for the most part the exceedances are marginal. In the case of marginal exceedances for ESLs, it is speculated that these would be of relatively short duration and that freshwater watershed inflow from snowmelt, runoff and precipitation combined with say an assumed 4 m water level elevation head difference retained in Marcil Lake would be sufficient to "flush out" sea water that might overtop the ridge and mix with the lake's freshwater. In addition, the sea level rise and ESL water level elevation exceedances are generally considered within the range in which relatively "low tech" mitigation could be considered and implemented such as construction of an earthen berm and shoreline armoring to protect against the upper limits of projected high tides and most extreme storm tides/ ESLs.

However, for a scenario of more extreme climate change (e.g. SSP5-8.5 *low confidence* scenario) it is expected there would be significant potential for climate change related processes (principally the combination of sea level rise and storm surge) to significantly impact the Marcil Lake freshwater supply; e.g. overtopping and/ or breaching of the lower lying lake outfall area along the northwest portion of the ridge that separates Marcil Lake from Arctic Bay.

In addition to direct impact from lateral intrusion of seawater, permafrost thaw may increase this risk in the event of erosion of the barrier ridge particularly along low lying sections (e.g. outflow area) as glacial deposits. Permafrost thaw also has the potential to impact lake water quality by releasing previously frozen saline porewater and/or possible other naturally occurring parameters of concern. At least one community in Nunavut (Sanikiluaq) is suspected to have been impacted in the past due to permafrost thaw releasing trapped seawater from frozen sediments within its potable water supply watershed. With increased warming in the region the possibility of permafrost thaw and the potential for release of previously frozen porewater could become the principal concern regarding potential for saline or other impacts to the overall freshwater quality of the Marcil Lake raw water source.

Recommendations to facilitate planning and address suspected or actual potential water quality impacts include:

- Enhanced site assessment
- Development and implementation of a regular and consistent raw water monitoring program
- Establishment of a community based Arctic Bay Climate Change Committee is also recommended to support site assessment initiatives that can be considered (e.g. geotechnical and geomorphologic characterization of the Marcil Lake barrier shoreline; tide, storm surge and sea level rise monitoring/ characterization; permafrost and active layer monitoring; and raw water and watershed inflow monitoring).This information could be reviewed by the Arctic Bay Climate Change Committee supported by outside technical specialists

and used to guide adaptation and possible mitigation measures that may be warranted should future climate change conditions suggest the lake water quality will be impacted.

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Regarding the use of IPCC AR6 sea level rise projections EXP Services Inc. is obligated to cite Chapter 9 of Working Group 1 contribution to the IPCC Sixth Assessment Report, the Framework for Assessment of Changes To Sea-level (FACTS) model description paper, and the version of the data set used:

> 3. Garner, G. G., T. Hermans, R. E. Kopp, A. B. A. Slangen, T. L. Edwards, A. Levermann, S. Nowikci, M. D. Palmer, C. Smith, B. Fox-Kemper, H. T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S. S. Drijfhout, T. L. Edwards, N. R. Golledge, M. Hemer, R. E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I. S. Nurhati, L. Ruiz, J-B. Sallée, Y. Yu, L. Hua, T. Palmer, B. Pearson, 2021. IPCC AR6 Sea-Level Rise Projections. Version 20210809. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at [placeholder for DOI].

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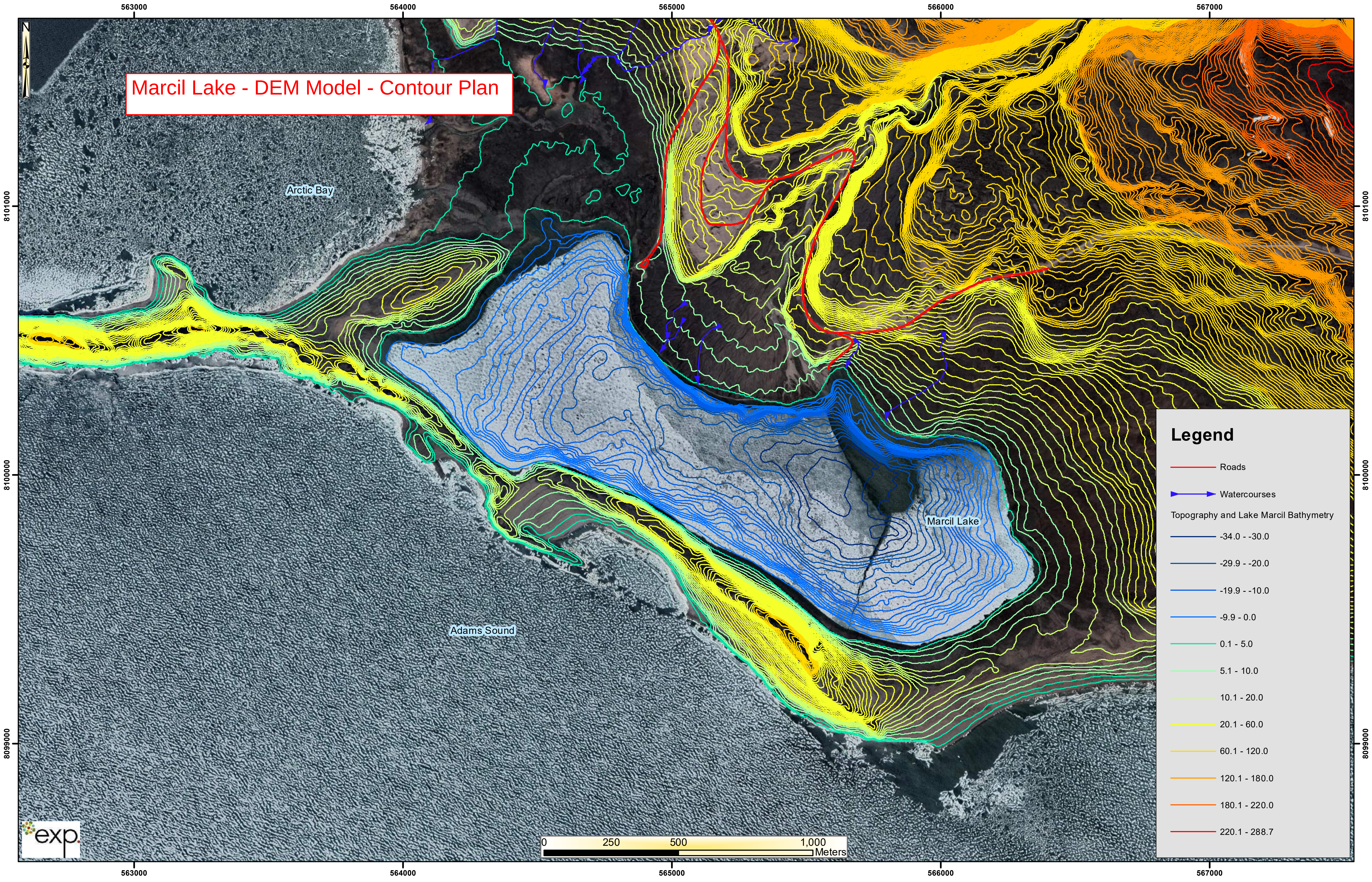
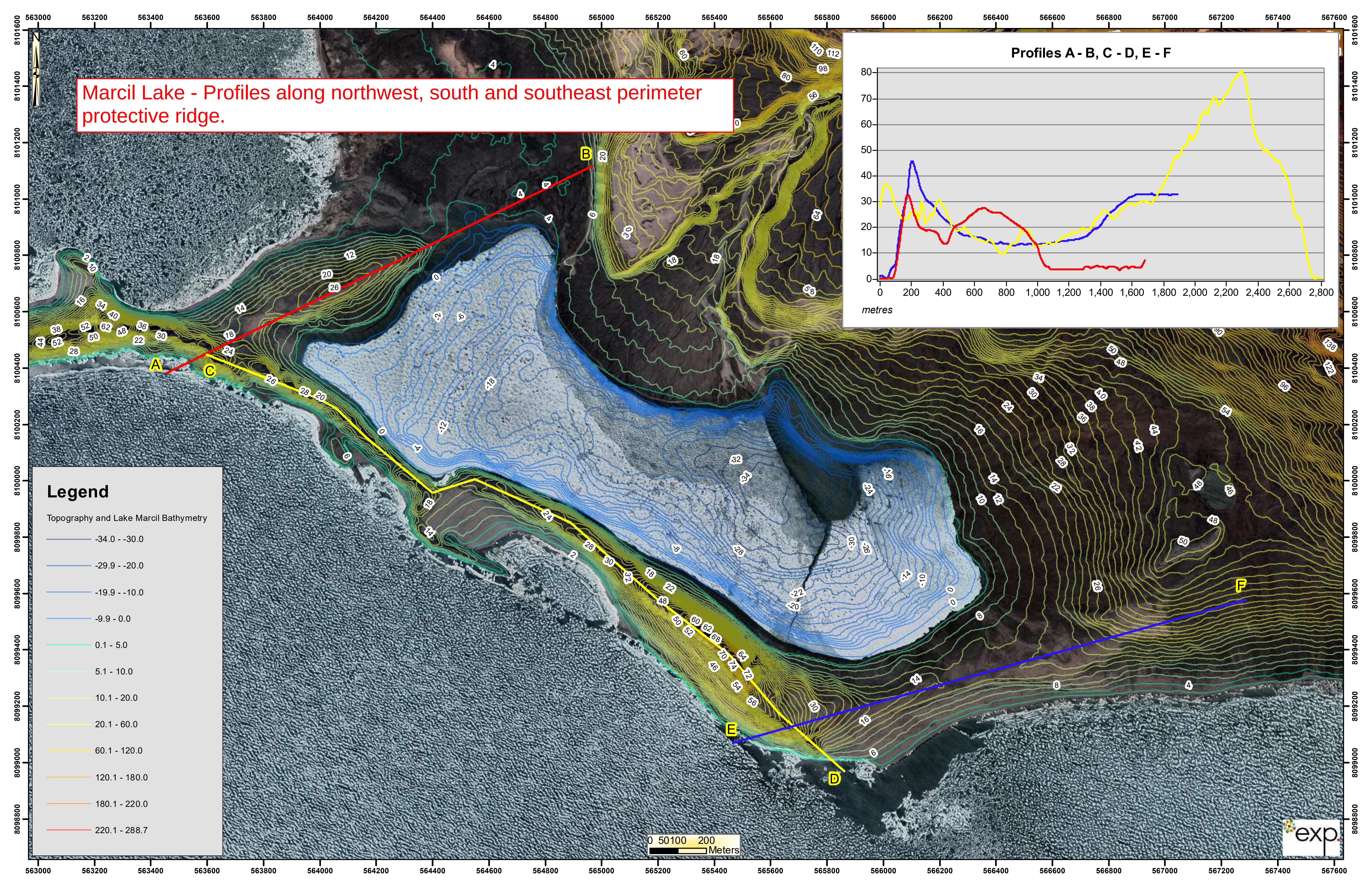
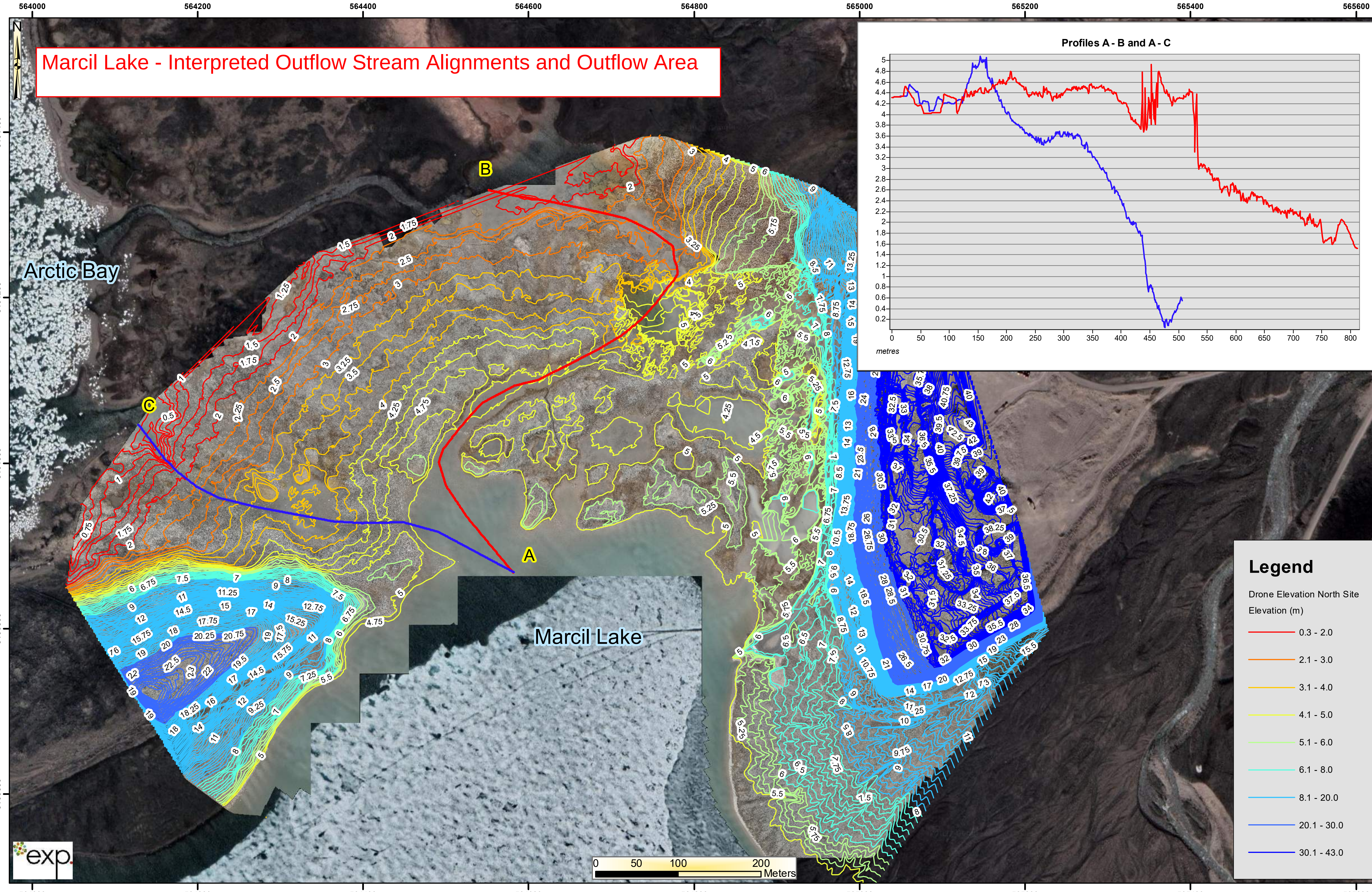
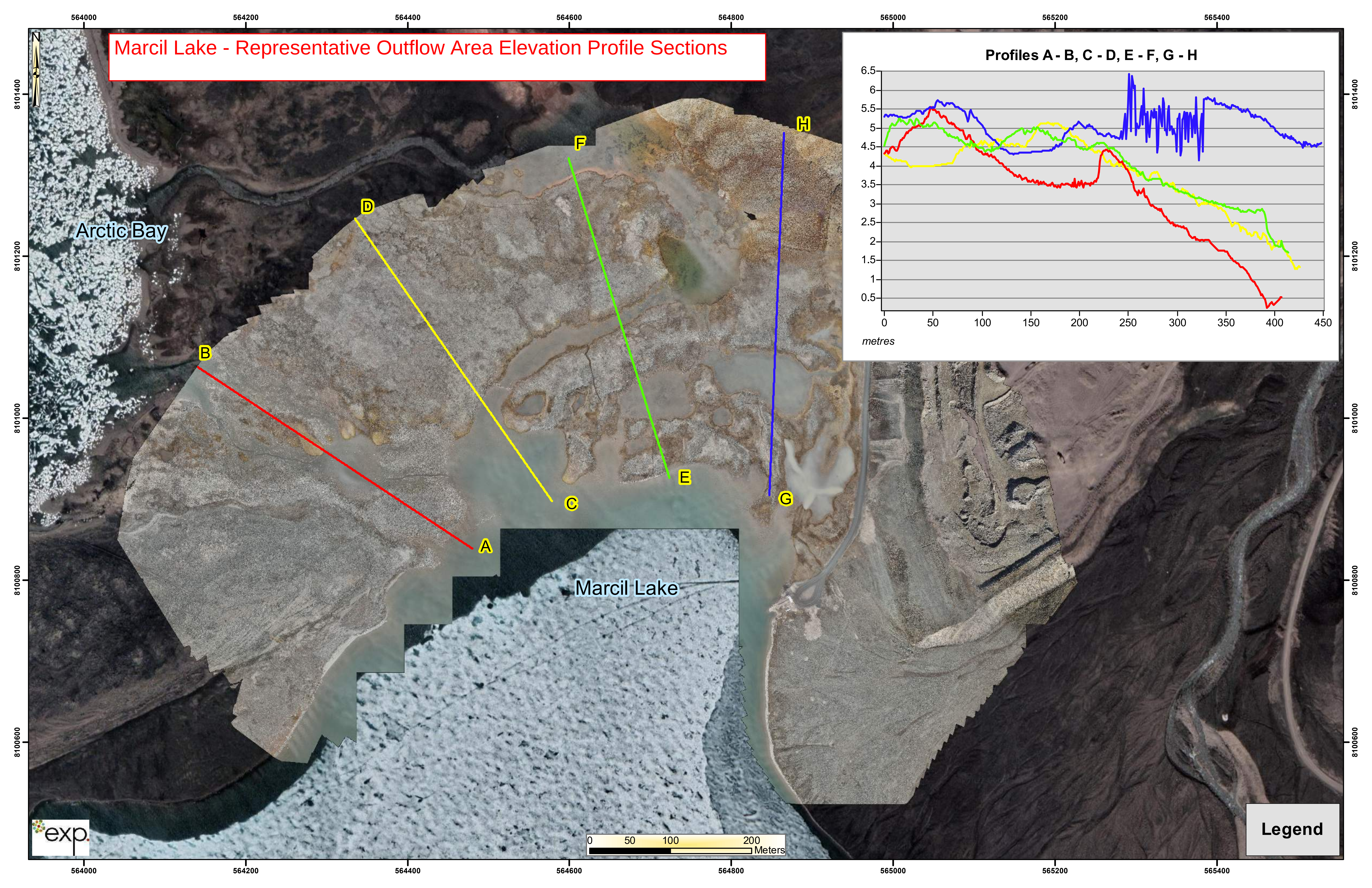
Appendix A – GIS developed Marcil Lake area Topographic Plans and Sections


Marcil Lake - DEM Model - Contour Plan
Arctic Bay
Adams Sound
Marcil Lake
Legend
Roads
Watercourses
Topography and Lake Marcil Bathymetry
-34.0 - -30.0
-29.9 - -20.0
-19.9 - -10.0
-9.9 - 0.0
0.1 - 5.0
5.1 - 10.0
10.1 - 20.0
20.1 - 60.0
60.1 - 120.0
120.1 - 180.0
180.1 - 220.0
220.1 - 288.7
0
250
500
1,000
Meters
563000
564000
565000
566000
567000
8101000
8100000
8099000
exp.

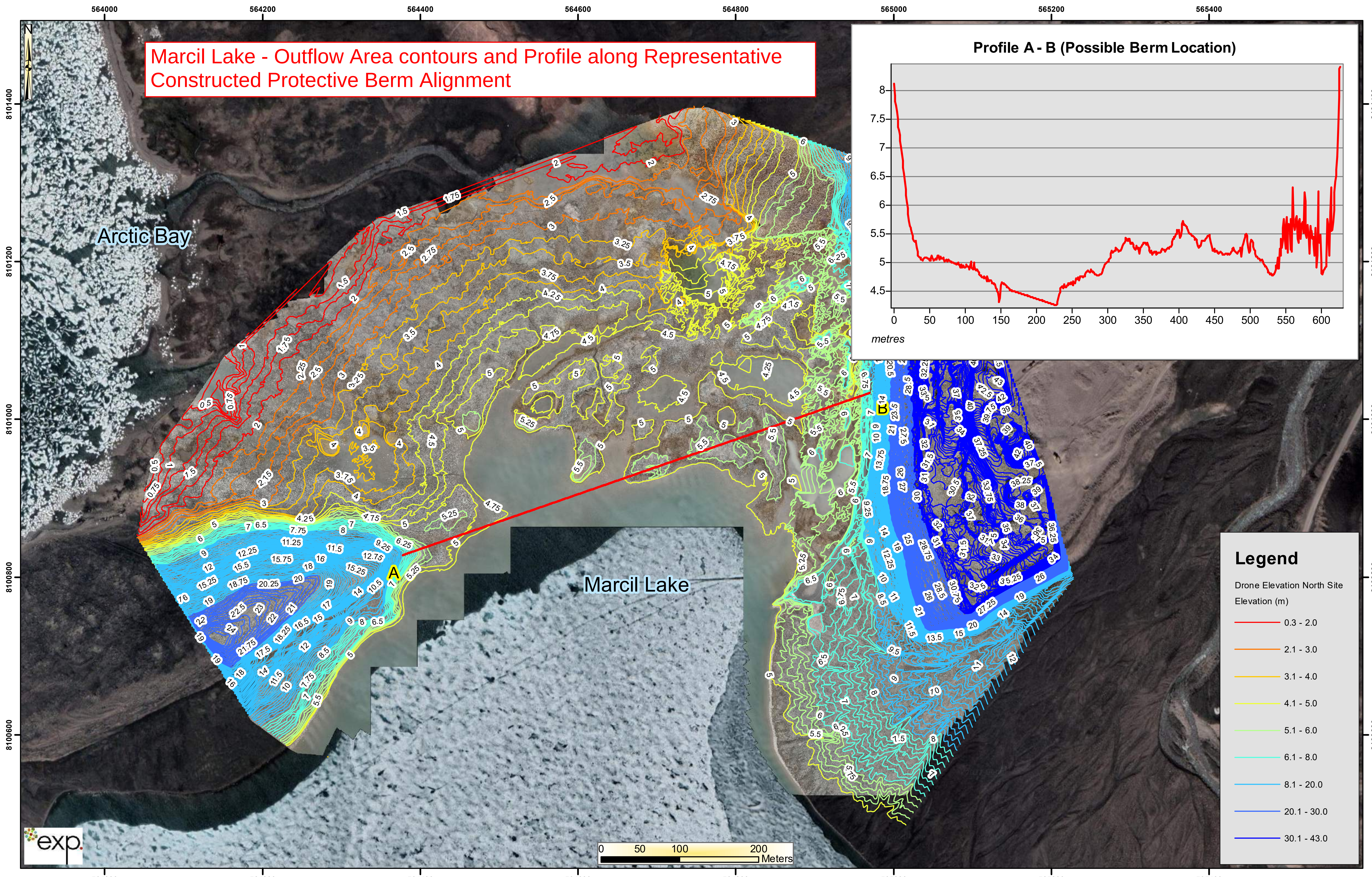

Marcil Lake - Profiles along northwest, south and southeast perimeter protective ridge.
Profiles A - B, C - D, E - F
metres
A
B
C
D
E
F
Legend
Topography and Lake Marcil Bathymetry
-34.0 - -30.0
-29.9 - -20.0
-19.9 - -10.0
-9.9 - 0.0
0.1 - 5.0
5.1 - 10.0
10.1 - 20.0
20.1 - 60.0
60.1 - 120.0
120.1 - 180.0
180.1 - 220.0
220.1 - 288.7
0 50100 200
Meters
exp.



Marcil Lake - Interpreted Outflow Stream Alignments and Outflow Area
Profiles A - B and A - C
metres
Arctic Bay
Marcil Lake
A
B
C
Legend
Drone Elevation North Site
Elevation (m)
0.3 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 6.0
6.1 - 8.0
8.1 - 20.0
20.1 - 30.0
30.1 - 43.0
0 50 100 200
Meters
exp.



Marcil Lake - Representative Outflow Area Elevation Profile Sections
Profiles A - B, C - D, E - F, G - H
metres
Arctic Bay
Marcil Lake
A
B
C
D
E
F
G
H
N
0 50 100 200 Meters
Legend
exp.
564000
564200
564400
564600
564800
565000
565200
565400
8101400
8101200
8101000
8100800
8100600



Marcil Lake - Outflow Area contours and Profile along Representative Constructed Protective Berm Alignment
Profile A - B (Possible Berm Location)
metres
Arctic Bay
Marcil Lake
A
B
Legend
Drone Elevation North Site
Elevation (m)
0.3 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 6.0
6.1 - 8.0
8.1 - 20.0
20.1 - 30.0
30.1 - 43.0
0 50 100 200
Meters
exp.

Appendix B – IPCC AR6 Sea Level Rise Projections (Source: NASA Sea Level Rise Projection Tool)

Output for Arctic Bay Region

‹ RETURN TO MAP

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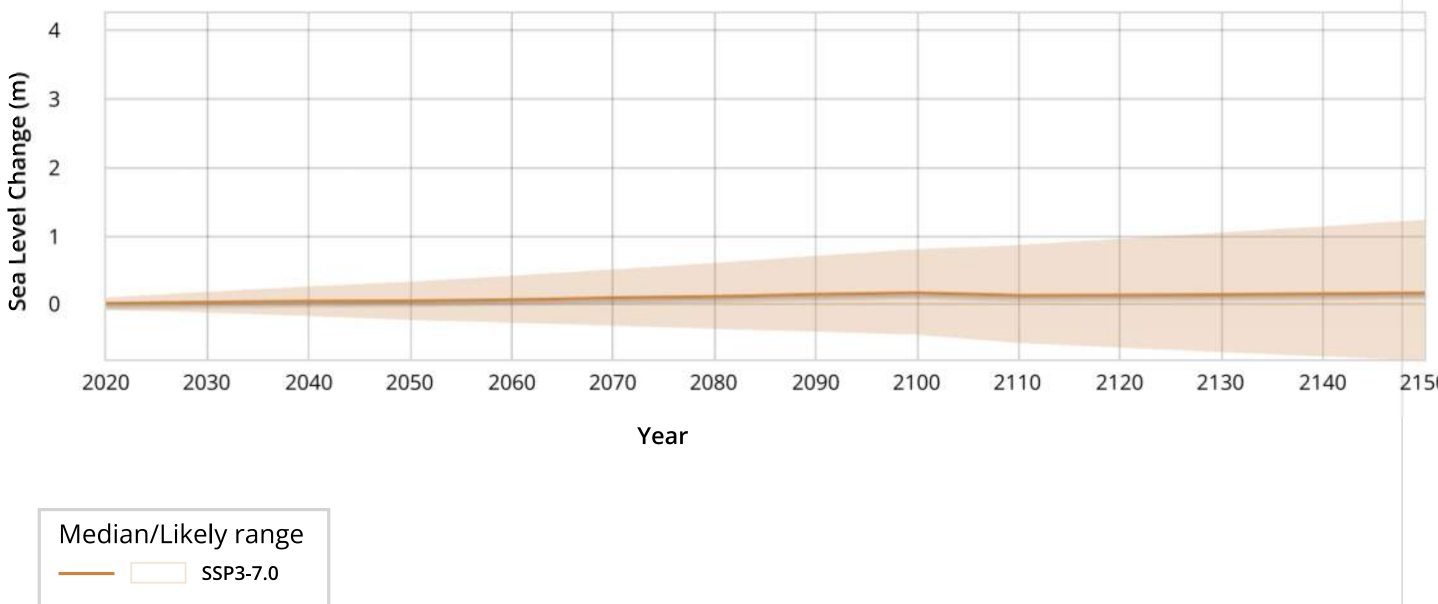
Projected Sea-Level Rise Under Different SSP Scenarios

Sea-level change for SSP scenarios resulting from processes in whose projection there is *medium confidence*. Two *low-confidence* scenarios, indicating the potential effect of low-likelihood, high-impact ice sheet processes that cannot be ruled out, are also provided. Shaded ranges show the 17th-83rd percentile ranges. Projections are relative to a 1995-2014 baseline. The plot below shows the projection and uncertainties for 'Total Sea Level Change'. Data for the individual contributions can be downloaded under 'Get Data'.



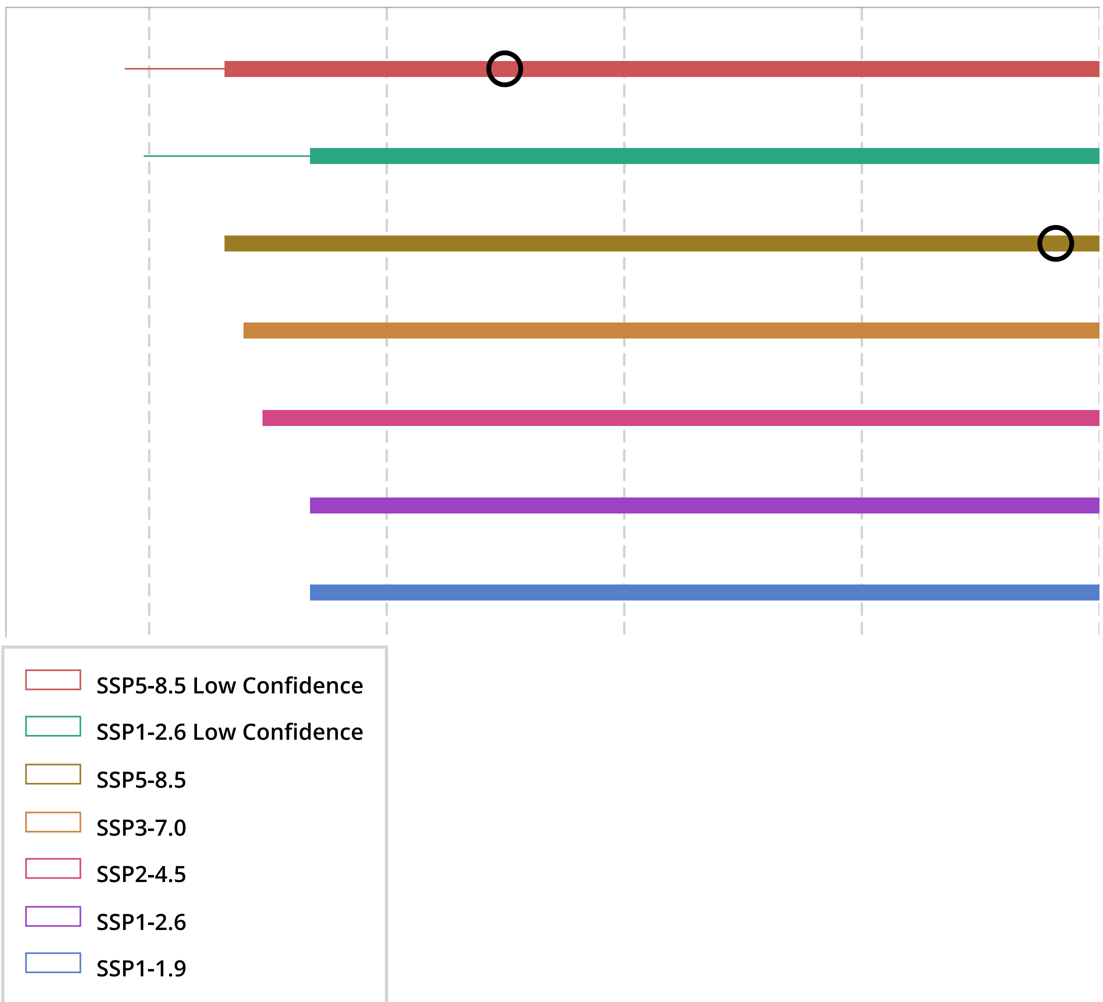
SCENARIO

SSP1-1.9 SSP1-2.6 SSP2-4.5 **SSP3-7.0** SSP5-8.5

SSP1-2.6 Low Confidence SSP5-8.5 Low Confidence GET DATA

Projected Timing of Sea-Level Rise Milestones

Timing of exceedance of different thresholds (increments of 0.1 m) under different SSPs. Thick bars show 17th-83rd percentile ranges, and black circles show median value. Thin bars also show 5th–95th percentile ranges for SSP1-2.6 Low Confidence and SSP5-8.5 Low Confidence scenarios.



METERS

0.5m

GET DATA

Projected Sea Level Rise

Sea level projections for 5 SSP scenarios, relative to a baseline of 1995-2014, in meters. Individual contributions are shown for the year 2100. Median values (*likely ranges*) are shown. Average rates for total sea-level change are shown in mm yr^{-1}. The SSP5-8.5 *low confidence* column incorporates a representation of the potential effect of low-likelihood, high-impact ice sheet processes that cannot be ruled out. In particular, this column shows the 17th-83rd percentile range factoring into account information from structured expert judgement and from a model incorporating Marine Ice Cliff Instability.

Percentile: Median (17th, 83rd)

	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 *Low Confidence*
Sterodynamic Sea Level	0.28 (0.20, 0.36)	0.30 (0.18, 0.42)	0.43 (0.29, 0.57)	0.54 (0.34, 0.73)	0.66 (0.40, 0.92)	0.66 (0.40, 0.92)
Glaciers	-0.05 (-0.09, -0.01)	-0.06 (-0.10, -0.01)	-0.08 (-0.13, -0.04)	-0.12 (-0.16, -0.07)	-0.14 (-0.19, -0.10)	-0.15 (-0.20, -0.10)
Greenland	-0.06 (-0.12, -0.00)	-0.07 (-0.13, -0.02)	-0.10 (-0.17, -0.05)	-0.14 (-0.20, -0.09)	-0.17 (-0.23, -0.11)	-0.23 (-0.75, -0.11)
Antarctica	0.12 (0.03, 0.29)	0.13 (0.04, 0.31)	0.13 (0.03, 0.34)	0.13 (0.03, 0.36)	0.13 (0.04, 0.39)	0.22 (0.03, 0.64)
Land Water Storage	0.02 (0.01, 0.04)	0.02 (0.01, 0.04)	0.03 (0.01, 0.04)	0.03 (0.02, 0.04)	0.02 (0.01, 0.04)	0.02 (0.01, 0.04)
Vertical Land Motion	-0.26 (-0.70, 0.19)	-0.26 (-0.70, 0.19)	-0.26 (-0.70, 0.19)	-0.26 (-0.70, 0.19)	-0.26 (-0.70, 0.19)	-0.26 (-0.70, 0.19)
Total (2030)	0.06 (-0.09, 0.21)	0.04 (-0.12, 0.19)	0.04 (-0.11, 0.19)	0.04 (-0.11, 0.19)	0.04 (-0.12, 0.19)	0.03 (-0.14, 0.19)
Total (2050)	0.08 (-0.19, 0.35)	0.06 (-0.21, 0.33)	0.06 (-0.21, 0.33)	0.06 (-0.22, 0.34)	0.07 (-0.21, 0.35)	0.06 (-0.26, 0.35)
Total (2090)	0.05 (-0.45, 0.56)	0.05 (-0.46, 0.57)	0.10 (-0.42, 0.64)	0.15 (-0.39, 0.71)	0.20 (-0.36, 0.78)	0.22 (-0.50, 0.82)
Total (2100)	0.05 (-0.51, 0.63)	0.06 (-0.52, 0.64)	0.13 (-0.46, 0.74)	0.17 (-0.44, 0.81)	0.25 (-0.39, 0.93)	0.30 (-0.56, 1.09)
Total (2150)	-0.02 (-0.89, 0.88)	-0.12 (-1.02, 0.80)	0.05 (-0.90, 1.05)	0.17 (-0.81, 1.24)	0.27 (-0.78, 1.43)	0.91 (-0.79, 4.24)
Rate (2040-2060)	0.0 (-5.0, 6.0)	0.0 (-5.0, 6.0)	1.0 (-5.0, 7.0)	1.0 (-5.0, 7.0)	2.0 (-4.0, 9.0)	1.0 (-6.0, 9.0)
Rate (2080-2100)	-1.0 (-7.0, 4.0)	-2.0 (-8.0, 4.0)	0.0 (-7.0, 7.0)	1.0 (-6.0, 9.0)	2.0 (-5.0, 12.0)	6.0 (-8.0, 23.0)

‹ RETURN TO MAP

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Projected Sea-Level Rise Under Different SSP Scenarios

These projections are based on the assessment presented in the IPCC Sixth Assessment Report

Details of the sea-level projections are provided in Box TS.4 and section 9.6 of the Working Group 1 contribution to the Intergovernmental Panel on Climate Change's Sixth Assessment Report.

Sea level projections considering only processes for which projections can be made with at least *medium confidence* are provided, relative to the period 1995–2014, for five Shared Socioeconomic Pathway (SSP) scenarios. The scenarios are described in sections TS1.3 and 1.6 and Cross-Chapter Box 1.4 of the Working Group 1 contribution.

As described in Cross-Chapter Box 1.4:

- SSP1-1.9 holds warming to approximately 1.5°C above 1850-1900 in 2100 after slight overshoot (median) and implies net zero CO2 emissions around the middle of the century.
- SSP1-2.6 stays below 2.0°C warming relative to 1850-1900 (median) with implied net zero emissions in the second half of the century.
- SSP2-4.5 is approximately in line with the upper end of aggregate Nationally Determined Contribution emission levels by 2030. SR1.5 assessed temperature projections for NDCs to be between 2.7 and 3.4°C by 2100, corresponding to the upper half of projected warming under SSP2-4.5. New or updated NDCs by the end of 2020 did not significantly change the emissions projections up to 2030, although more countries adopted 2050 net zero targets in line with SSP1-1.9 or SSP1-2.6. The SSP2-4.5 scenario deviates mildly from a 'no-additional- climate-policy' reference scenario, resulting in a best-estimate warming around 2.7°C by the end of the 21st century relative to 1850-1900.
- SSP3-7.0 is a medium to high reference scenario resulting from no additional climate policy under the SSP3 socioeconomic development narrative. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions.
- SSP5-8.5 is a high reference scenario with no additional climate policy. Emission levels as high as SSP5-8.5 are not obtained by Integrated Assessment Models (IAMs) under any of the SSPs other than the fossil fueled SSP5 socioeconomic development pathway.

Compared to 1850-1900, globally averaged surface air temperature over the period 2081–2100 is *very likely* (at least a 90% probability) to be higher by 1.0°C–1.8°C under SSP1-1.9, 1.3°C–2.4°C under SSP1-2.6, 2.1°C–3.5°C under SSP2-4.5, 2.8°C–4.6°C under SSP3-7.0, and 3.3°C–5.7°C under SSP5-8.5.

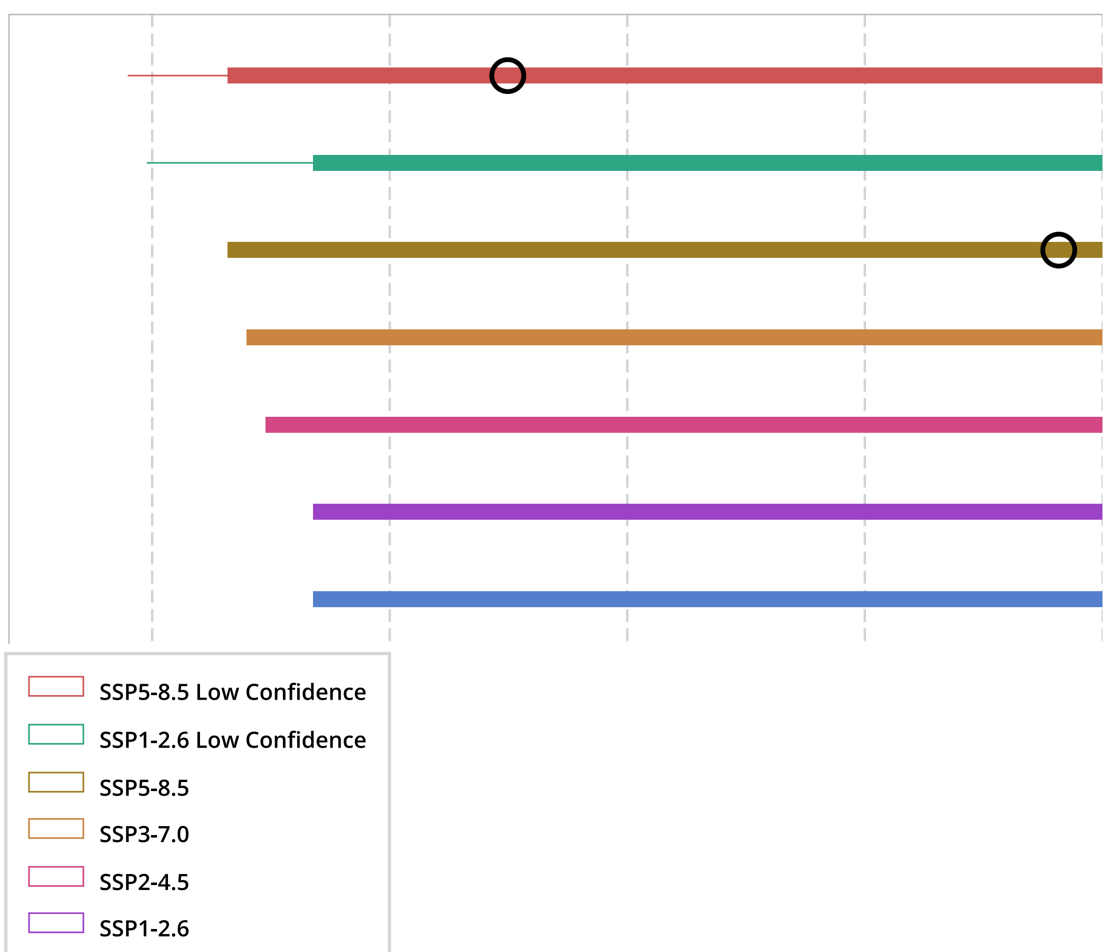
In the sea level projections, *likely* ranges are assessed based upon the combination of uncertainty in the temperature change associated with an emissions scenarios and uncertainty in the relationships between temperature and drivers of projected sea-level change, such as thermal expansion, ocean dynamics, and glacier and ice sheet mass loss. In general, 17th-83rd percentile results are interpreted as *likely* ranges, reflecting the use of the term *likely* to refer to a probability of at least 66%.

To indicate the potential impact of deeply uncertain ice sheet processes, about which there is currently a low level of agreement and limited evidence, *low confidence* projections are also provided for SSP1-2.6 and SSP5-8.5. For both the Greenland and Antarctic ice sheets, the *low confidence* projections integrate information from the Structured Expert Judgement study of Bamber et al. (2019). For the Antarctic ice sheet, the *low confidence* projections> projections also incorporate results from a simulation study that incorporates Marine Ice Cliff Instability (DeConto et al., 2021). The results shown are 17th-83rd percentile projections, but are not assessed as *likely* ranges because of the low agreement and limited evidence. See section 9.6 and Box 9.4 for more details.

For more information on the use of likelihood and confidence language by the Intergovernmental Panel on Climate Change, see Box 1.1.

Projected Timing of Sea-Level Rise Milestones

Timing of exceedance of different thresholds (increments of 0.1 m) under different SSPs. Thick bars show 17th-83rd percentile ranges, and black circles show median value. Thin bars also show 5th–95th percentile ranges for SSP1-2.6 Low Confidence and SSP5-8.5 Low Confidence scenarios.



SOURCE: Figure SPM 8 in IPCC AR6 (2021b) *Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*

Human activities affect all the major climate system components, with some responding over decades and others over centuries

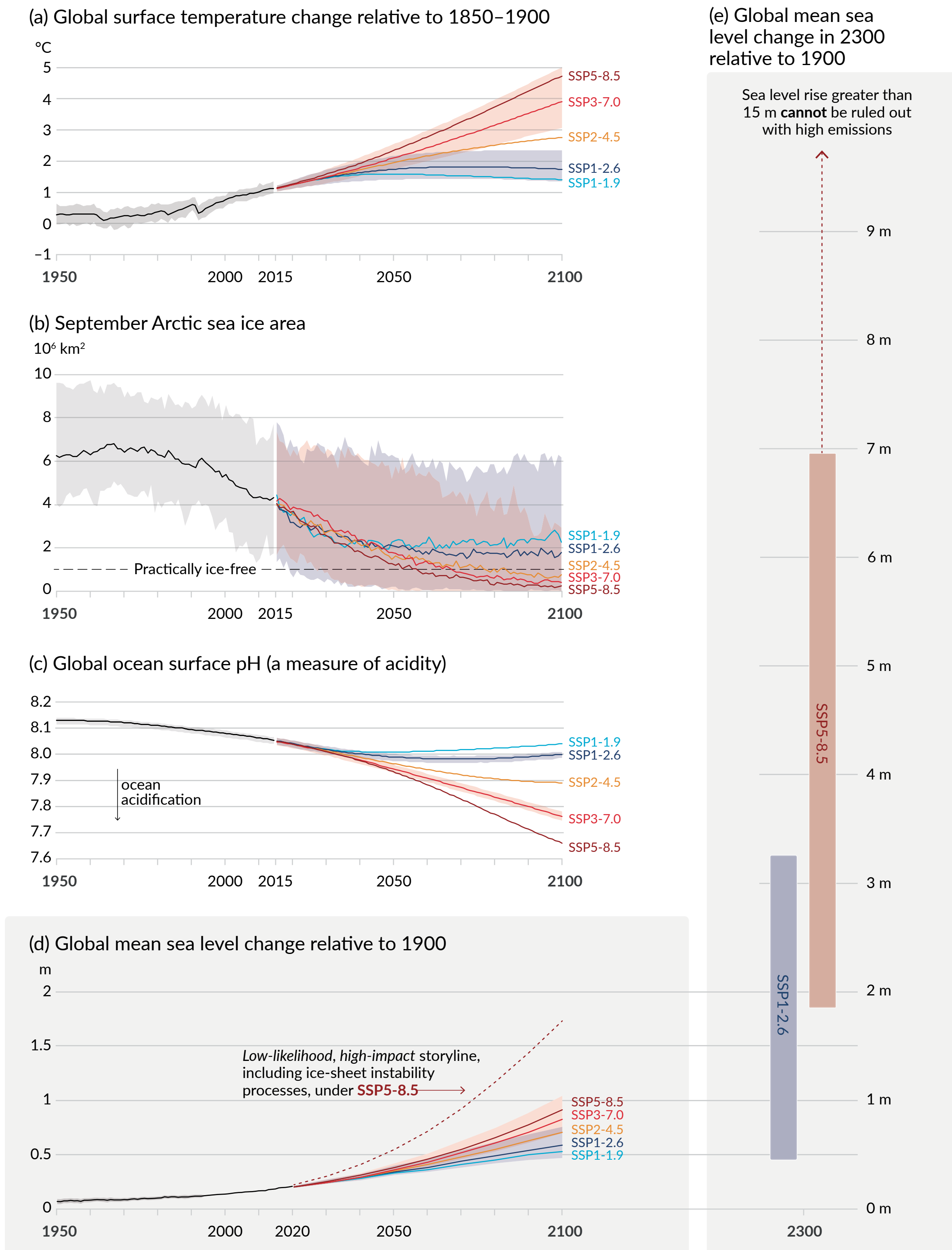


Figure SPM.8 | Selected indicators of global climate change under the five illustrative scenarios used in this Report

The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges – more detail is provided for each panel below. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

Panel (a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining Coupled Model Intercomparison Project Phase 6 (CMIP6) model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (see Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel (b) September Arctic sea ice area in 10^6 km^2 based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. The Arctic is projected to be practically ice-free near mid-century under intermediate and high GHG emissions scenarios.

Panel (c) Global ocean surface pH (a measure of acidity) based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel (d) Global mean sea level change in metres, relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models. *Likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Only *likely* ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out; because of *low confidence* in projections of these processes, this curve does not constitute part of a *likely* range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014.

Panel (e) Global mean sea level change at 2300 in metres relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out.

Panels (b) and (c) are based on single simulations from each model, and so include a component of internal variability. Panels (a), (d) and (e) are based on long-term averages, and hence the contributions from internal variability are small.

{4.3; Figures 4.2, 4.8, and 4.11; 9.6; Figure 9.27; Figures TS.8 and TS.11; Box TS.4, Figure 1}

C. Climate Information for Risk Assessment and Regional Adaptation

Physical climate information addresses how the climate system responds to the interplay between human influence, natural drivers and internal variability. Knowledge of the climate response and the range of possible outcomes, including low-likelihood, high impact outcomes, informs climate services, the assessment of climate-related risks, and adaptation planning. Physical climate information at global, regional and local scales is developed from multiple lines of evidence, including observational products, climate model outputs and tailored diagnostics.

C.1 Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.
{1.4, 2.2, 3.3, Cross-Chapter Box 3.1, 4.4, 4.6, Cross-Chapter Box 4.1, Box 7.2, 8.3, 8.5, 9.2, 10.3, 10.4, 10.6, 11.3, 12.5, Atlas.4, Atlas.5, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box Atlas.2}

C.1.1 The historical global surface temperature record highlights that decadal variability has both enhanced and masked underlying human-caused long-term changes, and this variability will continue into the future (*very high confidence*). For example, internal decadal variability and variations in solar and volcanic drivers partially masked human-caused surface global warming during 1998–2012, with pronounced regional and seasonal signatures (*high confidence*). Nonetheless, the heating of the climate system continued during this period, as reflected in both the continued warming of the global ocean (*very high confidence*) and in the continued rise of hot extremes over land (*medium confidence*).
{1.4, 3.3, Cross-Chapter Box 3.1, 4.4, Box 7.2, 9.2, 11.3, Cross-Section Box TS.1} (Figure SPM.1)

C.1.2 Projected human-caused changes in mean climate and climatic impact-drivers (CIDs),[36] including extremes, will be either amplified or attenuated by internal variability (*high confidence*).[37] Near-term cooling at any particular location with respect to present climate could occur and would be consistent with the global surface temperature increase due to human influence (*high confidence*).
{1.4, 4.4, 4.6, 10.4, 11.3, 12.5, Atlas.5, Atlas.10, Atlas.11, TS.4.2}

36 Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions (Glossary). CID types include heat and cold, wet and dry, wind, snow and ice, coastal and open ocean.

37 The main internal variability phenomena include El Niño–Southern Oscillation, Pacific Decadal Variability and Atlantic Multi-decadal Variability through their regional influence.