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Project Name
Geotechnical Investigation, Water Treatment Plant and Reservoir Expansion with New Storage Tank, Arviat, NU

Project Number
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Executive Summary

Exp Services Inc. (**exp**) has carried out a geotechnical investigation of the proposed footprints for the new water treatment plant, water storage tank and reservoir expansion in Arviat, NU. The purpose of the geotechnical investigation is to evaluate the subsurface conditions present throughout the areas of interest in support of design and construction recommendations.

The existing potable water reservoir is located just west of the community and consists of two cells. The proposed expansion project will include the construction of a third cell (Cell 3), a new water treatment plant, a small pump house and a vertical water storage tank. The water treatment plant, pump house and storage tank are proposed to be constructed between the road and Cell 1. The new Cell 3 is proposed to be constructed adjacent the west side of Cell 1 and the two cells will share a central berm, similar to Cell 1 and Cell 2. It is understood that both existing cells are fully lined and performing well.

The geotechnical investigation was carried out from February 23 to 26, 2017. Eight boreholes were drilled throughout the proposed site. In general, the eight boreholes encountered a surficial layer of silty sand with gravel to silty sand that extended the entire depth investigated (15 m below grade). The bedrock was not encountered within this depth. The active layer was completely frozen at the time of our investigation and the native soils were observed to contain no signs of excess ice content. Groundwater was not encountered; however, groundwater flow through the active layer is anticipated during the spring thaw.

On completion of drilling, multi-bead thermistor strings were installed to depths of 7.5 m and 8.0 m in Borehole Nos. 2 and 8, respectively. Single-bead thermistors were also installed at a depth of 7 m, 7 m and 10 m respectively below existing grade in Borehole Nos. 5, 6 and 8.

Based on the geotechnical findings outlined herein, the site is considered suitable for either adfreeze steel pipe pile foundations or shallow spread footings with horizontal insulation to support the proposed water treatment plant building and small pump house. Either foundation type will require that the addition be elevated at least 0.6 m above finished grade to provide an air gap between the underside of the heated building and the ground. The bedrock surface is deeper than 15 m below the current ground surface; therefore, the installation of rock socket pipe piles is not considered feasible using locally available drilling equipment. Recommendations to support design and construction of these foundation types are included herein.

The new vertical water storage tank can be supported on an insulated fill pad. The tank should be set on top of an elevated engineered fill pad at least 1.5 m thick, which extends a minimum of 3 m beyond the perimeter of the structure and is thereafter sloped at an inclination of 3H:1V. The tank should be set on 100 mm layer of rigid insulation. A 200-mm thick layer of inclusion should be provided in the granular fill pad located approximately 150 mm above the ground surface and extending at least 2.4 m beyond the edge of the tank in all directions.

Due to the timing of our investigation we were unable to make meaningful observations on the surface features of the site; therefore, we cannot comment on the presence or lack of boggy areas within the proposed footprint of Cell 3. Overall, the site appears well-suited for the construction of cut slopes and berms to create Cell 3. Recommendations pertaining to design and construction of Cell 3 are also included herein. The above and other related considerations are discussed in greater detail in the report.

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1 Introduction

Exp Services Inc. (**exp**) has carried out a geotechnical investigation of the proposed footprints for the new water treatment plant, water storage tank and reservoir expansion in Arviat, NU. The purpose of the geotechnical investigation is to evaluate the subsurface conditions present throughout the areas of interest in support of design and construction recommendations. The site is located within the community as shown on the appended Figure 1.

The existing potable water reservoir is located just west of the community and consists of two cells. The two cells were constructed side-by-side (sharing a central berm) along the north side of the existing road. The current cells required the construction of berms on all sides, with approximately 1 m high berms along the existing roadway and berms as high as 7 m on the north side of the cells. The proposed expansion project will include the construction of a third cell (Cell 3), a new water treatment plant, a small pump house and a vertical water storage tank. The water treatment plant, pump house and storage tank are proposed to be constructed between the road and Cell 1. The new Cell 3 is proposed to be constructed adjacent to the west side of Cell 1 and the two cells will share a central berm, similar to Cell 1 and Cell 2. It is understood that both existing cells are fully lined and performing well.

The scope of work for the geotechnical investigation included the following:

i. Drill boreholes throughout the areas of interest to establish the subsurface conditions present.

ii. Install single and multi-bead thermistor strings in select boreholes to establish the ground temperature profile throughout the site.

iii. Carry out a laboratory testing program suitable to classify the key engineering parameters of the soils present.

iv. Carry out geothermal modeling as required to support design of the required foundations.

v. Provide detailed geotechnical condition report including the findings of the investigation and recommendations to support design and construction of the most suitable foundation and liner types.

The comments and recommendations given in this report are based on the assumption that the above-described information is accurate. If new information not included in this report is discovered, this office must be given an opportunity to review the new information. The result of this review may be a modification of our recommendations or it may require additional field or laboratory work to validate whether the changes are acceptable from a geotechnical viewpoint.

2 Procedure

The geotechnical investigation was carried out between February 23 and 26, 2017. Eight boreholes were drilled throughout the proposed areas of interest; two boreholes adjacent the south berm of the existing water reservoir and six boreholes west of the existing water reservoir. The approximate borehole locations are shown on the appended Figure 1, Borehole Location Plan.

All eight boreholes were advanced to a depth of 15.0 m below grade using a locally available air-track drill. The soil stratigraphy and presence of bedrock was assessed based on drill progress and the soil/bedrock cuttings returned to the surface by the drill rig. The drilling operation was supervised on a full-time basis by a geotechnician from **exp** experienced with permafrost soils. The samples were visually examined and logged in accordance with the *Standard Practice for Description and Identification of Soils Visual-Manual Procedure* (ASTM D 2488) and *Standard Practice for Description of Frozen Soils, Visual-Manual Procedure* (ASTM D 4083). The samples were then stored in moisture tight containers for transportation to the **exp** laboratory for further classification and testing.

Prior to the end of each day, the initial weights of the samples were determined in case the samples thawed and drained during transportation (to ensure accurate moisture content determinations). Laboratory testing included the determination of natural moisture contents of all the soil samples and grain-size, pH, sulphate, and electrical conductivity tests on select soil samples.

On completion of drilling, multi-bead thermistor strings were installed to depths of 7.5 m and 8.0 m in Borehole Nos. 2 and 8, respectively. Single-bead thermistors were also installed at a depth of 7 m, 7 m and 10 m below existing grade, within Borehole Nos. 5, 6 and 8, respectively. The thermistor strings were installed to the desired depth by **exp**, held in place and slowly backfilled to the surface with drill cuttings. The other three boreholes were backfilled to the surface with drill cuttings on completion.

The borehole locations were established using a commercial grade handheld GPS device. The elevations of the boreholes were established in the office based on the GPS locations and available topographic survey for the site, and are therefore considered approximate.

Following our departure from the site, **exp** contracted a local representative to obtain additional readings from the thermistors. The additional readings were obtained from the two multi-bead thermistors on March 11, 2017 and reported to **exp** via email and have been included herein. The three single-bead thermistor locations were buried in snow; therefore, additional readings could not be obtained by the local representative.

3 Site and Soil Description

3.1 General

The site is located approximately 1 km west of the community, along the north side of the road that leads out to the lake from where the community sources potable water. In general, the site grades down from the road to the low-lying lands to the north and ocean to the east. Based on available topographic survey the site grades in the proposed water treatment plant, pump house and storage tank are relatively flat at about Elevation 10.5 m. Within the proposed footprint of Cell 3, elevations drop from Elevation 10.5 m along the road to Elevation 5.4 m near the proposed northeast corner of the new cell. It is understood that three berms will be constructed to form Cell 3 and Cell 3 will share an existing berm with Cell 1, as shown on appended Figure 1. The topographic survey indicates swampy/marshy ground along the proposed north berm of Cell 3. It is noted that our site visit occurred during the winter and the site was covered in a substantial amount of snow. Therefore, meaningful observations on surface conditions, ground cover and presence of soft ground was not possible.

Based on a review of available satellite imagery (Google Earth) the area of the proposed north berm for Cell 3 and the area to the north contains some patterned ground, which may indicate boggy and/or ice-rich terrain. Several small lakes/ponds are scattered around the area of interest; however, it does not appear that any ponded water or significant drainage courses exist within or near the site.

3.2 Climate and Permafrost

Based on the permafrost map of Canada, the Hamlet of Arviat (located at approximately 61° 06’ 29” N and 94° 03’ 25” W) is within the zone of continuous permafrost. The depth of seasonal thaw is expected to vary from 1.0 m to 3.0 m depending on site use, sun exposure, surface disturbance, overburden composition, depth to bedrock, groundwater flow, etc. Based on a review of the environment Canada average monthly air temperatures from 1981 to 2010 the Mean Annual Air Temperature (MAAT) was calculated to be -9.5ºC, with a freezing index of -4420ºC-days and a thawing index of 962ºC-days.

3.3 Subsurface Conditions

A detailed description of the subsurface conditions encountered in the boreholes is given on the appended Borehole logs. The Borehole logs and related information depict subsurface conditions only at the specific locations and times indicated. It should be noted that the soil boundaries indicated on the borehole logs 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.

In general, the eight boreholes drilled throughout the proposed water treatment plant and reservoir expansion footprints encountered a surficial layer of silty sand to silty sand with gravel that extended the entire depth investigated (15 m below grade). The bedrock surface was not encountered within this depth and the overburden did not appear to contain significant quantities of cobbles or boulders based on observed drill progress and cuttings. The active layer was completely frozen at the time of our investigation and no zones of excess ice were observed. The principal strata encountered at the site are summarized in Table 1 below.

Table 1 – Borehole Summary

Borehole No.	Elev. (m)	Total Drilled Depth (m)	Soil Stratigraphy Thickness (m)	Depth To (m)		Figure No.
			Silty Sand to Silty Sand with Gravel	Bedrock	Frozen Soil	
BH1	11.0	15.0	> 15.0	N.E.	Surface	2
BH2	11.0	15.0	> 15.0	N.E.	Surface	3
BH3	8.7	15.0	> 15.0	N.E.	Surface	4
BH4	8.0	15.0	> 15.0	N.E.	Surface	5
BH5	5.4	15.0	> 15.0	N.E.	Surface	6
BH6	9.1	15.0	> 15.0	N.E.	Surface	7
BH7	8.4	15.0	> 15.0	N.E.	Surface	8
BH8	6.9	15.0	> 15.0	N.E.	Surface	9

3.3.1 Rootmat/Topsoil

The site was snow covered at the time of our site visit and investigation. No significant surficial rootmat/topsoil layer was observed at any of the eight borehole locations; however, it should be noted that the drilling method does not allow for accurate measurement of layers much less than 150 mm thick. Therefore, some surficial rootmat/topsoil may exist throughout the undeveloped areas of the site.

3.3.2 Silty Sand with Gravel

A layer of silty sand to silty sand with gravel was apparently encountered directly beneath the snow cover at all eight borehole locations. The sand overburden was observed to be light to dark grey in color, with the gravel and fines content observed to vary dependant on location and depth across the site, with no distinct layering distinguishable. All eight boreholes were terminated within the silty sand with gravel layer at depths of 15.0 m (target depth). Cobbles and boulders were not interpreted to be present throughout the sand layer based on drill behaviour and cuttings returned to the surface; however, some cobbles and boulders may exist. Bedrock was not encountered within the depth explored at any of the eight borehole locations.

The moisture content of samples obtained from the overburden ranged from 1.1% to 14.9%, with an average value of 5.3% (based on 32 samples). The sand returned to the surface was observed to be frozen from the surface at the time of drilling, with some chunks of frozen sand observed to contain non-visible excess ice (Nbe).

Table 2 summarizes gradation tests results for ten samples obtained from various depths throughout the sand layer. The moisture content of each sample is also included in the table for information. The gradation test results are shown in greater detail on the appended Figures.

Table 2 – Sand Layer Gradation Test Results

BH No.	Sample No.	Depth (m)	Percentage (%)			Moisture Content (%)	Figure No.
			Gravel	Sand	Fines[1]		
1	1	2 to 3	5	79	16	2.6	10
1	4	13 to 14	17	61	22	10.8	11
2	3	10 to 11	28	67	5	3.3	12
3	1	2 to 3	36	61	3	1.1	13
3	2	5 to 6	33	64	3	3.1	14
4	1	2 to 3	7	59	34	11.8	15
4	3	9 to 10	16	58	26	6.8	16
5	1	2 to 3	21	52	27	7.0	17
6	4	13 to 14	25	71	4	2.3	18
8	2	7 to 8	27	47	26	7.0	19

NOTES: 1) Material passing the 0.075 mm sieve

3.3.3 Bedrock

Bedrock was not encountered within the 15.0 m depth explored in any of the eight boreholes.

3.3.4 Groundwater

Groundwater was not encountered within the 15.0 m depth explored in any of the eight boreholes. However, it was inferred that the active layer was completely frozen at the time of drilling. It is anticipated that groundwater will flow through the active layer during thaw periods, and groundwater levels will fluctuate with seasonal weather trends, during particular precipitation events, site use and construction activities.

4 Ground Temperature Readings and Salinity

A multi-bead thermistor was installed down Borehole No. 2, with a total of 9 thermistor bead locations distributed from 0.0 m to 7.5 m depth below the existing ground surface. A multi-bead thermistor was installed down Borehole No. 8, with a total of 11 thermistor bead locations distributed from 0.0 m to 8.0 m depth below the existing ground surface. The Thermistor Installation Reports appended as Figures 20 and 21 fully document the multi-bead thermistor installations and readings, including; depths of individual thermistor beads and the profile of ground temperature on each day we obtained readings. Additionally, single-bead thermistors were installed at 7 m, 7 m and 10 m depths down Boreholes Nos. 5, 6 and 7, respectively. Temperature readings obtained from the single-bead thermistors 1 day after they were installed indicated ground temperatures of -2.8°C, -9.8°C and -7.3°C in Boreholes No. 5, 6 and 7, respectively. It is noted that drilling activities typically result in a rise in ground temperature around the borehole and based on our experience it can take several days to weeks for the ground thermal regime to return to previous stable conditions. Due to snow cover it was not possible for the local representative to obtain additional readings on the single-bead installations.

Based on the temperature readings obtained in Borehole No. 2 (area of new water treatment plant) a ground temperature of -5.0°C has been chosen for adfreeze pile design. The active layer was completely frozen at the time of our site investigation and ground temperature monitoring to date provides no summer time data. Therefore, accurate estimation of the active layer thickness at the site is not possible. For design purposes, it is assumed that the maximum active layer for the site is 3.0 m based on the environmental data available.

The salinity of the soil at the site was measured by conducting electrical conductivity tests on selected soil samples. Table 3 lists the test results.

Table 3 – Salinity of On-Site Soils

Borehole No.	Sample Depth (m)	Salinity Parts Per Thousand (ppt)
1	6 to 7	< 0.1
2	7 to 8	< 0.1
2	13 to 14	< 0.1
4	6 to 7	< 0.1
5	6 to 7	< 0.1
5	12 to 13	< 0.1
6	6 to 7	< 0.1
7	5 to 6	< 0.1

The test results indicate that the salinity of the on-site soils was < 1 ppt; therefore, it is considered that the salinity of the soil is low (negligible).

5 Subsurface Concrete Requirements

Chemical tests limited to pH and sulphates content were performed on selected soil samples obtained from the site. The test results are given in Table 4 below.

Table 4 – Results of Chemical Tests on Soil Samples

Borehole No.	Depth (m)	pH	Sulphate (%)
1	6 to 7	8.2	< 0.1
2	7 to 8	8.1	< 0.1
2	13 to 14	8.1	< 0.1
4	6 to 7	8.4	< 0.1
5	6 to 7	8.3	< 0.1
5	12 to 13	8.1	< 0.1
6	6 to 7	8.1	< 0.1
7	5 to 6	8.0	< 0.1

The test results indicate that the on-site soils contain a water-soluble sulphate content of less than 0.1 percent. This concentration of sulphates in the soil would have a negligible potential of sulphate attack on subsurface concrete. In such cases, National Standards of Canada, CAN/CSA - A23.1-09 permits the use of General Use (GU) Portland cement in the concrete. However, the concrete should be well compacted, dense and adequately cured.

6 Discussion and Recommendations

Based on the geotechnical findings outlined herein, the site is considered suitable for adfreeze steel pipe pile foundations to support the proposed water treatment plant building and small pump house. The bedrock surface is deeper than 15 m below the current ground surface; therefore, the installation of rock socket pipe piles is not considered feasible due to the limitations of the locally available drilling equipment. Alternatively, the water treatment plant and small pump house could be supported by shallow spread footings with horizontal insulation designed and constructed as outlined below. Either foundation type will require that the addition be elevated at least 0.6 m above finish grade to provide an air gap between the underside of the heated building and the ground. The air space must be maintained free of any obstructions throughout the entire year to allow air flow beneath the building. Recommendations to support design and construction of these foundation types are included below.

Due to the timing of our investigation we were unable to make meaningful observations on the surface features of the site; therefore, we cannot comment on the presence or lack of boggy areas within the proposed footprint of Cell 3. As noted above, the topographic survey of the site indicates boggy land to the north and our boreholes throughout this area did indicate some elevated moisture contents. It is possible that some over-excavation may be required throughout this area during site preparation for fill placement to create Cell 3. Additionally, groundwater control may be a challenge as outlined below and the contractor should be adequately prepared. Overall, the site appears well-suited for the construction of cut slopes and berms to create Cell 3. Recommendations pertaining to design and construction of Cell 3 are also included below.

6.1 Foundations for Heated Structures

The investigation has revealed that the geotechnical conditions at the site are suitable to found the proposed structures (water treatment plant and small pump house) on one of the following foundation types; adfreeze piles, buried spread footings with insulation, adjustable surface footings or fill pad with insulation and thermosyphons. It is currently understood that the surface footings and thermosyphons options are not desired due to long-term maintenance requirements; therefore, further recommendations regarding the design and construction of these foundation types can be provided upon request. Recommendations pertaining to the design and construction of adfreeze piles and buried spread footings with horizontal insulation are provided below.

6.1.1 Adfreeze Piles

Based on results of the investigation and a review of the available information, the following parameters were used in computing the load carrying capacity of the adfreeze piles.

- Design active layer thicknesses = 3.5 m (includes allowance for global warming)
- Mean annual ground temperature = - 4.0°C
- Allowance for global warming = + 1.5°C over 25 years
- Pore water salinity = <2 ppt

- Design mean annual ground temperature = - 4°C
- Assumed Pile diameter = 141 mm
- Allowable long term settlement of the piles = 25 mm in 25 years.

The values in Table 5 below were computed for the allowable shaft stress for adfreeze piles. A factor of safety of 1.5 has been incorporated in the design.

Table 5 – Allowable Shaft Stress for Adfreeze Piles	
Depth of Pile below final grade (m)	**Allowable Adfreeze Strength (kPa)**
0 – 3.5 m	0
Below 3.5 m	30

The upper portion of the piles within the design 3.5 m active zone should be covered with heavy grease and wrapped with polyethylene sheets coated with heavy grease to minimize uplift forces. Even with this precaution the piles should be designed to resist an ultimate frost-jacking force of 150 kPa through the active zone. The minimum embedment for a 141 mm O.D. adfreeze pipe pile to resist the anticipated frost jacking forces is 13.0 m. Recommendations for additional pile sizes can be provided upon request.

For lateral load design purposes, the upper 3.5 m of the piles should also be considered as unsupported.

Adfreeze piles carry the load in bond between the pile and the surrounding soil. Normal practice is to use sand slurry for this purpose. It is essential that a good bond is developed between the pile and the frozen sand slurry. Round hollow structural section (HSS) steel is recommended as the pile material. The steel piles below 3.5 m active zone must be properly cleaned. They must be free of paint, lacquer, oil, grease, dirt and excessive rust to ensure development of a good bond.

The piles should be installed open ended in pre-drilled oversized holes. In order to obtain proper backfill around a pile, the hole should be partially backfilled with saline free sand and fresh water slurry prior to installing the pile. The pile should then be placed in the hole and vibrated down to the bottom of the hole whilst adding more sand and fresh water around the pile diameter.

Piles installed per the above procedure will require a drilled hole, which is 50 mm larger in diameter than the outside diameter of the pile. The interior of the piles should be filled with dry low saline sand to the final ground elevation to prevent air circulation inside the pile.

It is noted that the site is understood to have some groundwater flow that can be problematic for pile installations carried out when the active layer is thawed (extensive sidewall sloughage). Therefore, it is recommended that the pile installations take place when the active layer is fully frozen.

It is noted that freeze back around the piles may take 2-3 months before full pile capacity can develop. It is recommended that thermistors be installed at various depths along the surface of select piles to monitor the freeze back. The piles should not be fully loaded until such time that the ground temperature readings indicate stabilized frozen conditions around the piles.

The base of the heated structures should be at least 600 mm above the final grade to permit air circulation under the building. It is necessary to maintain this clear space to ensure that heat from the structure will not degrade the permafrost and reduce the pile capacity. The air space should not be hoarded and should not be used for storage.

It is noted that the worse effects of climate warming on pile capacities may not be realized for 15 to 20 years in the future. The active layer is expected to deepen with time and may impact the capacity of the adfreeze piles. Rather than abandon the current pile design strategy, it is recommended that the pile design be adapted to address potential climate warming effects. It is recommended that thermistors should be installed at the site to monitor the ground temperature. In addition, thermistor beads should be installed on select piles to measure the ground temperature at the interface of soil and piles. If the ground temperatures are found to be warming and the active layer deepening, then remedial actions can be initiated before pile capacities are compromised and structural distress results. Potential mitigation strategies may include the placement of rigid insulation, the installation of thermosyphons, the installation of pile adjustment devices, etc.

6.1.2 Buried Footings with Horizontal Insulation

To eliminate seasonal movements, spread footings can be buried below grade and founded within permafrost soils stabilized using horizontal insulation. It is recommended that the spread footings be founded at least 1.2 m below finished grade on a compacted granular pad at least 300 mm thick; therefore, the total anticipated excavation depth would be 1.5 m below finish grade. It is crucial that excavation, footing construction and backfilling to top of insulation be carried out in a continuous and fluent manner such that the entire process is completed as quickly as possible, ideally within 2 hours. This is intended to limit the time of exposure for the underlying permafrost soils and minimize issues with seepage and sloughage. Delays in completing the installation of a given footing and backfilling to finish grade may result in additional thaw of underlying permafrost soils and excessive movements during freeze back.

The native bearing surface beneath each footing should be inspected and approved by qualified northern geotechnical personnel to assure that frozen permafrost soils are present as expected. Excavating through the frozen soils may be difficult to impossible with standard equipment; therefore, it is recommended that excavation take place in late summer, when the active layer is near the design founding elevation. It is further recommended that 10% of the footings be instrumented with single-bead thermistors installed within the frozen permafrost surface directly beneath the granular pad of the footing. Monitoring of the thermistor installations will provide confirmation of freeze-back and allow for long-term monitoring.

Spread footings for this purpose are typically designed/constructed using pressure treated wood pads and steel pedestals as piers. The use of wood pad footings with steel piers allows for some pre-assembly prior to excavation, swift footing placement/installation and immediate backfilling. Other footing materials such as concrete and steel can be considered, although concrete footings would need to be pre-cast (i.e. onsite) and fully cured prior to excavation and installation to limit time of exposure for the permafrost soils as outlined above.

Some heave and differential movement is likely to occur during freeze back of the original ground or freezing of the fill pad. Therefore, some allowance should be made for leveling the tops of pedestals following freeze back and prior to building construction. Furthermore, flexible connections between the existing water treatment plant and the proposed addition are recommended for this foundation type, as the behaviour of the exiting and new foundations may be different.

Based on the anticipated subsurface conditions, long-term creep of the underlying permafrost soils will govern design. Therefore, the footings should be designed based on a serviceability limit state (SLS) bearing resistance of 150 kPa, which is based on 25 mm of settlement over 25 years.

The granular fill pad beneath the footings should be constructed of frost stable material, preferably well-graded sand and gravel, preferably meeting the specifications of Table 8 for Type 1 granular and compacted to at least 100% of the standard Proctor dry density (SPMDD) determined for the material. The remaining backfill around each footing should consist of well-graded sand and gravel, preferably meeting the specification of Table 7 for Type 2 material. Typically, the uncompacted lift thickness should not exceed 150 mm for the smaller plate tampers typically used for this kind of installation throughout the north. Surface water from the remainder of the site should be directed away from the fill pad in all directions.

The insulation should be Styrofoam HI-40, or equivalent with a recommended thickness of at least 100 mm thick. The insulation should be buried at least 0.3 m below finish grade and extend out past the edge of each individual footing by at least 2.4 m in all directions. A protective layer of sand, about 100 mm thick, should be placed above and below the insulation if the fill material being used contains material larger than about 10 mm in size. A minimum 0.6 m high air space should be provided between the building and the pad to provide a thermal break and protect the underlying permafrost soils.

As noted above, it is anticipated that groundwater will flow along the bottom of the active layer during warmer months. It is further anticipated that groundwater seepage into the excavations will occur at an unknown rate; therefore, the contractor should be adequately prepared to dewater the excavations to allow for material placement and footing construction. The pumping/discharging of water from the excavations should be carried out in accordance with the applicable regulations. It should also be appreciated that **exp** has not assessed the site for any potential environmental concerns and it is not known if any environmental contamination will be encountered during excavation work.

6.2 Vertical Water Storage Tank

It is understood that the proposed vertical water storage tank will be heated throughout the year. Therefore, it is anticipated that a substantial thaw bulb would develop beneath the tank if it were simply constructed on grade. For this reason, Naviq Consulting Inc. was contracted to carry out geothermal modelling to assess the feasibility of this approach. Based on the geotechnical analysis undertaken by Naviq, it is recommended that the water storage tank be founded atop a granular fill pad that includes horizontal insulation to minimize the vertical extent (depth) of thaw bulb progression beneath the tank. The water tank should be set on a 1.5 m thick elevated engineered fill pad, which extends a minimum of 3 m beyond the perimeter of the structure and is thereafter sloped at an inclination of 3H:1V. The tank should be provided with 100 mm thick layer of rigid insulation set in the granular fill pad approximately 1 m below the top of the engineered fill pad. The 200-mm thick rigid insulation layer should extend at least 2.4 m beyond the perimeter of the structure. A protective layer of sand approximately 100 mm thick should be placed on either side of the insulation if the fill material used for construction of the engineered fill pad contains material larger than 10 mm in size.

The granular fill pad should be constructed of frost stable material, preferably well-graded sand and gravel meeting the gradation requirement specifications for Type 2 material in Table 7 of Section 8. The fill pad should extend at least 3 m beyond the perimeter of the tank in all directions and be sloped at 3H:1V beyond this. To reduce potential settlements as much as possible, the footprint of the fill pad should be stripped of any organics and/or soft soils present and proof rolled using a minimum 10-ton vibratory roller prior to the placement of any granular fill for the pad. Any soft spots identified during the proof roll should be over-excavated and replaced with frost stable granular fill as outlined above. The proof roll and subsequent over-excavation/replacement should be carried out under the direction of qualified geotechnical personnel. The fill pad materials should be placed in lifts compatible with the compaction equipment used and compacted to 100% of the standard Proctor maximum dry density. Typically, this would require maximum 300 mm thick lifts and 5 passes from a minimum 10-ton vibratory roller.

The insulation should be Styrofoam HI-40, HI-60 or HI-100, depending on applied loads from the tank and overlying fill pad granular material. For design purposes, it can be assumed that the 1.5 m thick granular fill pad has a wet unit weight of 20 kN/m^3; therefore, the fill pad would represent an additional 30 kPa of loading atop the layer of horizontal insulation.

Surface water from the remainder of the site should be directed away from the fill pad in all directions.

6.3 New Water Reservoir Cell

It is currently understood that the proposed Cell 3 will be constructed adjacent the west side of Cell 1 and the current west berm of Cell 1 will be shared with Cell 3 (becoming the east berm for Cell 3). The existing north and south berms of Cell 1 will be extended west to create the north and south berms of Cell 3 and a new berm will be required along the west side of Cell 3. Therefore, the construction of Cell 3 will require the construction of three new berms/slopes and tying into the exiting berms of Cell 1. It is further understood that the crest of the new berms will be 4.5 m wide and consistent with the existing reservoir at Elevation 11.0 m and the base at Elevation 4.5 m.

Based on available topographic survey of the site, the surrounding site grades are all greater than Elevation 4.5 m. Therefore, it is anticipated that the new berms will range between 1.0 m and 5.4 m above current grade outside Cell 3 and excavations ranging between 3.5 m and 4.6 m below current grade inside Cell 3.

6.3.1 Geothermal Considerations and Thaw Settlement

Detailed geothermal analysis of the lagoon structure was not part of our previous or current scope of work. However, based on experience with other sewage lagoon designs throughout zones of continuous permafrost, we have made the following assumptions related to permafrost degradation/aggradation that should be considered during design:

- Existing permafrost beneath the interior base of the cells will thaw for tens of meters below finished grade due to the storing of sewage within the cells. This thaw may be shallower but will extend for some distance behind/under the inside toes of all berms.
- Drifting snow along the outside toes of exterior berms will serve as increased insulation during the winter months and result in additional permafrost thaw for some distance in front of and behind/under the outside toes of exterior berms.
- Permafrost thaw will be less approaching the core of each berm due to the increased soil cover.
- The depth of permafrost degradation (thaw) will vary substantially over the sewage lagoon footprint.

Permafrost degradation will result in differential settlements of the lagoon and the berms. The magnitude of thaw settlement is a function of the type of soil, density, ice content and the depth of thaw. Thaw settlement of ice-rich soils present beneath a fully lined lagoon cell can cause the liner to strain beyond its capacity and fail.

The site soils encountered during our investigation were not observed to be ice-rich and based on available literature are considered to be thaw stable. Furthermore, the existing reservoir is fully lined and reportedly performing well with no noticeable movement observed to date. Therefore, the use of fully lined lagoon cell is considered suitable at the site.

6.3.2 Site Preparation

6.3.2.1 Excavation

It is recommended that the prepared footprint of new cell extend at least 2 m beyond the toe of the slopes. The expanded footprint should be stripped of any existing surficial organic/peat layer and/or any other soft saturated materials encountered to expose a structurally stable subgrade of either unfrozen or frozen well-graded soils approved by qualified geotechnical personnel.

It is recommended that any over-excavation be carried out in stages such that an over-excavated area can be backfilled to pre-existing grades within one day. This is intended to limit the time of exposure for underlying permafrost soils and minimize short-term permafrost thaw and global instability of the berms. If over-excavated areas are not backfilled to at least the current grade the same day, then additional thawing of the frozen soils is anticipated, potentially resulting in soft soil conditions throughout the base and requiring over-excavation for its removal.

The site soils encountered in the boreholes varied from well-graded silty sand and gravel to poorly graded fine-grained silty sand with trace gravel. For the most part the moisture contents appeared to be well below the values that would generate issues reusing the material as fill; however, some wetter soils were encountered throughout the lower-lying areas of the site explored (northern portion of the footprint). Therefore, the excavated material will need to be evaluated at the time of excavation to determine if the gradation and moisture contents are appropriate for immediate reuse as outlined below.

Cut Slopes: It is currently proposed to create 3H:1V cut slopes within Cell 3 by excavating well below existing grade. The stability of a cut slope is typically more than that of fill slope constructed of the same material. However, the possibility exists that excavation throughout the proposed footprint may encounter zones of excess ice and/or elevated moisture content. Therefore, excavation should be carried out under the full-time supervision of qualified geotechnical personnel working under the direction and guidance of a qualified geotechnical engineer experienced with permafrost soils. If possible, it is recommended that the stored water level within the existing Cell 1 be lowered as much as possible during the construction of Cell 3, or at least during construction of the cut slope along the shared berm.

6.3.2.2 Water Control

It is anticipated that controlling surface and groundwater flow through the lower sections of site (north side) may be a challenge given the surrounding boggy/wet ground identified on the topographic survey and general tendency of groundwater to travel along the surface of the permafrost during thaw. It is possible that the existing access road running along the south side of the site will considerably limit water inflow from this direction. However, diversion ditches having positive outlet may need to be established up gradient of the site to minimize the amount of surface and groundwater entering the excavation(s).

Any water that does enter the excavation(s) should be gathered via swales/ditches having positive outlet or led to adequately sized sumps equipped with pumps for immediate removal offsite. Discharge of collected water should be conducted and controlled in a manner that does not induce erosion or transport of sediment, and is in accordance with all applicable government requirements.

6.3.2.3 Embankment Fill

Once the site has been prepared as outlined above, embankment fill should be placed to the desired grades. Embankment fill for the base of the cell and containment berms should comprise of well-graded silty sand and gravel having a maximum size of 150 mm.

The embankment fill should be placed in maximum of 300 mm lifts and compacted to at least 95% of the standard Proctor maximum dry density (SPMDD) determined for the material. This will typically require that the material be within about 2% of its optimum moisture content at the time of placement.

Depending on the exposed soils, the placement and compaction of the initial lift(s) of material throughout over-excavations may be inhibited by the build-up of excess porewater pressures within the native subgrade. It is recommended that emphasis be placed on covering the permafrost the same day as excavation and returning the area to current grade. Compaction should be monitored by qualified geotechnical personnel, but if the lift begins to exhibit signs that excess porewater pressure exists within the underlying materials (spongy or rolling appearance under traffic), then compaction should be stopped immediately and the next lift placed. Lifts above current grade should be placed and compacted to at least 95% of the SPMDD as outlined above and this may require that the initial lifts be allowed to drain over the course of several days.

Tying into the existing berms of Cell 1 will require placement of fill against the existing slopes. For this purpose, the surface soils on the existing slopes should be cut/stepped (about 0.6 m vertically) and worked into each lift of new embankment fill placed to create a stable slope for the expanded berm.

It is anticipated that some or most of the native sand excavated from the footprint of Cell 3 will be reusable as embankment fill. However, this will need to be confirmed in the field by qualified geotechnical personnel. For this reason, excavation should be monitored on a full-time basis (required anyways during the excavation of cut slopes as noted above) and zones of native soils deemed too wet for immediate reuse or too fine/poorly graded for reuse identified and stockpiled separately from any material deemed suitable for immediate reuse. Typically, the ability of a native soil to be reused immediately following excavation requires that it be of a suitable gradation (i.e. well-graded silty sand with gravel) and be at a suitable moisture content (i.e. within 2% of the optimum moisture content determined for the material).

6.3.3 Synthetic Liner

Synthetic liners offer advantages to provide primary containment in cold regions. They are useful in locations where fine-grained soils are not available to construct a natural low permeability liner and containment structure. They are also insensitive to climate warming and will be effective in both frozen and unfrozen conditions. They have good performance where the ground is stable and not subject to subsidence due to thawing of permafrost. Most liner materials require burial for several reasons including ultraviolet light protection, traffic protection and ice run-up or gouging protection.

It is noted that a number of liners have been used in the past in permafrost regions to make reservoirs and sewage lagoons constructed with granular materials impervious. These materials include polyvinylchloride (PVC), reinforced polyethylene (RPE), polypropylene (PP) and synthetic clay liners.

The liner should be provided with a suitable bedding (such as sand) as specified by the manufacturer. The upper end of the liner (at the crest of the berm) should be buried in an approximately 0.6 m deep key trench and backfilled with well-compacted embankment fill.

Although it is anticipated that the site soils are thaw stable, as an added precaution it is recommended that the liner material chosen and installed for this application be capable of accommodating differential movement. Typically, this can be accomplished by building in folds within the installed liner (liner types that have low strain capability but high tensile strength) or by providing specialized materials capable of experiencing large strains prior to failure. It is understood that the current reservoir has a PVC liner with several folds built into it.

6.3.4 Permanent Slopes

Based on site preparation and embankment fill gradation/placement as outlined above, as well as the slope stability analyses outlined below, the proposed embankment slopes of 3H:1V (outside) and 3H:1V (inside) are considered acceptable at the site.

All slopes should be provided with suitable erosion protection. The inside (upstream) face of each berm may be subject to some wave action during the summer months and ice impact/run-up during winter. This should be considered when designing erosion protection and choosing a liner type. Additionally, the inside and outside slopes will be subject to seasonal freeze/thaw action. Frost susceptible soils placed within this zone may slough as a result, causing slope stability issues over time.

6.3.4.1 Slope Stability

Although it is understood that a synthetic liner will be installed along the upstream slope to render it impervious, there is potential that a steady-state seepage condition may develop in the berms if the liner is damaged. Therefore, the slope stability analyses presented below was based on unfrozen soils.

The stability of slopes was analyzed using Slope W, Geoslope Office, version 7.2 computer program using Morgenstern-Price Method. One cross-section taken through the proposed north berm of the proposed Cell 3 (near the northeast corner) was analyzed. The cross-section was chosen based on the height of berm being proposed and least favorable surrounding site grades. It is considered to be the most critical berm section proposed.

The berm was analyzed using effective stress analysis with static loading and total stress analysis with seismic loading. Total stress analysis for static loading conditions was not undertaken since the factors of safety would be greater than obtained by the effective stress analysis. The following assumptions were made for slope stability analysis:

1.) The crest of the berm will be at Elevation 11.0 m whereas the base of the lagoon to the south will be at Elevation 4.5 m and the outside toe of the lagoon will be at Elevation 5.0 m. The crest width of the berm will be 7.8 m. The upstream and downstream slopes of the berms were analyzed for slopes of 3H:1V and 3H:1V respectively.

2.) The water level in the lagoon will be maintained at Elevation 10.0 m or lower and that the berm will not be overtopped at any time. Overtopping of the berm(s) may be prevented by construction of a proper spillway structure.

3.) Sufficiently sized toe drains will be provided along the downstream toe of each berm to prevent the phreatic surface from day lighting at the downstream slope of the berm.

4.) The berms will be constructed in accordance with the recommendations outlined above.

5.) The soils below the berms are unfrozen.

6.) The engineering properties of the various soil strata were assumed as given on Table 6 based on previous experience in the region and literature research.

Table 6 – Engineering Properties Used in Slope Stability Analyses

Soil Type	Unit Weight (kN/m3)	Effective Cohesion c' (kPa)	Effective Angle of Internal Friction ϕ (degrees)
Silty sand with gravel fill	21	0	34
Silty sandy with gravel	20	0	32

The results of the slope stability analyses are given on Table 7.

Table 7 – Results of Slope Stability Analyses

Section	Slope Inclination		Loading Condition	Computed Factor of Safety	Figure No.
	Downstream	Upstream			
A-A	3H:1V	3H:1V	Effective stress analysis	2.1	22
			Total stress analysis with seismic loading	1.91	23
			Rapid drawdown analysis	1.11*	24
B-B	3H:1V	3H:1V	Effective stress analysis	2.04	25
			Total stress analysis with seismic loading	1.85	26
			Rapid drawdown analysis	1.11*	27

***Note**: * Rapid drawdown analysis assumes that the lagoon will be drained in a minimum of eight days.*

Based on current practice in the industry, a minimum factor of safety of 1.5 is required for static loading conditions and a factor of safety of 1.1 is required for seismic loading conditions. A review of Table 7 indicates that a 3H:IV upstream and downstream slope would satisfy the requisite factors of safety. Therefore, this slope may be used in the design of the berms.

6.3.4.2 Rapid Drawdown Condition

The upstream slopes of the berms were also analyzed for rapid drawdown condition. The analysis was based on Morgenstern-Price Method coupled with the Seep W computer program to simulate the rapid drawdown condition. As a somewhat conservative approach, the following permeability value was assumed for the analysis:

Silty sand with gravel (fill or native) 1×10^{-8} m/sec

The shortest time required to empty the lagoon while maintaining a minimum acceptable factor of safety of 1.1 against slope failure for rapid down condition was computed as eight hours. The factor of safety will be the minimum on emptying of the lagoon and is expected to increase thereafter as the excess pore pressure in the berm dissipates with time.

7 Site Classification and Seismic Site Response

Based on the current subsurface conditions and the assumption that the existing permafrost condition will be maintained by providing a thermal break (i.e. air space) between the underside of proposed buildings and the ground surface, the site can be classified as "Class C" for seismic site response in accordance with the requirements of Section 4.1.8.4 of the National Building Code of Canada, 2010. In addition, the overburden soils are also considered to be non-liquefiable during a seismic event.

8 Site Grading and Drainage

Fill for raising the site grades should be unfrozen, well-graded sand and gravel, free of deleterious materials and compacted to at least 95 percent of the SPMDD. Table 8 provides recommended gradation requirements for Type 1, Type 2 and Select Subgrade materials at the site. Other gradations may also be suitable, but subject to review and approval by the geotechnical engineer-of-record.

Table 8 - Recommended Gradation for Type 1, Type 2 and Select Subgrade Material

Property	ASTM Test Method	Type 2 (Sub-Base)	Type 1 (Base)	Select Subgrade Material
Gradation (sieve/% passing)				
150 mm	C136			100
75 mm	C136	100		
37.5 mm	C136			
25.0 mm	C136	50-100	100	50-100
19.0 mm	C136	-	75-100	
9.5 mm	C136	-	50-85	
4.75 mm	C136	20- 55	35-65	20-100
2.0 mm	C136		25-50	
0.425 mm	C136	5-35	15-30	
0.300 mm	C136	-		5-95
0.150 mm	C136	-		2-65
0.075 mm	C117	0-8	5-8	0-25
Crushed Content (%) min.	-			
50 to 37.5 mm	-	60	60	-
37.5 to 19.0 mm	-	60	60	-
19.0 to 4.75 mm	-	60	60	-
Plasticity Index (%) max.	D4318	NP	NP	-
Abrasion Loss (%) max.	C131	50	45	-
Flat or Elongated Particles (%) Max.	D4791	15	15	-

9 Subsurface Concrete Requirements and Corrosion Potential of On-Site Soils

Chemical tests limited to pH and sulphate tests were performed on five selected soil samples. The results are given on Table 9. The testing was performed by AGAT Laboratories, Mississauga, Ontario.

Table 9: Results of Chemical Tests on Soil Samples

Parameter	Lab Test Results								Threshold Values
	BH 1	BH 2	BH 2	BH 4	BH 5	BH5	BH6	BH8	
Depth (m)	6-7 m	7-8 m	13-14 m	6-7 m	6-7 m	12-13 m	6-7 m	5-6 m	
pH	8.22	8.13	8.10	8.37	8.29	8.14	8.13	7.98	<5
Sulphates (%)	0.0124	0.0048	0.0063	0.0077	0.0059	0.0031	0.0066	0.0319	<0.1
Electrical Resistivity Ohm/cm	2207	3703	2639	1075	1548	5556	2370	1550	<1500 ohm.cm High corrosion potential

The test results indicate the soil contains a sulphate content of less than 0.1 percent. This concentration of sulphates in the soil would have a negligible potential of sulphate attack on subsurface concrete. Therefore, General Use (GU) Portland cement may be used in the subsurface concrete at this site. The concrete for the site should be designed in accordance with the requirements of CSA A23.1-09.

The resistivity results indicate that the subsurface soil is moderately corrosive to corrosive to buried steel. It is recommended that a corrosion specialist should be consulted to determine mitigating measures required if buried steel structures are to be located on the site.

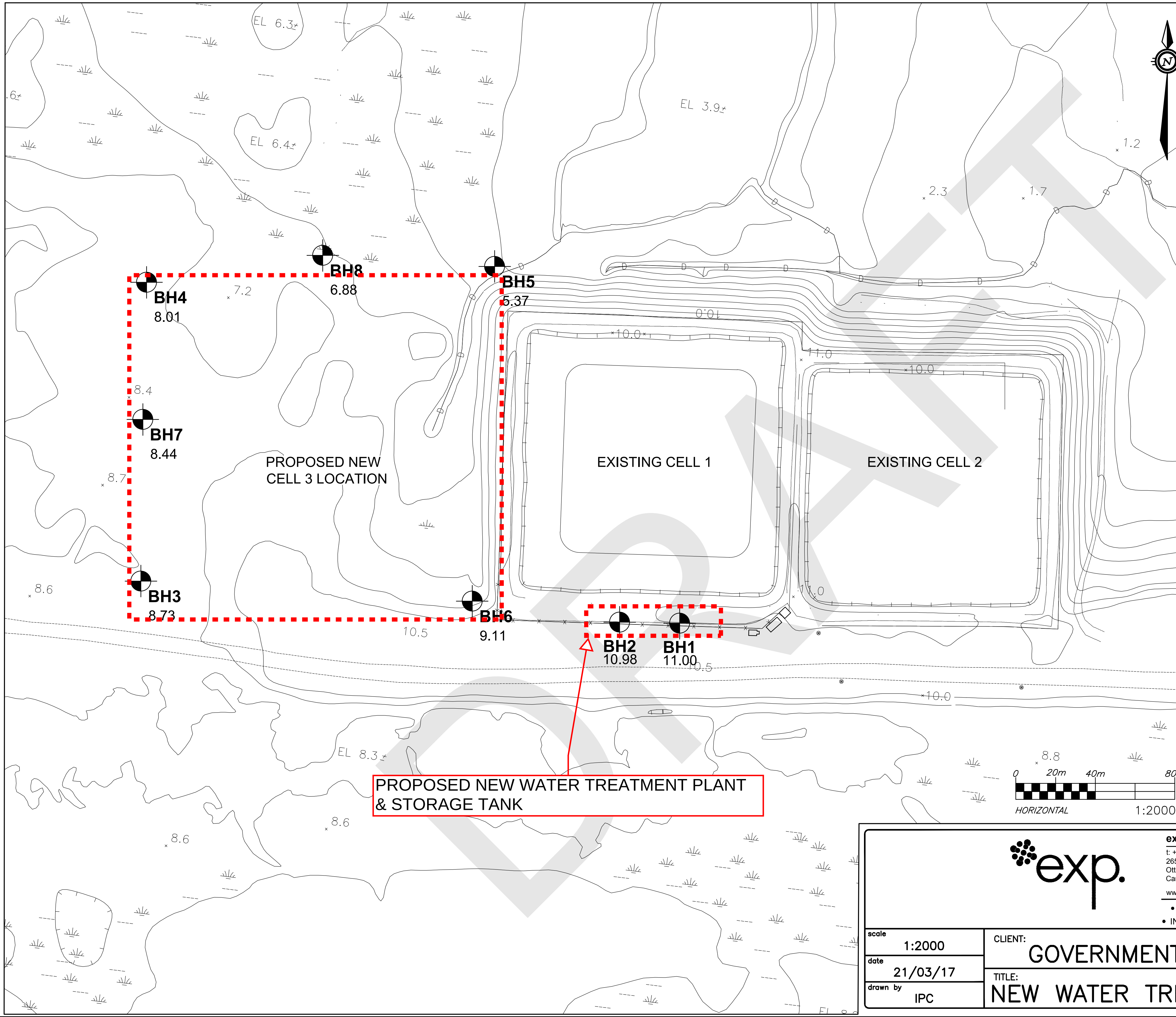
10 General Comments

The comments given in this report are intended only for guidance of design engineers. 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 results, so that they may draw their own conclusions as to how the subsurface conditions may affect them.

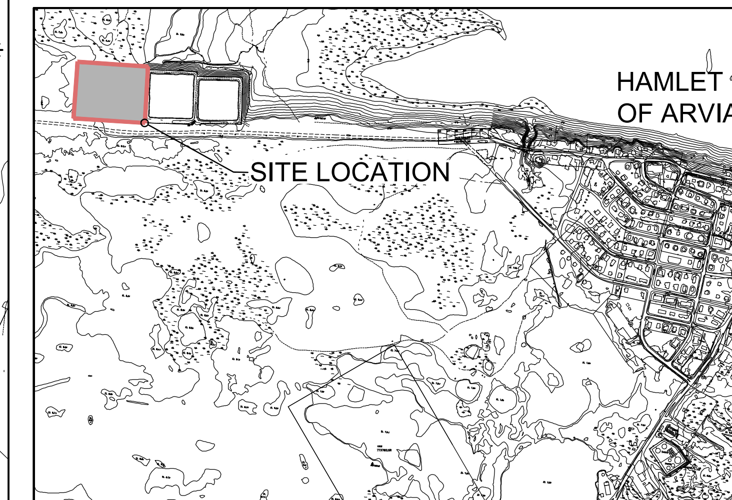
The information contained in this report in no way reflects on the environmental aspects of soil. Should specific information be required, additional testing may be necessary.

Should you have any questions, please do not hesitate to contact this office.

Figures



KEY PLAN



LEGEND

BH1 11.00 — BOREHOLE NUMBER, LOCATION AND ELEVATION

Elev. to 1 decimial

NOTES :

1. THE BOUNDARIES AND SOIL TYPES HAVE BEEN ESTABLISHED ONLY AT BOREHOLE LOCATIONS. BETWEEN BOREHOLES THEY ARE ASSUMED AND MAY BE SUBJECT TO CONSIDERABLE ERROR.
2. SOIL SAMPLES AND ROCK WILL BE RETAINED IN STORAGE FOR THREE MONTHS AND THEN DESTROYED UNLESS THE CLIENT ADVISES THAT AN EXTENDED TIME PERIOD IS REQUIRED.
3. TOPSOIL QUANTITIES SHOULD NOT BE ESTABLISHED FROM THE INFORMATION PROVIDED AT THE BOREHOLE LOCATIONS.
4. BOREHOLE ELEVATIONS SHOULD NOT BE USED TO DESIGN BUILDING(S) OR FLOOR SLABS OR PARKING LOT(S) GRADES.
5. THIS DRAWING FORMS PART OF THE REPORT PROJECT NUMBER AS REFERENCED AND SHOULD BE USED ONLY IN CONJUNCTION WITH THIS REPORT.

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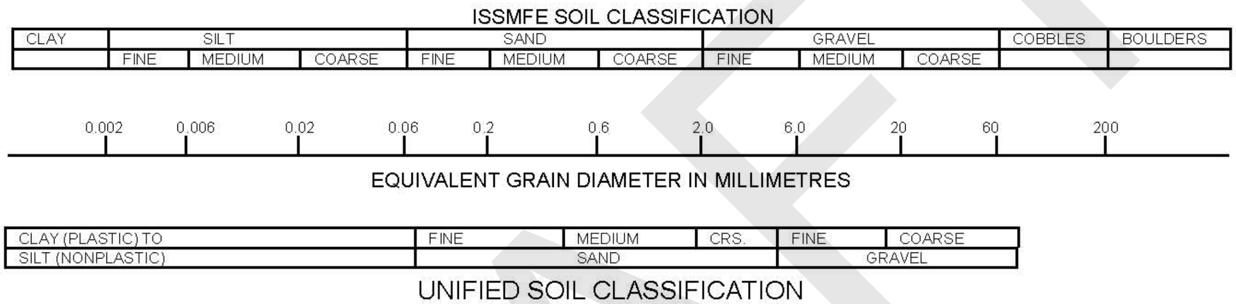
scale 1:2000	CLIENT: GOVERNMENT OF NUNAVUT–CGS	project no. OTT–00236239–A0
date 21/03/17	TITLE: NEW WATER TREATMENT PLANT ARVIAT	FIG. 1
drawn by IPC		

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.



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: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 2

Page. 1 of 1

Date Drilled: 2/23/17

Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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 Elevation 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
		SILTY SAND Light grey, silty sand with trace fine gravel - snow covered - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	11	0				
		- 5% gravel, 79% sand, 16% fines		2.5		×	grab	
		SILTY SAND WITH GRAVEL - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	6.0	5.0				
				6.5		×	grab	
				10.5		×	grab	
		- 17% gravel, 61% sand, 22% fines		13.5		×	grab	
		Borehole Terminated at 15.0 m Depth - target depth	-4.0	15.0				

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Borehole backfilled with drill cuttings upon completion.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 02

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 3

Page. 1 of 1

Date Drilled: 2/24/17

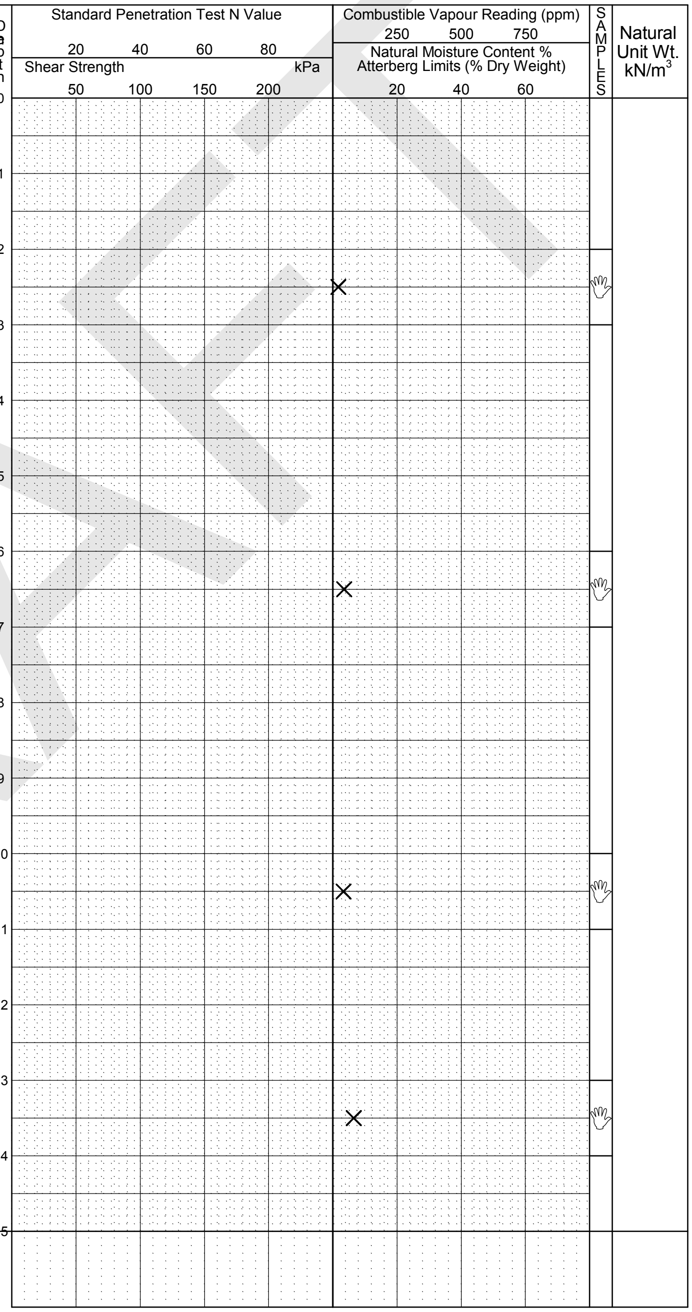
Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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 Elevation m	Depth
			11	0
		SILTY SAND Light grey, silty sand with trace fine gravel - snow covered - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)		
		SAND WITH GRAVEL - FROZEN THROUGHOUT - Nbn (bonded with no excess ice) - 28% gravel, 67% sand, 22% fines	6.0	5
		Borehole Terminated at 15.0 m Depth - target depth	-4.0	15



NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Multibead thermistor installed to 7.5 m depth upon completion and backfilled with sand/cuttings.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 03

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 4

Page. 1 of 1

Date Drilled: 2/26/17

Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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 Elevation m	Depth	Natural Moisture Content %
		SAND WITH GRAVEL - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	8.7	0	
		- 36% gravel, 61% sand, 3% fines		2.5	×
		- 33% gravel, 64% sand, 3% fines		5.5	×
				9.5	×
				13.5	×
		Borehole Terminated at 15.0 m Depth - target depth	-6.3	15	

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); SAMPLES; Natural Unit Wt. kN/m³

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Borehole backfilled with drill cuttings upon completion.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 04

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 5

Page. 1 of 1

Date Drilled: 2/26/17

Drill Type:

Datum: GEODETIC

Logged by: B.V.   Checked by: J.S

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	▲

Column headings: GWL | SYMBOL | SOIL DESCRIPTION | Geodetic Elevation 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 Elevation (m)	Depth (m)	Soil Description
8	0	**SILTY SAND** Light grey, silty sand with trace fine gravel - snow covered - FROZEN THROUGHOUT - Nbn (bonded with no excess ice) - 7% gravel, 59% sand, 34% fines
4.0	4	**SILTY SAND WITH GRAVEL** - FROZEN THROUGHOUT - Nbn (bonded with no excess ice) - 16% gravel, 58% sand, 26% fines
-7.0	15	**Borehole Terminated at 15.0 m Depth** - target depth

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Borehole backfilled with drill cuttings upon completion.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 05

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 6

Page. 1 of 1

Date Drilled: 2/25/17

Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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 Elevation m	Depth (m)	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
		SILTY SAND WITH GRAVEL - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	5.4	0				
		- 21% gravel, 52% sand, 27% fines		2.5		× (~7)	grab	
				6.5		× (~9)	grab	
				9.5		× (~15)	grab	
				12.5		× (~14)	grab	
			-9.6	15				
		Borehole Terminated at 15.0 m Depth - target depth						

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Multibead thermistor installed to 8.5 m depth upon completion and backfilled with sand/cuttings.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 06

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 7

Page. 1 of 1

Date Drilled: 2/25/17

Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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 Elevation m	Depth
		SILTY SAND Light grey, silty sand with trace fine gravel - snow covered - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	9.1	0
		SAND WITH GRAVEL - FROZEN THROUGHOUT - Nbn (bonded with no excess ice) - 25% gravel, 71% sand, 4% fines	4.1	5
		Borehole Terminated at 15.0 m Depth - target depth	-5.9	15

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

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Singlebead thermistor installed at 7 m depth upon completion and backfilled with sand/cuttings.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 07

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 8

Page. 1 of 1

Date Drilled: 2/26/17

Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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 Elevation (m)	Depth (m)	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)	SAMPLES	Natural Unit Wt. kN/m³
	SILTY SAND Light grey, silty sand with trace fine gravel - snow covered - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	8.4	0				
	- 5% gravel, 79% sand, 16% fines		2.5		×	✋	
	SILTY SAND WITH GRAVEL - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)	3.4	5.0		×	✋	
			9.5		×	✋	
			12.5		×	✋	
	- 17% gravel, 61% sand, 22% fines						
	Borehole Terminated at 15.0 m Depth - target depth	-6.6	15				

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Singlebead thermistor installed at 10 m depth upon completion and backfilled with sand/cuttings.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

Log of Borehole BH 08

Project No: OTT-00236239-A0

Project: GEOTECHNICAL INVESTIGATION - WATER TREATMENT & RESERVOIR

Location: ARVIAT, NU

Figure No. 9

Page. 1 of 1

Date Drilled: 2/25/17

Drill Type:

Datum: GEODETIC

Logged by: B.V. Checked by: J.S

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	▲

Geodetic Elevation (m)	Depth (m)	SOIL DESCRIPTION	Natural Moisture Content	Samples
6.9	0	**SILTY SAND** Light grey, silty sand with trace fine gravel - snow covered - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)		
	~2.5	- 5% gravel, 79% sand, 16% fines	×	Grab
1.9	5	**SAND WITH GRAVEL** - FROZEN THROUGHOUT - Nbn (bonded with no excess ice)		
	~7.5		×	Grab
	~10.5		×	Grab
	~12.5		×	Grab
	~14	- 17% gravel, 61% sand, 22% fines		
-8.1	15	**Borehole Terminated at 15.0 m Depth** - target depth		

Chart 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); Natural Unit Wt. kN/m³

NOTES:
1. Borehole/Test Pit data requires Interpretation by exp. before use by others
2. Singlebead thermistor installed at 6 m depth upon completion and backfilled with sand/cuttings.
3. Field work supervised by an **exp** representative.
4. See Notes on Sample Descriptions
5. This Figure is to read with exp. Services Inc. report OTT-00236239-A0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Upon Completion	Dry	15.0

CORE DRILLING RECORD

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

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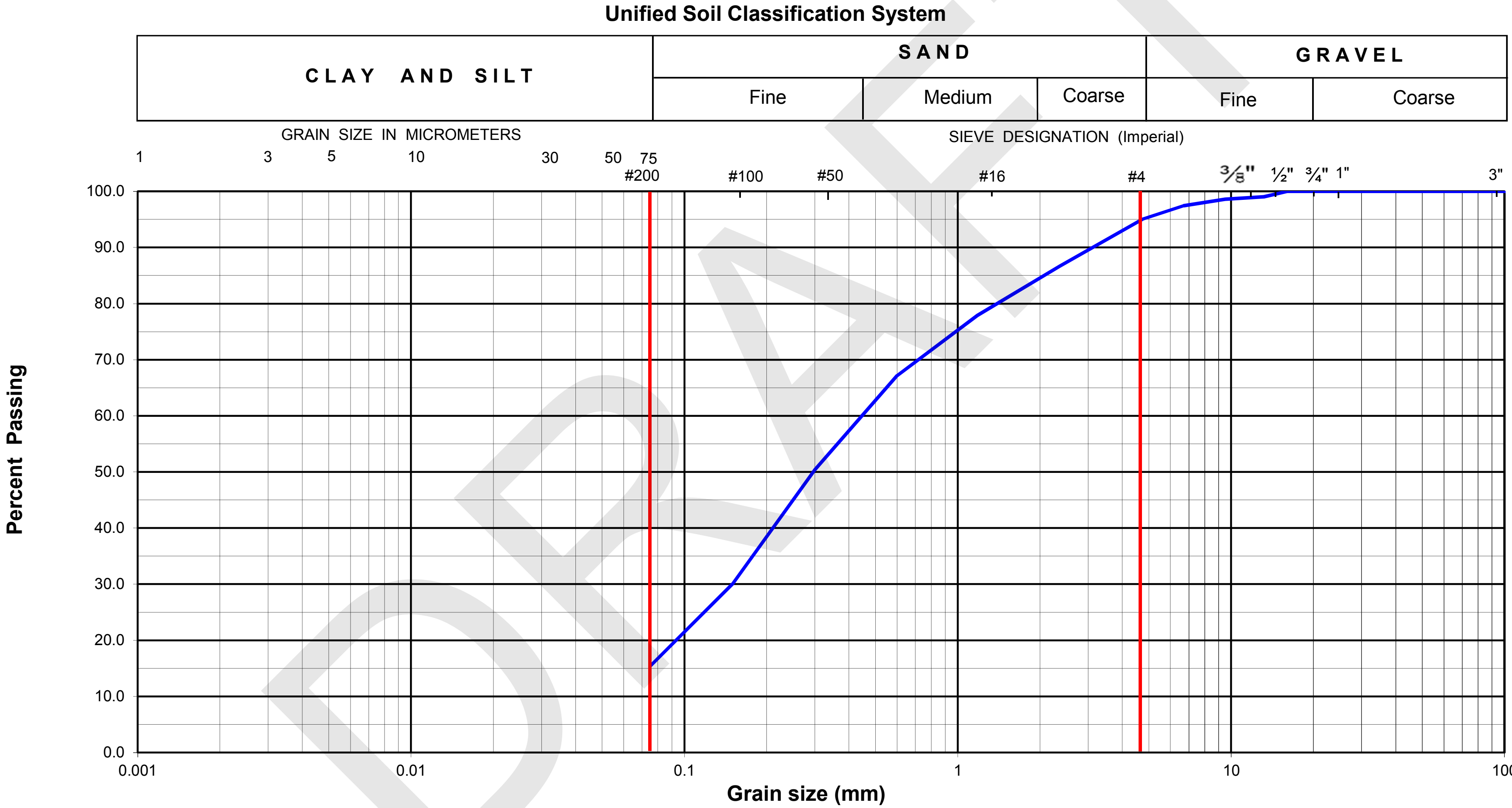
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)



Exp Project No.: OTT-00236239-A0	Project Name :	Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion			
Client : Government of Nunavut	Project Location :	Arviat, NU			
Date Sampled : February 21, 2017	Borehole:	1	Sample: 1	Depth (m) :	2-3m
Sample Description :	Silty Sand			Figure :	10

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Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

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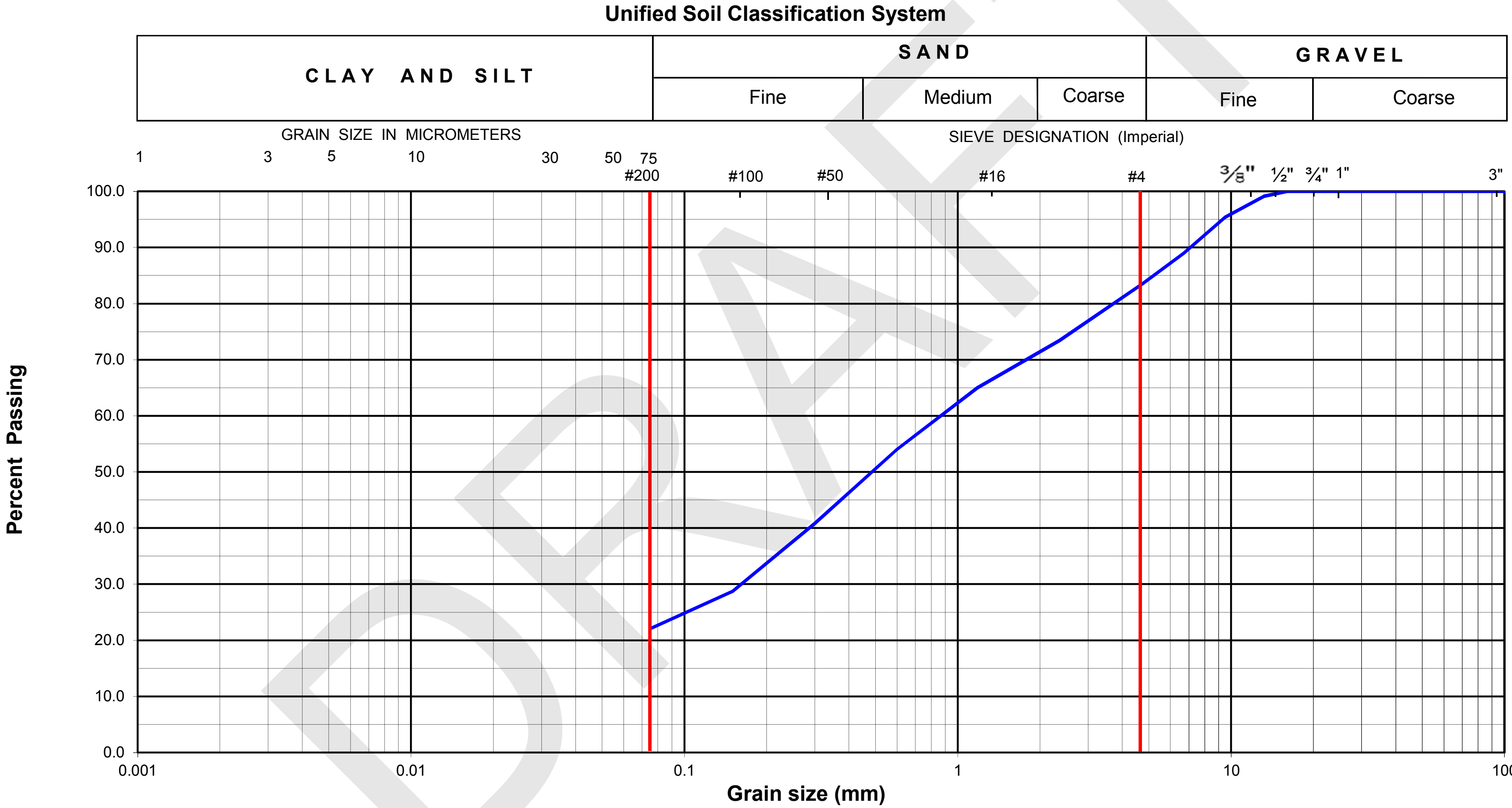

Exp Project No.:	**OTT-00236239-A0**	**Project Name :**	**Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion**		
Client :	**Government of Nunavut**	**Project Location :**	**Arviat, NU**		
Date Sampled :	**February 21, 2017**	**Borehole:**	**1**	**Sample: 4**	**Depth (m) : 13-14m**
Sample Description :	**Silty Sand with Gravel**				**Figure : 11**

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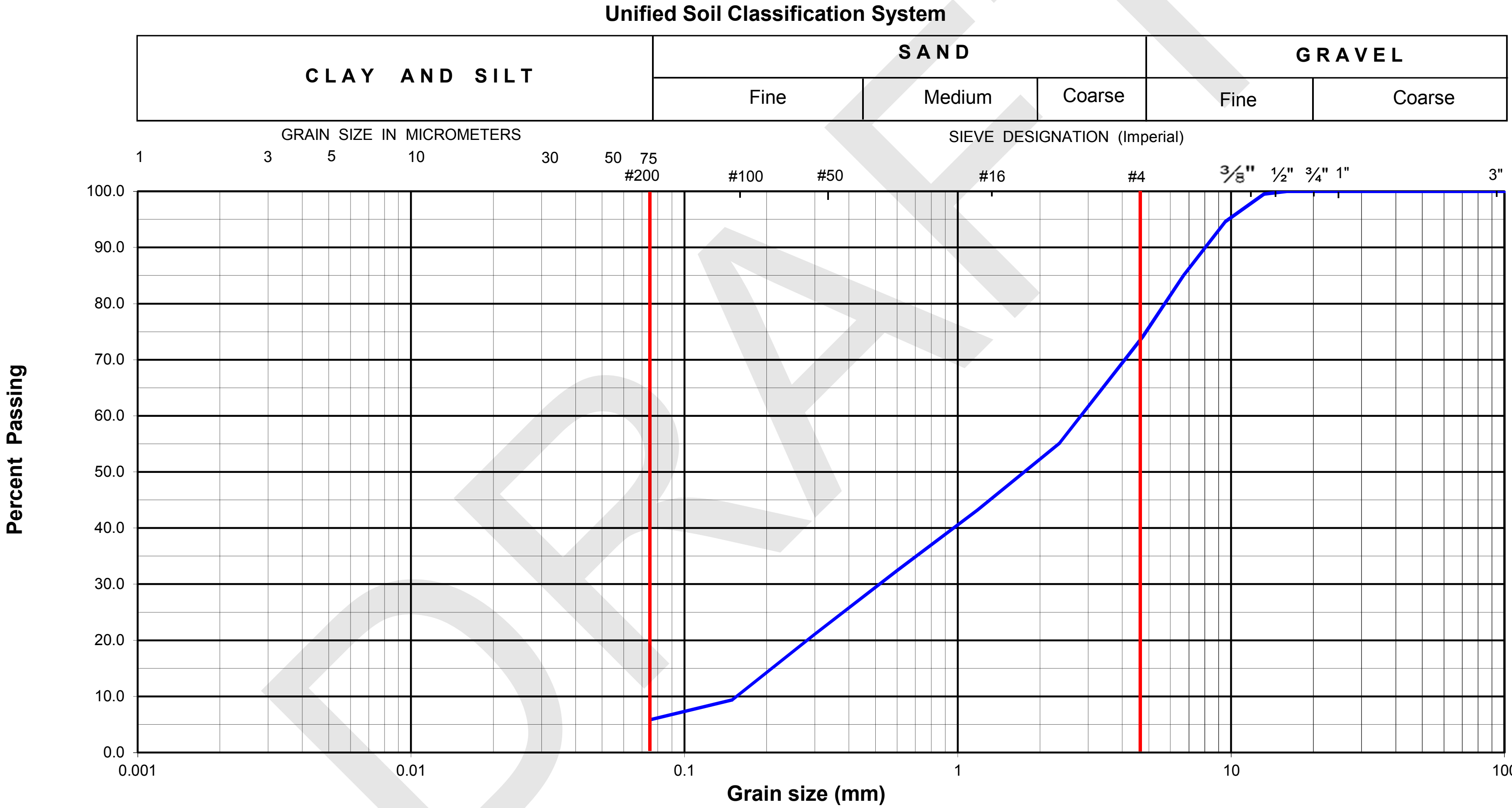
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)



Exp Project No.:	OTT-00236239-A0	Project Name :	Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion			
Client :	Government of Nunavut	Project Location :	Arviat, NU			
Date Sampled :	February 24, 2017	Borehole:	2	Sample: 3	Depth (m) :	10-11m
Sample Description :		Sand with Gravel			Figure :	12

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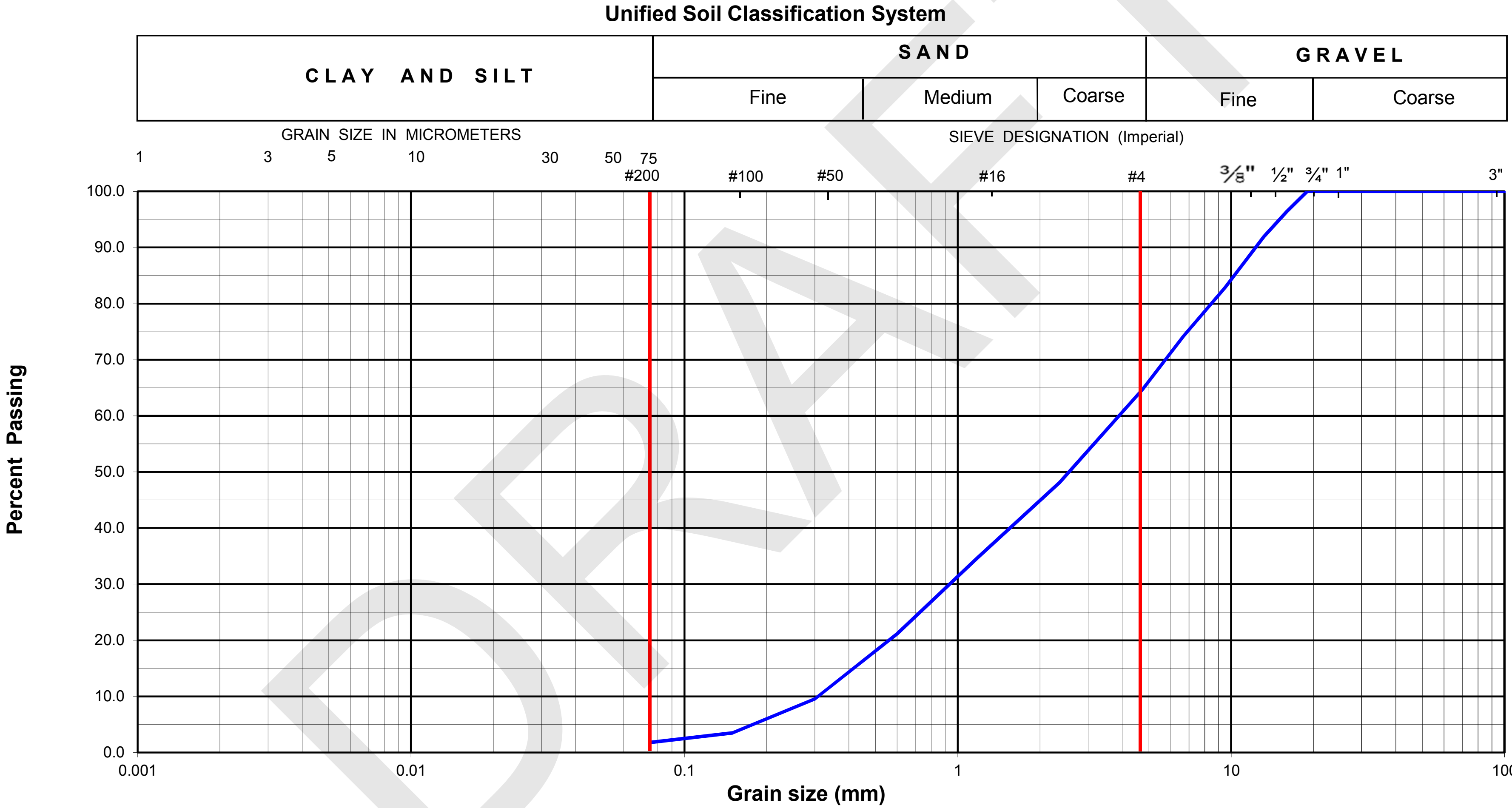
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)



Exp Project No.: OTT-00236239-A0	Project Name : Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion				
Client : Government of Nunavut	Project Location : Arviat, NU				
Date Sampled : February 26, 2017	Borehole: 3	Sample: 1		Depth (m) : 2-3m	
Sample Description :	Sand with Gravel			Figure : 13	

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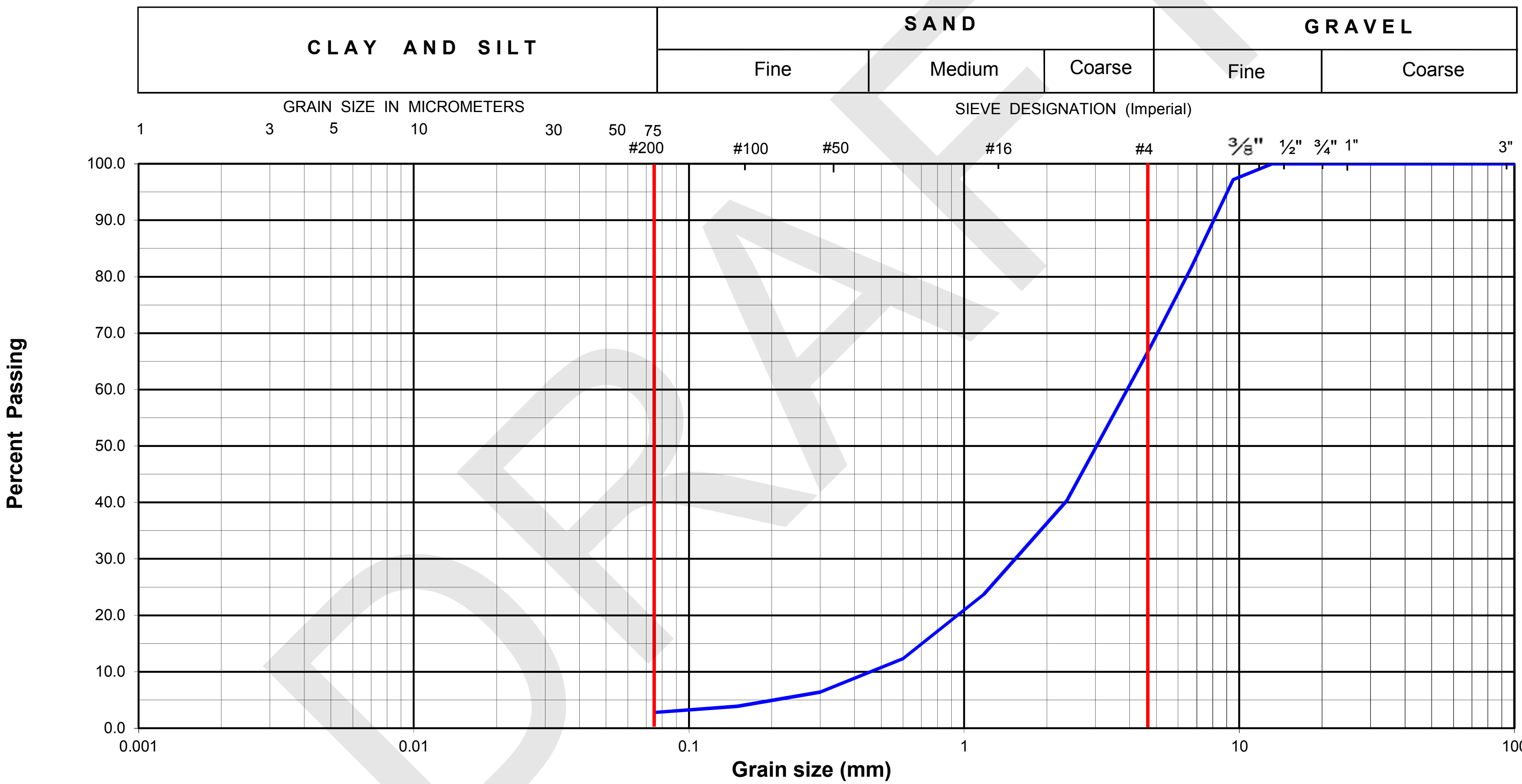
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)

Unified Soil Classification System



Exp Project No.: OTT-00236239-A0	Project Name :	Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion			
Client : Government of Nunavut	Project Location :	Arviat, NU			
Date Sampled : February 26, 2017	Borehole:	3	Sample: 2	Depth (m) :	5-6m
Sample Description :		Sand with Gravel		Figure :	14

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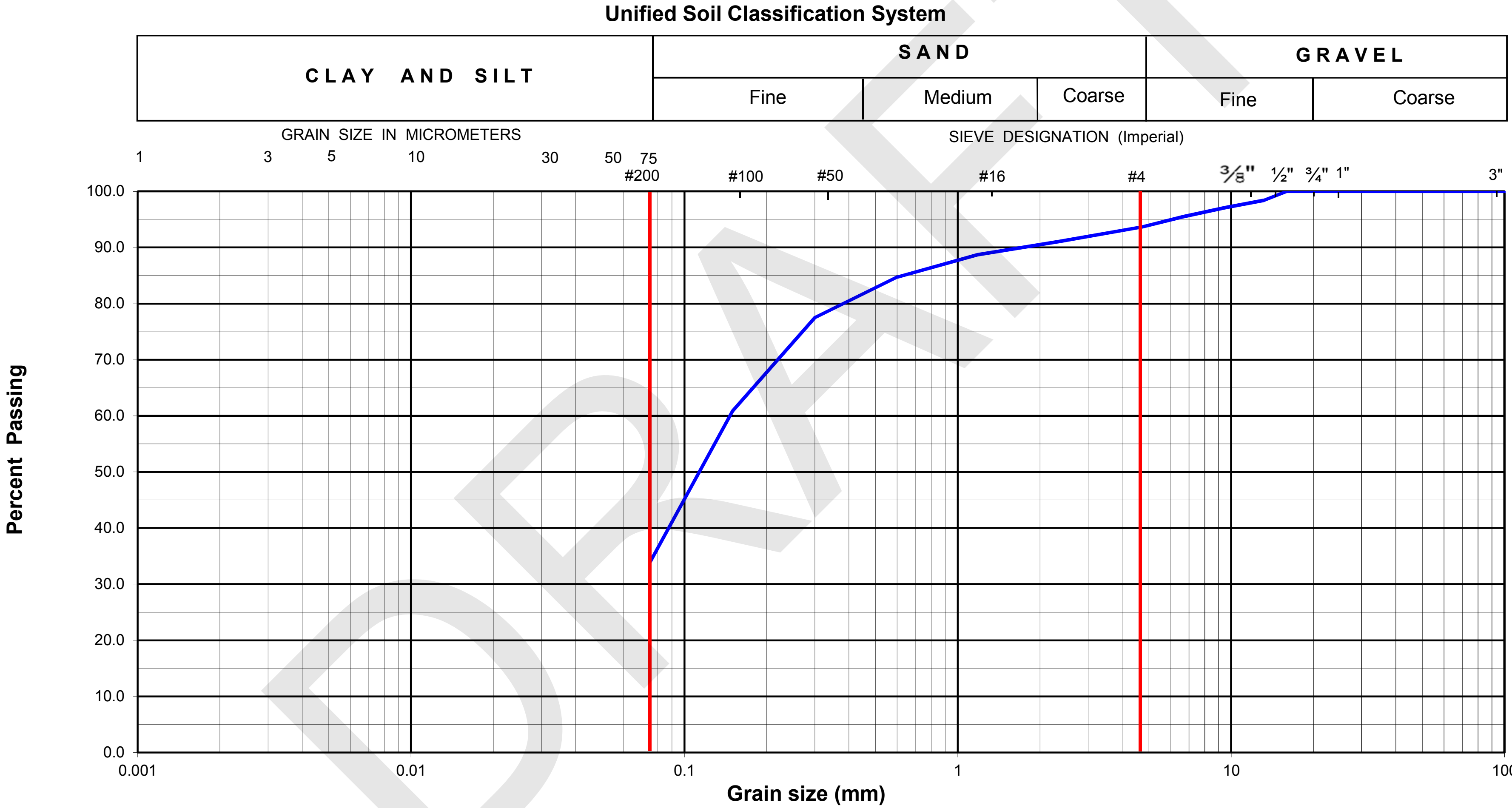
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)



Exp Project No.:	**OTT-00236239-A0**	**Project Name :**	**Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion**		
Client :	**Government of Nunavut**	**Project Location :**	**Arviat, NU**		
Date Sampled :	**February 26, 2017**	**Borehole:** 4	**Sample:** 1	**Depth (m) :**	**2-3m**
Sample Description :		**Silty Sand**		**Figure :**	**15**

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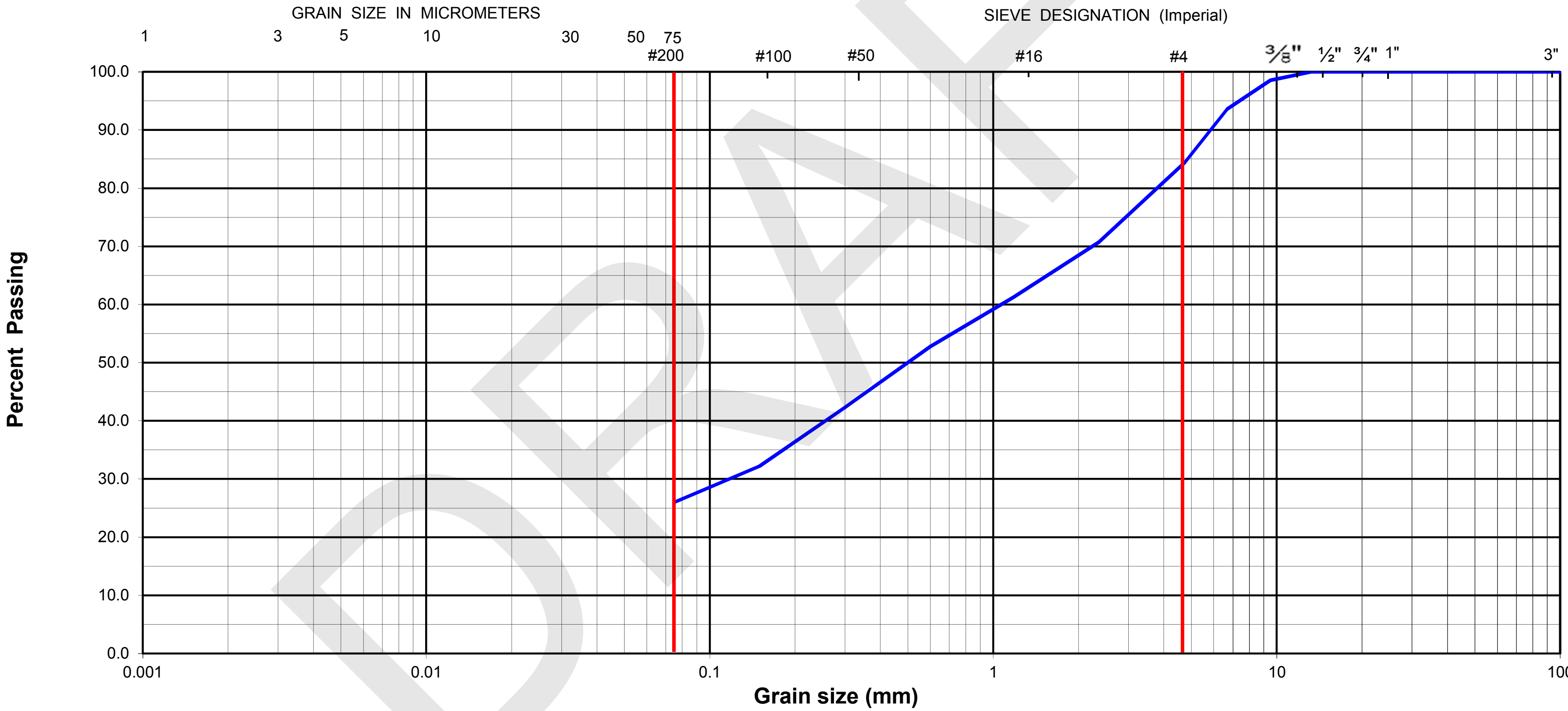
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)

Unified Soil Classification System

CLAY AND SILT	SAND			GRAVEL	
	Fine	Medium	Coarse	Fine	Coarse



Exp Project No.:	OTT-00236239-A0	Project Name :	Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion		
Client :	Government of Nunavut	Project Location :	Arviat, NU		
Date Sampled :	February 26, 2017	Borehole: 4	Sample: 3	Depth (m) :	9-10m
Sample Description :	Silty Sand with Gravel			Figure :	16

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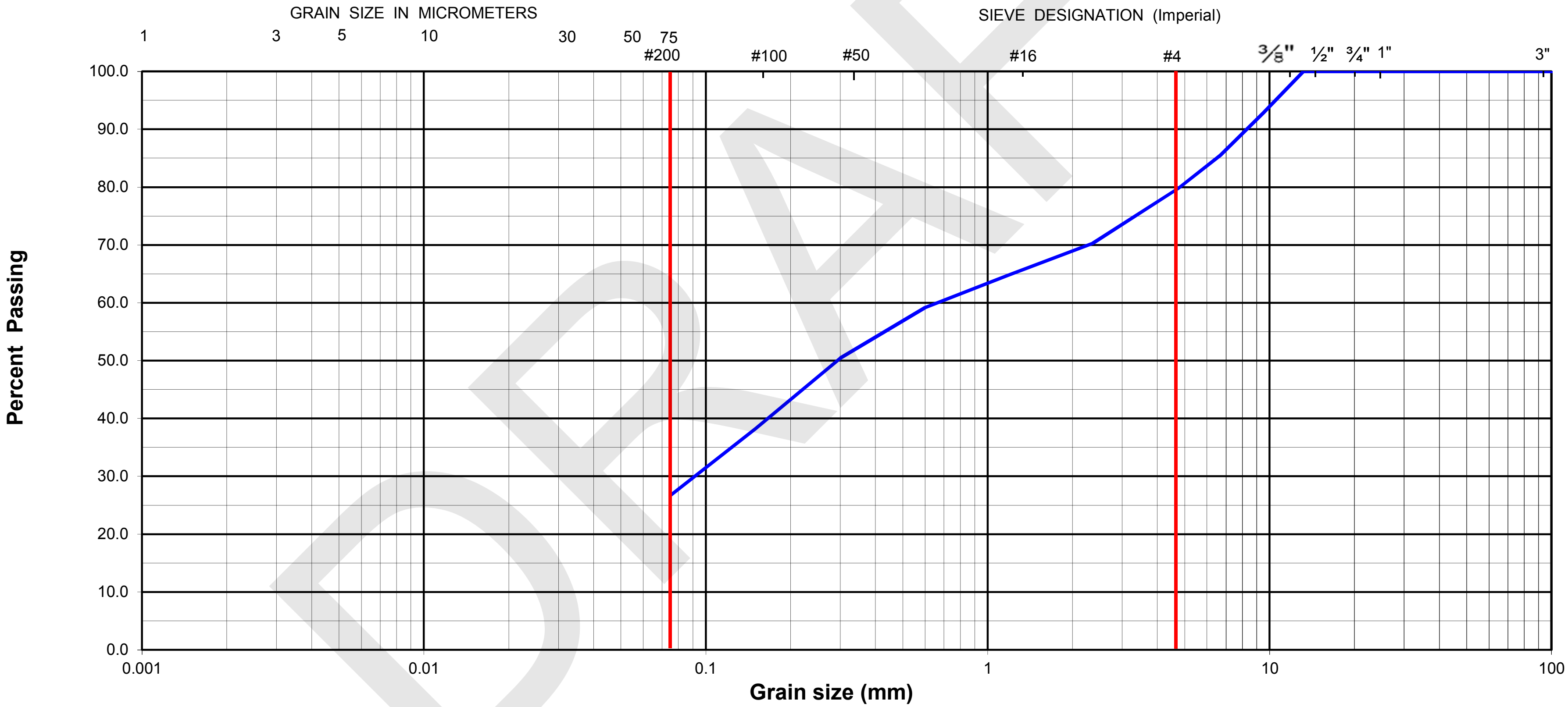
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)

Unified Soil Classification System

CLAY AND SILT	SAND			GRAVEL	
	Fine	Medium	Coarse	Fine	Coarse



Exp Project No.:	OTT-00236239-A0	Project Name :	Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion		
Client :	Government of Nunavut	Project Location :	Arviat, NU		
Date Sampled :	February 25, 2017	Borehole:	5	Sample: 1	Depth (m) : 2-3m
Sample Description :	Silty Sand with Gravel				Figure : 17

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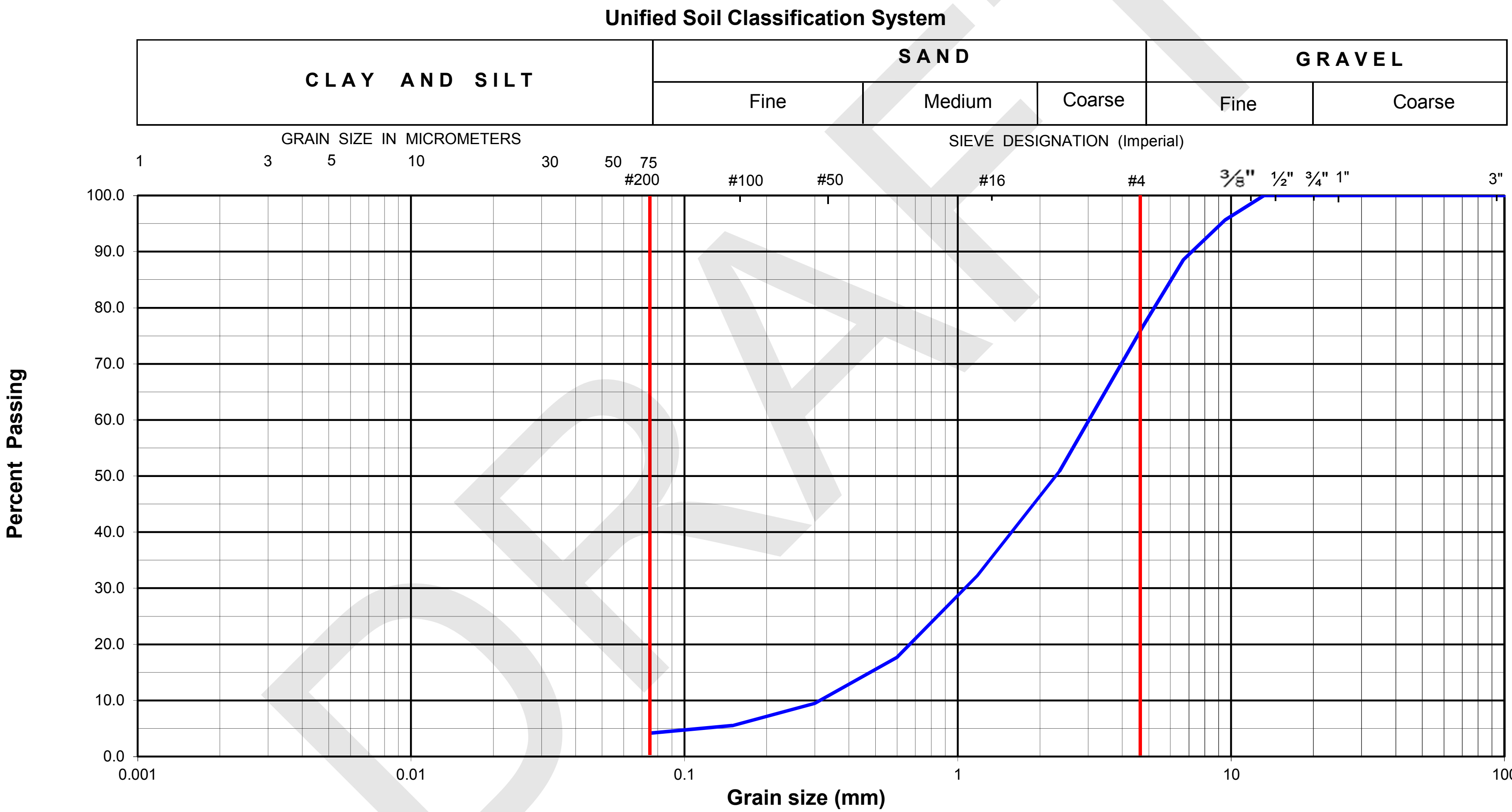
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)



Exp Project No.:	**OTT-00236239-A0**	**Project Name :**	**Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion**		
Client :	**Government of Nunavut**	**Project Location :**	**Arviat, NU**		
Date Sampled :	**February 25, 2017**	**Borehole:**	**6**	**Sample:** 4	**Depth (m) :** 13-14m
Sample Description :			**Sand with Gravel**		**Figure :** 18

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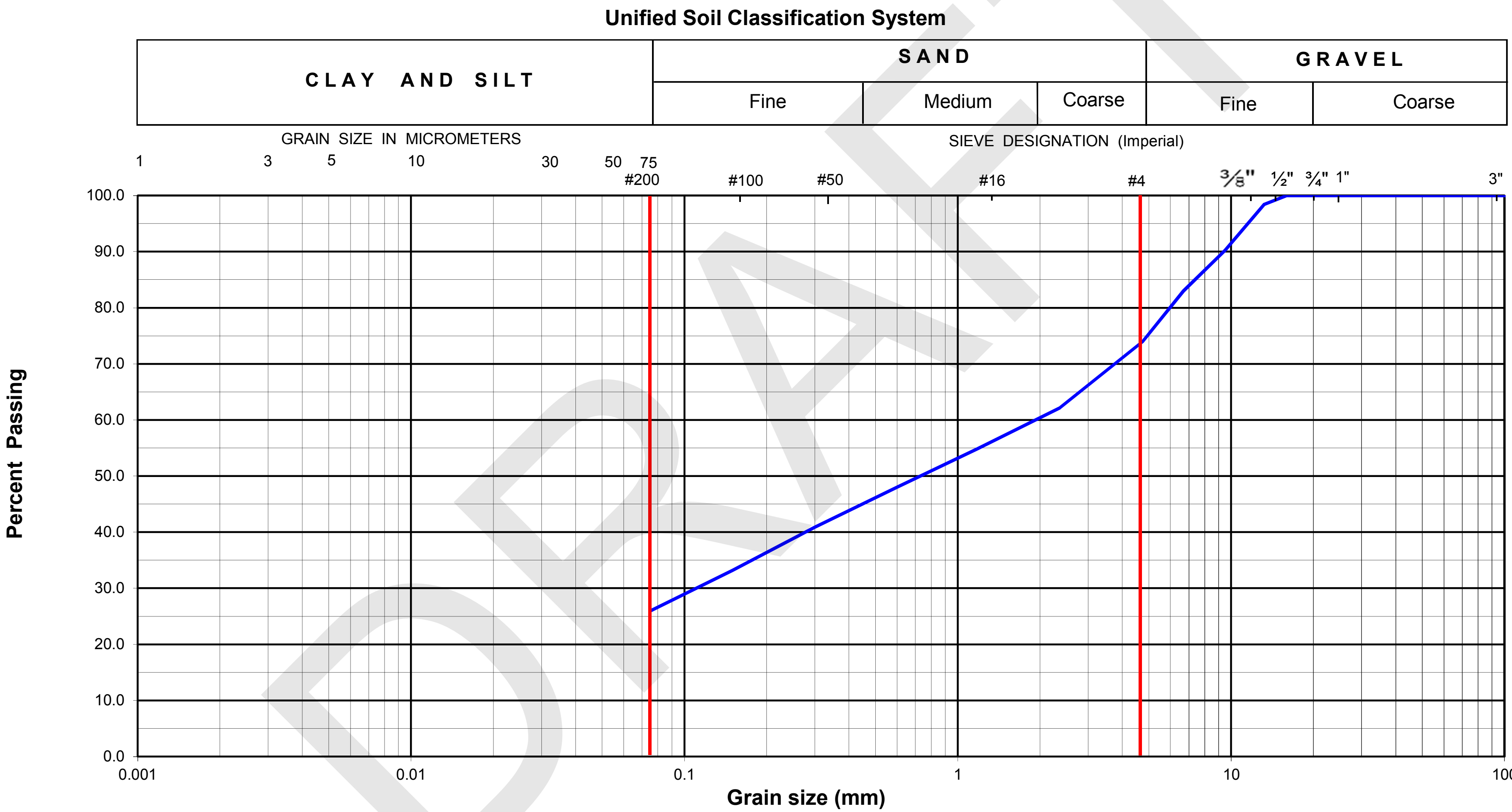
Grain-Size Distribution Curve

Method of Test for Sieve Analysis of Aggregate

ASTM C-136 (LS-602)

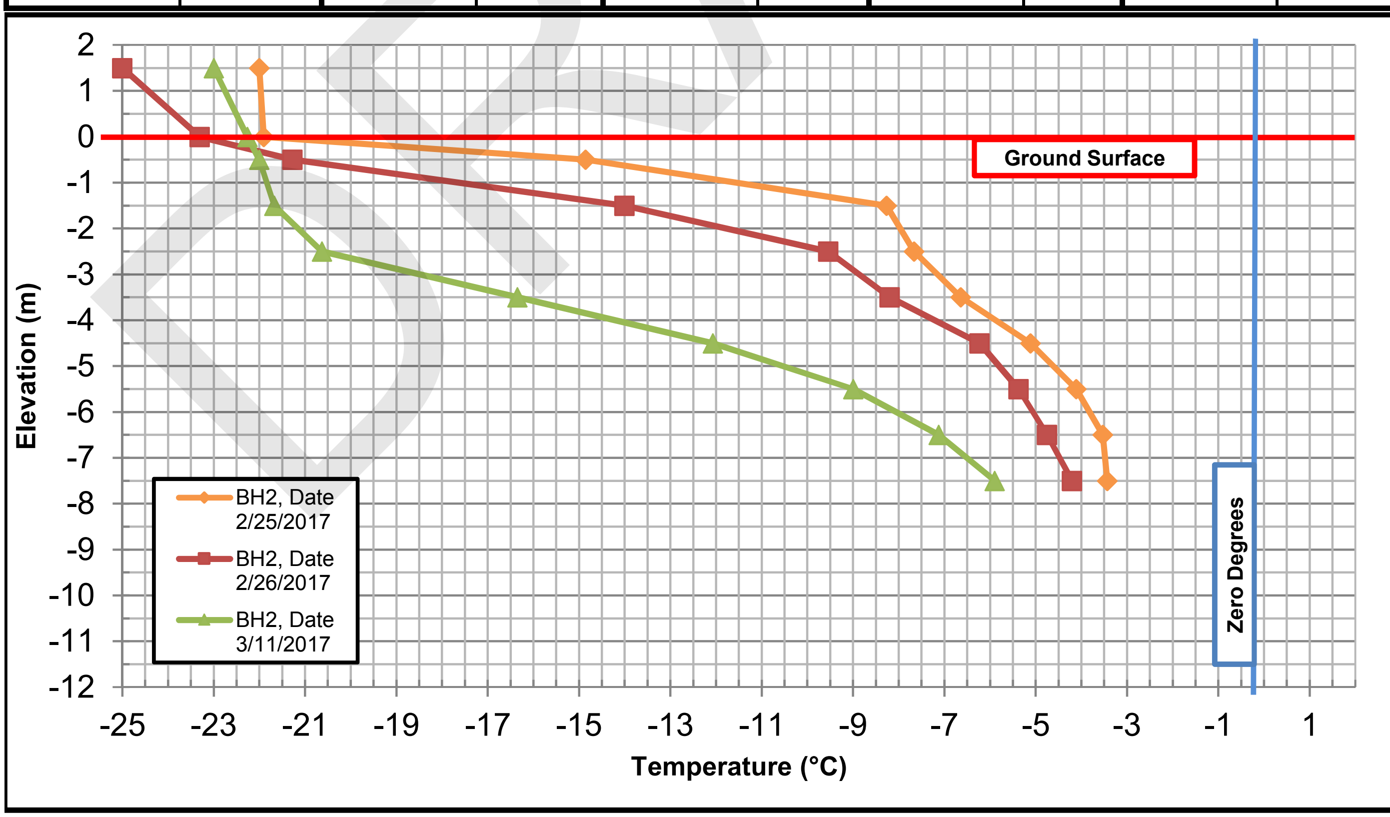


Exp Project No.:	OTT-00236239-A0	Project Name :	Geotechnical Investigation - Water Treatment Plant and Reservoir Expansion			
Client :	Government of Nunavut	Project Location :	Arviat, NU			
Date Sampled :	February 25, 2017	Borehole:	8	Sample: 2	Depth (m) :	7-8m
Sample Description :	Silty Sand with Gravel				Figure :	19

Summary of Thermistor Installation and Readings

Project No.:	OTT-00236239-AO	Figure No.	20
Project Name:	Water Reservoir Expansion	Date Installed:	February 24, 2017
Project Location:	Arviat, NU	Coords:	

		BH2, Date 2/25/2017	Time 12:30	BH2, Date 2/26/2017	Time 12:30	BH2, Date 3/11/2017	Time 12:30		
Thermistor Bulb	**Elevation (m)**	**Meter Reading (kohms)**	**Temp (^oC)**	**Meter Reading (kohms)**	**Temp (^oC)**	**Meter Reading (kohms)**	**Temp (^oC)**	**Meter Reading (kohms)**	**Temp (^oC)**
AIR	**1.5**	**BH2**	**-22**		**-25**		**-23**		
1	0.0	54.2	-21.9	59.0	-23.3	55.4	-22.3		
2	-0.5	36.2	-14.9	52.3	-21.3	54.5	-22.0		
3	-1.5	25.2	-8.3	34.5	-14.0	53.5	-21.7		
4	-2.5	24.4	-7.7	27.0	-9.5	50.4	-20.6		
5	-3.5	23.1	-6.6	25.1	-8.2	39.4	-16.4		
6	-4.5	21.3	-5.1	22.6	-6.2	31.0	-12.1		
7	-5.5	20.2	-4.1	21.6	-5.4	26.2	-9.0		
8	-6.5	19.6	-3.5	20.9	-4.8	23.7	-7.1		
9	-7.5	19.5	-3.4	20.3	-4.2	22.2	-5.9		

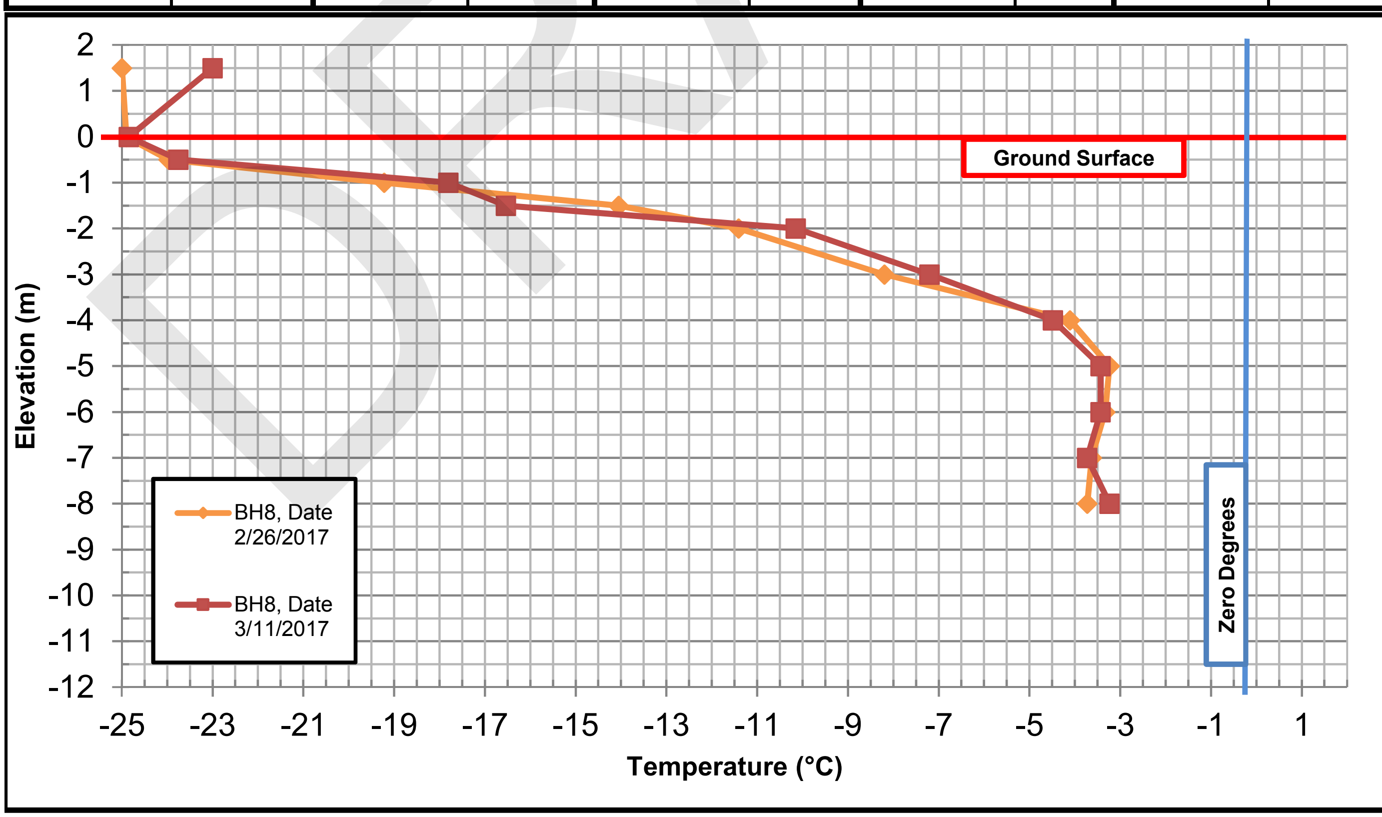


NOTES: At the time of drilling, the active layer was no longer thawed. The borehole was drilled to 15 m depth without encountering bedrock. The frozen soil was not observed to contain obvious visual signs of ice or excess ice content within the soil matrix.

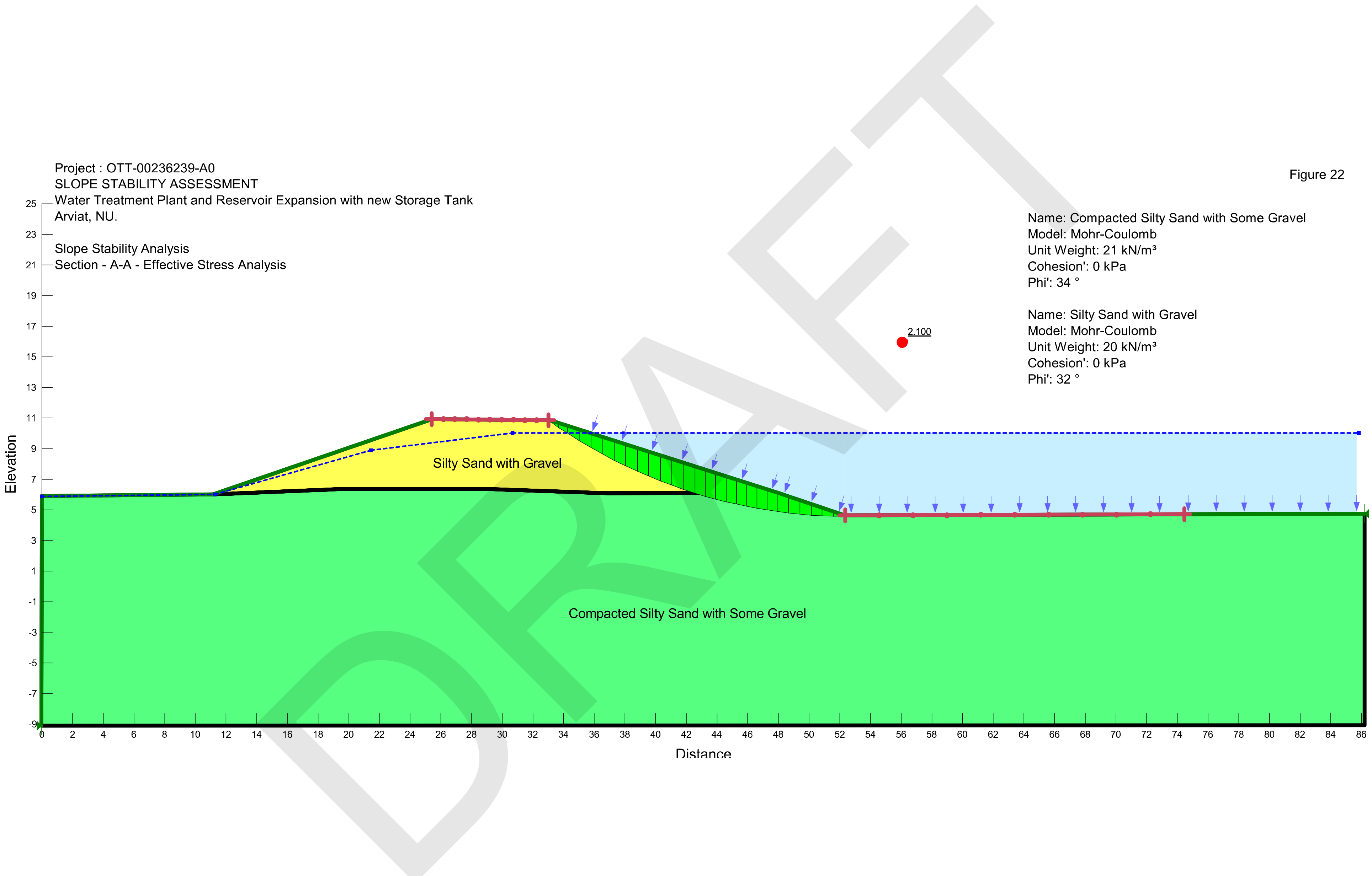
Summary of Thermistor Installation and Readings

Project No.:	OTT-00236239-AO	Figure No.	21
Project Name:	**Water Reservoir Expansion**	Date Installed:	**Feburary 25, 2017**
Project Location:	**Arviat, NU**	Coords:	

		BH8, Date 2/26/2017	Time 18:30	BH8, Date 3/11/2017	Time 18:30				
Thermistor Bulb	**Elevation (m)**	**Meter Reading (kohms)**	**Temp (°C)**	**Meter Reading (kohms)**	**Temp (°C)**	**Meter Reading (kohms)**	**Temp (°C)**	**Meter Reading (kohms)**	**Temp (°C)**
AIR	**1.5**	**BH8**	**-25**	**BH8**	**-23**				
1	0.0	65.0	-24.9	64.8	-24.8				
2	-0.5	61.4	-24.0	60.6	-23.8				
3	-1.0	46.4	-19.2	42.8	-17.8				
4	-1.5	34.4	-14.1	39.8	-16.5				
5	-2.0	29.9	-11.4	27.9	-10.1				
6	-3.0	25.1	-8.2	23.8	-7.2				
7	-4.0	20.2	-4.1	20.6	-4.5				
8	-5.0	19.3	-3.2	19.5	-3.4				
9	-6.0	19.4	-3.3	19.5	-3.4				
10	-7.0	19.7	-3.6	19.8	-3.7				
11	-8.0	19.8	-3.7	19.3	-3.2				



NOTES: At the time of drilling, the active layer was no longer thawed. The borehole was drilled to 15 m depth without encountering bedrock. The frozen soil was not observed to contain obvious visual signs of ice or excess ice content within the soil matrix.

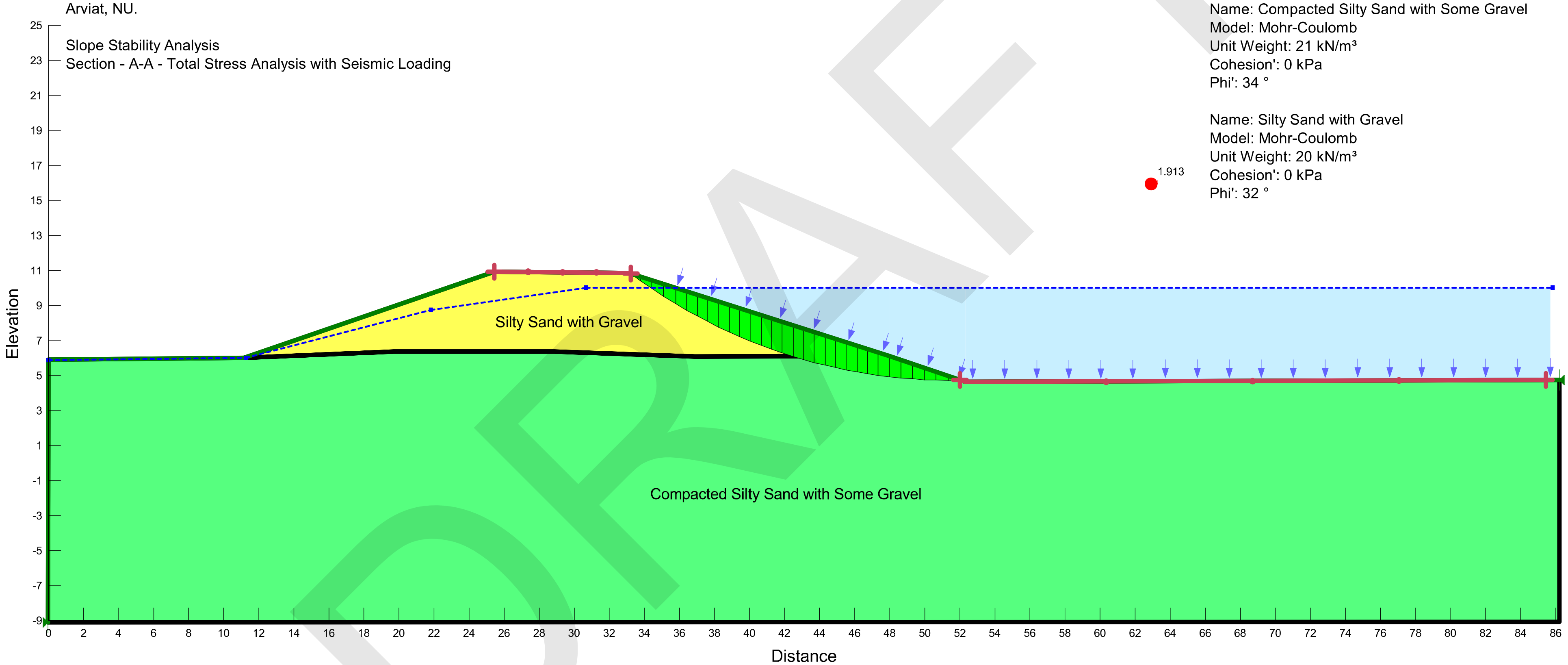


Project : OTT-00236239-A0
SLOPE STABILITY ASSESSMENT
Water Treatment Plant and Reservoir Expansion with new Storage Tank
Arviat, NU.
Slope Stability Analysis
Section - A-A - Effective Stress Analysis
Figure 22
Name: Compacted Silty Sand with Some Gravel
Model: Mohr-Coulomb
Unit Weight: 21 kN/m³
Cohesion': 0 kPa
Phi': 34 °
Name: Silty Sand with Gravel
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 32 °
2.100
Silty Sand with Gravel
Compacted Silty Sand with Some Gravel
Elevation
Distance
DRAFT

Project : OTT-00236239-A0
SLOPE STABILITY ASSESSMENT
Water Treatment Plant and Reservoir Expansion with new Storage Tank
Arviat, NU.

Slope Stability Analysis
Section - A-A - Total Stress Analysis with Seismic Loading

Figure 23



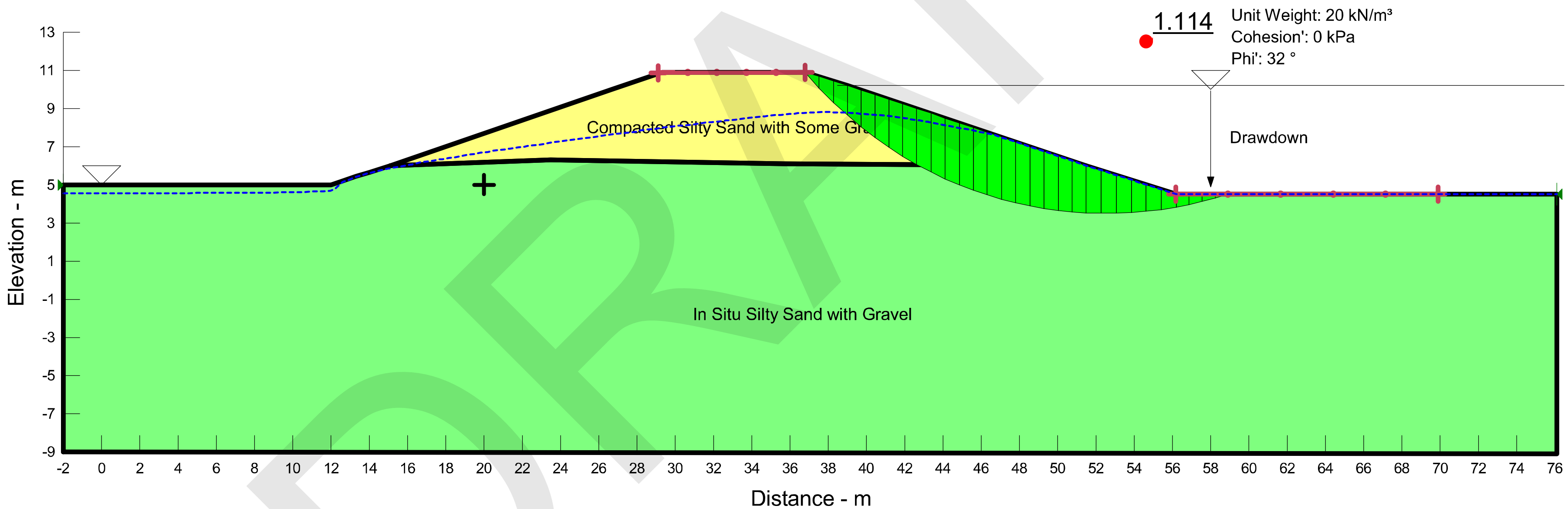
Project : OTT-00236239-A0
SLOPE STABILITY ASSESSMENT
Water Treatement Plant and Reservoir Expansion
with New Storage Tank.
Arviat, NU.

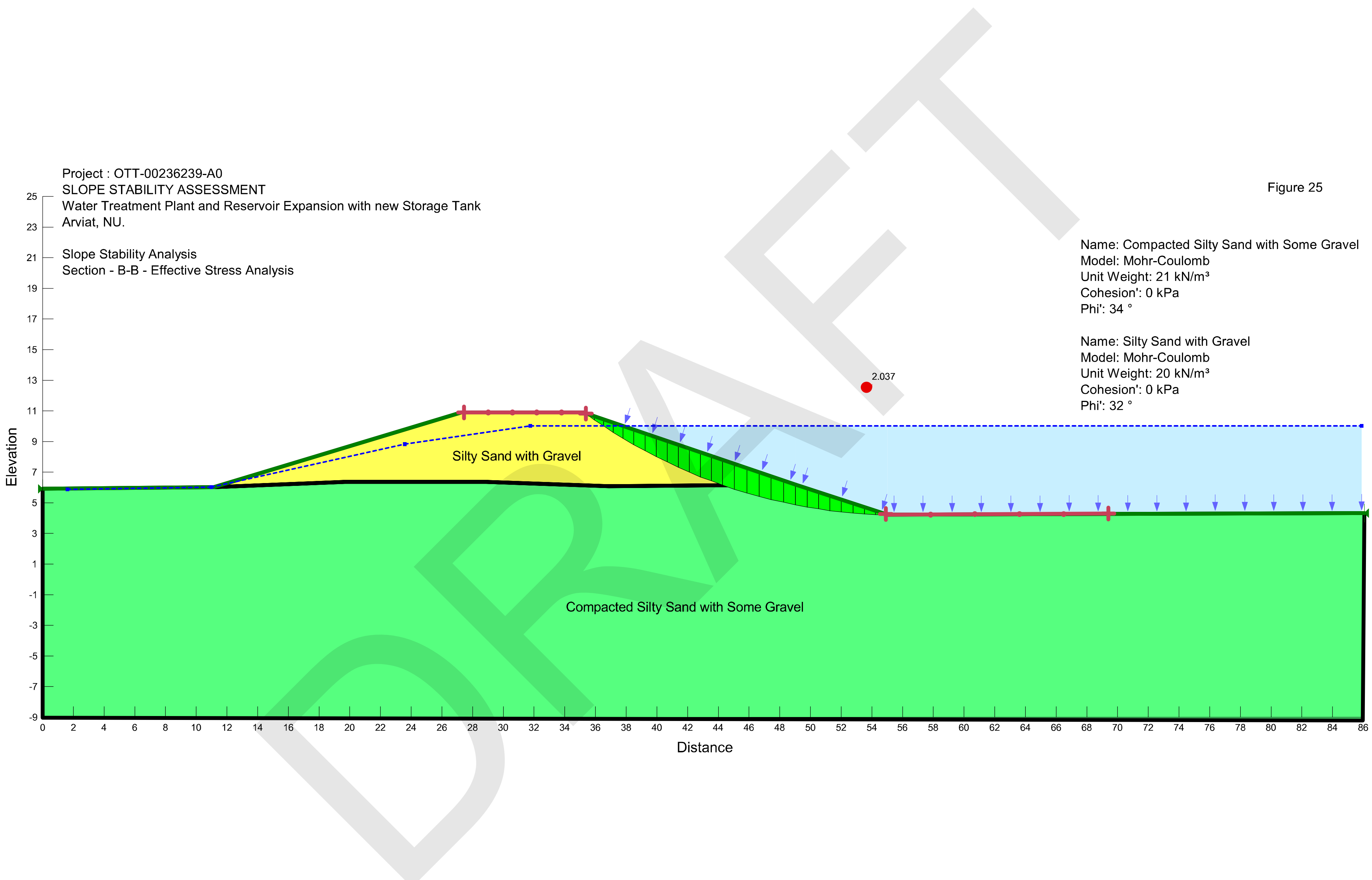
Slope Stability Analysis
Section - A-A - Rapid Drawdown Analysis

Figure 24

Name: Compacted Silty Sand with Some Grav
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 34 °

Name: In Situ Silty Sand with Gravel
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 32 °




Project : OTT-00236239-A0
SLOPE STABILITY ASSESSMENT
Water Treatment Plant and Reservoir Expansion with new Storage Tank
Arviat, NU.
Slope Stability Analysis
Section - B-B - Effective Stress Analysis
Figure 25
Name: Compacted Silty Sand with Some Gravel
Model: Mohr-Coulomb
Unit Weight: 21 kN/m³
Cohesion': 0 kPa
Phi': 34 °
Name: Silty Sand with Gravel
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 32 °
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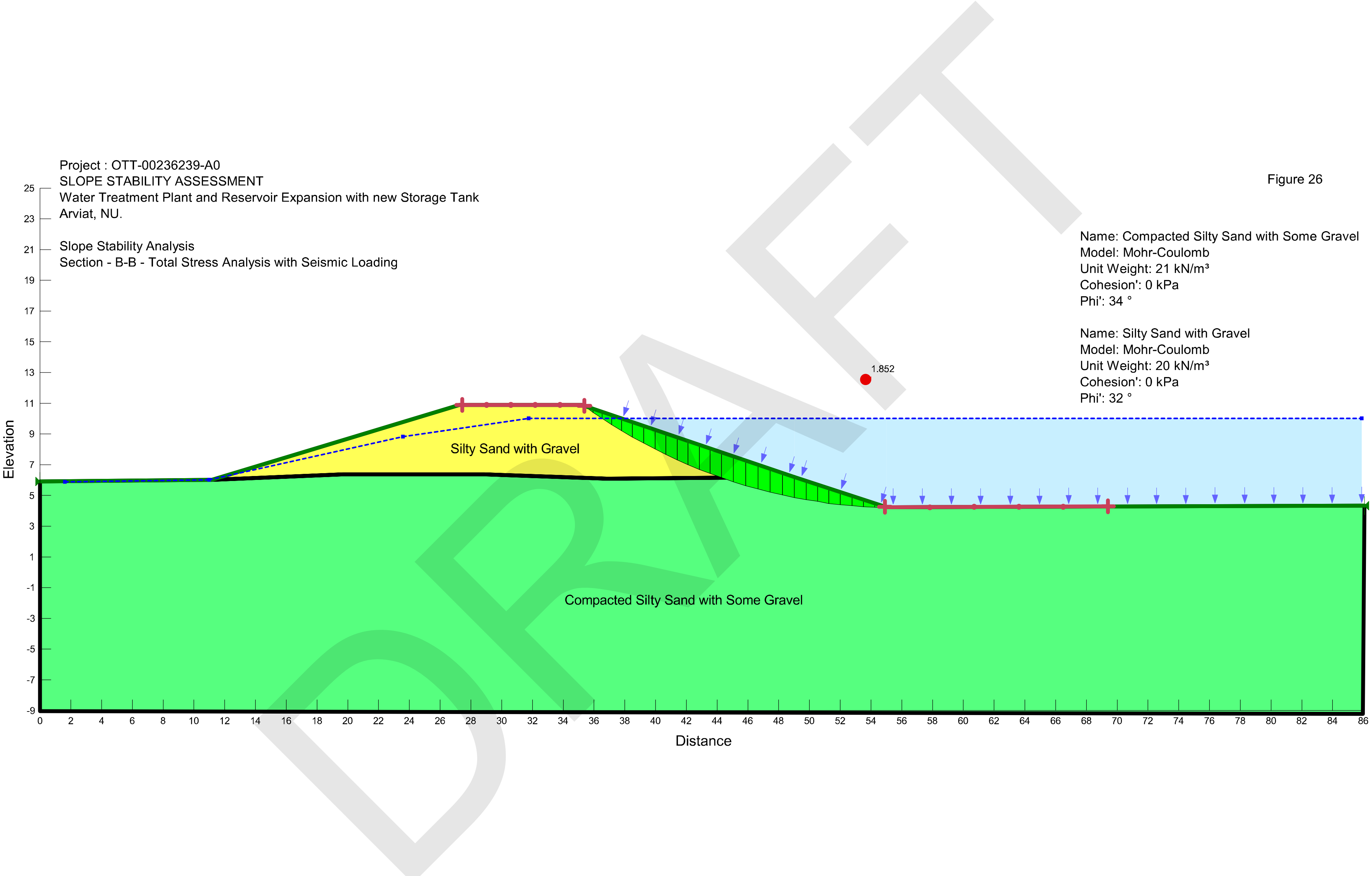
Silty Sand with Gravel
Compacted Silty Sand with Some Gravel
Elevation
Distance
DRAFT



Project : OTT-00236239-A0
SLOPE STABILITY ASSESSMENT
Water Treatment Plant and Reservoir Expansion with new Storage Tank
Arviat, NU.
Slope Stability Analysis
Section - B-B - Total Stress Analysis with Seismic Loading
Figure 26
Name: Compacted Silty Sand with Some Gravel
Model: Mohr-Coulomb
Unit Weight: 21 kN/m³
Cohesion': 0 kPa
Phi': 34 °
Name: Silty Sand with Gravel
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 32 °
1.852
Silty Sand with Gravel
Compacted Silty Sand with Some Gravel
Elevation
Distance
DRAFT

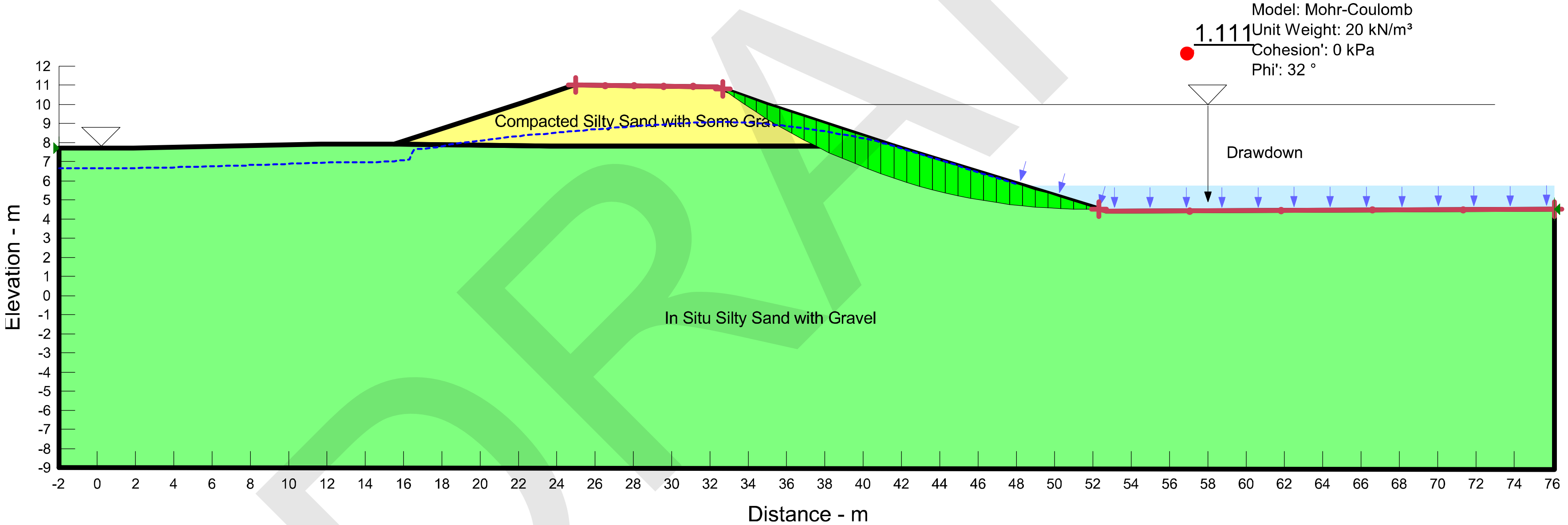
Figure 27

Project : OTT-00236239-A0
SLOPE STABILITY ASSESSMENT
Water Treatement Plant and Reservoir Expansion
with New Storage Tank.
Arviat, NU.

Slope Stability Analysis
Section - B-B - Rapid Drawdown Analysis

Name: Compacted Silty Sand with Some Gravel
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 34 °

Name: In Situ Silty Sand with Gravel
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion': 0 kPa
Phi': 32 °



Appendix A:
Naviq Consulting Inc. Report on Geotechnical Analysis of Proposed Water Tank, Arviat, NU

NAVIQ

Naviq Consulting Inc.
Specialist Geotechnical and Permafrost Engineering

GEOTHERMAL ANALYSIS OF PROPOSED WATER TANK ARVIAT, NU

Prepared for:

exp Services Inc.
Ottawa, ON

Prepared by:

Naviq Consulting Inc.
Calgary AB

Naviq Project No. J011AE
April, 2017

Report No. J011AF-RP001_RevB1

Important Notice

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Important Terms and Conditions that apply to this Report are contained in Appendix A. These Terms and Conditions limit the liability of Naviq Consulting Inc.

GEOTHERMAL ANALYSIS OF PROPOSED WATER TANK; ARVIAT, NU

REV	DESCRIPTION	ORIGINATOR	REVIEWER	NAVIQ APPROVAL	DATE (DD-MON-YYYY)	CLIENT APPROVAL	DATE (DD-MON-YYYY)
B	Issued for review	JMO Jim Oswell	Ron Coutts	JMO Jim Oswell	21 April 2017	N/A	N/A

EXECUTIVE SUMMARY

This report provides details of geothermal analyses conducted in support of the design of a water storage tank at Arviat, NU. The analyses considered a variety of conditions including climate warming.

Soil conditions were taken from geotechnical boreholes provided by **exp** Services Inc. Long-term climate data for the community from Environment Canada was used to establish the mean annual air temperature and the historical climate warming rate. A climate warming rate of 0.1°C/year (2.5°C over 25 years) was applied.

The goal of this study was to estimate the long-term thaw depth under the proposed water tank and to assess the beneficial effects of rigid insulation placed within the engineered granular fill embankment on which the water tank will be constructed.

The mean annual ground temperature was estimated to be -4°C based on ground temperature data from the local region and compared to more distant communities. The natural water content, based on laboratory testing of samples collected in the field was assumed to be low, about 8 percent.

Based on the geothermal modelling results, it is estimated that the long-term thaw under the water tank and granular fill pad would be well within the engineered pad thickness without climate warming and only to the approximate base of the 1.5 m thick engineered pad, with the applied climate warming rate. Rigid insulation placed in the gravel pad reduced the long-term thawing under the water tank for the climate warming scenario to within the engineered pad. Under the central part of the water tank, 10 cm of insulation and 20 cm on the outer part of the water tank was deemed to be sufficient to limit thaw to within the engineered pad. These insulation thicknesses would also be suitable for the recommended design temperature of -1°C, when accounting for the assumed presence of pore water salinity of up to 20 ppt.

For a natural water content in the order of 8 percent, excess ice would not be expected and therefore minimal thaw settlement would be expected to develop under the water tank.

The possible presence of massive ice deposits within the subgrade soils was not considered in this study.

REVISION LOG

The following table lists the changes made in this version of the report compared to previous revisions.

Section/Figure	Description of Revision
	This table is blank in the current version (Revision B).

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1.0 INTRODUCTION

Naviq Consulting Inc. (Naviq) was retained by **exp** Services Inc. (**exp**) of Ottawa, ON to provide geothermal analyses with respect to the design of a potable water tank in Arviat, NU.

The primary scope of work was to conduct a geothermal assessment of the proposed water tank to assess the geothermal behavior of the structure over its projected 25 year lifespan.

This report addresses the geothermal modelling of the proposed water storage tank.

2.0 GEOTECHNICAL INVESTIGATIONS AND RELATED INFORMATION

exp undertook a geotechnical investigation at the site of the proposed water tank in February 2017 (**exp**, 2017). Two boreholes were drilled within the general footprint of the proposed project site. This section provides a summary of the geotechnical character of the subsurface conditions. For a full description of the site conditions and other important details of the investigation and testing, the reader is referred to the geotechnical investigation report (**exp**, 2017).

2.1 Subsurface Conditions

Eight boreholes within the general project footprint were advanced by **exp** to depths of 15 m. Two boreholes (BH1 and BH2) were advanced at the location of the proposed water treatment plant and storage tank. In general, the stratigraphy was uniform to at least 15 m depth, comprising silty sand to silty sand with gravel. Fines content (particles smaller than 0.08 mm) varied from 4% to 34%, by weight, with no correlation to depth. Natural water contents ranged from about 1.1% to about 12%, with no correlation between water content and depth. Table 2.1 lists the interpreted soil stratigraphy used in the geothermal modeling.

exp measured porewater salinities of less than 0.1 ppt. However Hivon and Sego (1993) report that natural porewater salinities in the Arviat area range from 0.8 to 38 ppt. An average value of about 20 ppt may be considered appropriate. Using an average salinity of 20 ppt, the freezing point depression of water may be in the order of 1.1°C (0.28°C for every 5 ppt of salt).

2.2 Ground Temperatures

Ground temperature data is sparse. The **exp** thermistor data for the site is reported to be unreliable. **exp** provided several data points from an EBA report approximately 1 km north of the site. Ground temperature data were also reviewed for Rankin Inlet (Brown, 1978) and for Whale Cove, located 215 km and 148 km north of Arviat, respectively. From these data, a mean annual ground temperature of -4°C was inferred. See Figure 2.1.

Table 2.1. Inferred soil stratigraphy for geothermal modeling.

Depth (m)	Soil	Water content (%)	Comments
Under potable water storage tank			
0	Gravel and sand	8	Engineered fill placed to support tank (new)
1.5	Silty sand	8	Undisturbed, native soil, frozen 5% gravel, 79% sand, 16% fines
6.5	Sand with gravel	8	28% gravel, 67% sand, 22%fines
15+	Bedrock	1	Assumed depth.
Remote from potable water storage tank			
0	Silty sand	8	Undisturbed, native soil, frozen 5% gravel, 79% sand, 16% fines
5	Sand with gravel	8	28% gravel, 67% sand, 22%fines
15+	Bedrock	1	Assumed depth

2.3 Water Tank Structure Dimensions and Construction

exp reports that the proposed potable water storage tank will have an outside diameter of 10.2 m and construction will comprise the following, from the inside out:

a. Water at a fixed annual temperature of +5°C
b. 100 mm of polyurethane insulation
c. Metal shell cladding
d. 50 mm air gap
e. Exterior metal cladding

3.0 GEOTHERMAL ANALYSIS OF WATER TANK STUCTURE

The geothermal performance of the subgrade below the water tank is a function of the thermal energy balance between the atmosphere and the ground surface around the tank and the temperature of the base of the tank. Ground surface temperatures (not covered by the tank) depend on heat energy flux exchange at the ground surface and vary continuously throughout the year. To simulate climate warming in the geothermal model, the seasonal air temperature was assumed to increase at a specified constant rate. The mean annual ground temperatures will respond to long-term changes in the mean annual air temperature.

The objectives of the geothermal analyses were:

- Assess the effect of the water tank on the subgrade temperatures, with and without climate warming conditions.
- Assess insulation thicknesses that would reduce the seasonal thawing under the water tank to a depth within an engineered fill pad on which the water tank would be constructed.

This section outlines the geothermal modelling approach, boundary conditions, and other modelling input parameters applied to the physical problem, and presents the results of the modelling analyses. Numerical modelling results are presented in Section 4 of this report.

3.1 Numerical Model Input Parameters and Boundary Conditions

3.1.1 Climatic Data

The Community of Arviat is located on the west coast of Hudson Bay, at 61.1078° N, 94.0624° W. The Environment Canada climate normal data (1981 – 2010) reports the mean annual air temperature for Arviat to be -9.3°C. Figure 3.1 presents the mean annual air temperatures for the period from 1985 to 2016. For these latter data the mean annual air temperature is approximately -9.0°C.

Climate warming for the period 1985 to 2016 is estimated to be 0.1°C/year. See Figure 3.1. This value was applied as a ramp function in the geothermal model for the climate warming simulation.

Snow cover on the ground at month end were taken from Environment Canada climate normal data for 1981 to 2010 and the climate data from 1985 - 2007. Figure 3.2 present these data.

Wind direction data is available from both Environment Canada and from NavCanada, the latter of which is shown on Figure 3.3. Winds exceed 37 kph (20 knots) less than 2 percent of the time in summer and up to 5.6 percent of the time in winter.

Additional climate data, for temperatures, winds and cloud cover are shown at https://www.meteoblue.com/en/weather/forecast/modelclimate/arviat_canada_5887448

3.1.2 Ground Temperatures and Permafrost Depth

On the Canada Permafrost Map (Natural Resources Canada, 1995), Arviat is located in an area of continuous permafrost.

Section 2.2 addressed ground temperatures in the general project area. For this study, a mean annual ground temperature of -4°C was used.

Permafrost is likely to extend to more than 50 m below ground surface.

3.1.3 Climate Warming

The design life of the water tank is expected to be in the order of 25 years. For this period, climate warming is assumed to be active and should be considered in the design of the structure. One method of addressing the potential for atmospheric warming in a particular location is to extrapolate the historical warming rate forward for the design life of the project. Figure 3.1 presents the mean annual air temperature for Arviat for the period of 1986 to 2016. A linear regression best-fit line has been fitted to the data, and the slope of the regression line represents the annual historical warming trend. For the available data, the historical warming rate is 0.1°C/year.

Using the Arviat recent 30 year climate warming data, if this climate warming rate is projected forward for a design life of 25 years, the mean annual air temperature may rise by approximately 2.5°C.

Canadian Standards Association (CSA, 2010) published predicted climate warming scenarios for northern Canada based on the use of several global circulation models. For the southern Arctic latitude zone of central Canada (zone C1), an average air temperature rise of 1.3°C between 2011 and 2040 is predicted. This represents an annual air temperature increase of approximately 0.04°C, which is considerably lower than the estimated annual warming rate experienced between 1986 and 2016 for Arviat. CSA (2010) also notes that the warming rate is not the same throughout the year, with the rate being higher in the fall and winter and lower in the spring and summer.

For this geothermal assessment work, a climate warming rate of 0.1°C/year was used, as this was conservative compared to the CSA (2010) data.

Climate warming was accounted for by increasing the monthly air temperatures at a rate of 0.1°C/yr (or 0.0083°C/month). Under conditions of ramped or linearly applied climate warming rate, ground temperatures at depths below nominally 10 m increase very slowly with time and do not warm as much as the mean annual ground temperature near the ground surface after 25 years.

3.1.4 Soil Pore Water Salinity

Section 2.1 discussed pore water salinity. An average value of about 20 ppt may be considered appropriate for this study. Using an average salinity of 20 ppt, the freezing point depression of water may be in the order of 1.1°C (0.28° for every 5 ppt of salt).

3.1.5 Water Tank Temperatures

exp advised that the water tank temperature should be assumed to be a constant +5.0°C throughout each year.

3.2 Geothermal Input Parameters

Table 3.1 lists the geothermal properties of the various soil layers assumed in the analysis. Table 3.2 list the climatic input data for the analysis.

3.3 Analysis Scenarios

Geothermal analyses are conducted using the commercial program TEMP/W, developed by Geo-Slope International. This program is capable of analyzing a variety of complex temperature problems, both steady state and transient in nature. Both one dimensional and two dimensional problems can be modeled.

The first modelling step is to perform a one-dimensional model calibration whereby climate data representative of Arviat are input to the model, and calibration is performed such that the model-calculated mean annual ground temperature is generally representative of Arviat. The purpose of the calibration is to establish the surface boundary conditions (surface energy balance) that would result in ground temperatures typical of the local environment. The metrological inputs included monthly air temperature, wind speed, solar radiation, and snow cover, together with ground properties such as winter and summer surface albedos, and evapotranspiration factors.

Table 3.1. Thermal data of soils for input to geothermal model.

Material	Thermal Conductivity Thawed (W/m-°C)	Thermal Conductivity Frozen (W/m-°C)	Water Content (g/g)	Dry Density (kg/m^3)	Heat Capacity Thawed (kJ/d-m-°C)	Heat Capacity Frozen (kJ/d-m-°C)
Gravel and sand fill	2.0	2.1	0.08	1800	1880	1590
Bedrock	4	4	0.01	2600	1960	1900

Table 3.2. Baseline climatic data for input to geothermal model.

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Air temperature (°C)	-29.3	-28.3	-22.8	-14	-4.3	4.4	11.1	10.8	4.8	-3.6	-16.1	-24.1
Wind velocity (km/hr)	24.9	25.2	23.5	22.6	22.5	20.4	20.6	20.9	22.2	25.1	25.6	23.7
Monthly solar radiation (W/m^2)	21.8	55.7	125.9	217.9	273.6	261.5	230	169.5	89.6	43.6	16.9	9.7
Snow depth at month end (cm)	14.4	17.6	17.6	22.5	12.7	.2	0	0	0	1.2	8.5	13.6
Notes: Monthly solar radiation data was taken from published historical data for the Canadian arctic (Thompson, 1967).												

The surface energy balance model for the ground surface includes calculations presented in Hwang, 1976.

The analyses conducted for this study included the following:

- Initial model calibration of site conditions without the presence or influence of the water tank structure and underlying engineered fill pad.
- Instantaneous application of the engineered fill pad and water tank.
- Geothermal modelling of various insulation thicknesses, from 0 mm to 200 mm placed within the engineered fill pad, to assess the depth of seasonal thawing under the water tank.
- Assessment of the effect of climate warming.

3.4 Modelling Domain

A two-dimensional axisymmetric (2DA) model was setup with the left boundary of the model corresponding to the vertical axis through the centre of the tank. Figure 3.4 shows the finite element mesh used for the modelling and Figure 3.5 shows the 2DA geothermal model layout within the vicinity of the water tank. The model domain extends to a depth of 30 m below the original ground surface and to a radius of 36 m horizontally from the centre of the water tank.

4.0 GEOTHERMAL MODELLING RESULTS

This section addresses the results of the geothermal modelling described in Section 3. In interpreting geothermal modeling, the results are a reflection of the assumptions made as input parameters and boundary conditions, such as air and ground temperatures and ice/water contents of the soils, all of which have some uncertainty associated with them. If these values are representative of the actual conditions, then the results should be comparably representative of the future conditions.

A one-dimensional geothermal model was used to calibrate the model by varying the snow thermal conductivity such that the model reproduced a mean annual ground temperature of -4 °C under the applied site climatic conditions. Once the model was calibrated, the same ground surface boundary conditions were used for the non-tank terrain in the two-dimensional axisymmetric model.

The natural long-term active layer at the site is estimated to be in the order of 2.3 m for this locale and the reported soil conditions. This value is considered appropriate given the expected air temperatures, and the low natural water content of the native soil.

4.1 Long-Term Thermal Performance – No Climate Warming

Figure 4.1 shows the long-term temperature isotherms with no insulation in 1.5 m thick engineered gravel pad. The presence of the granular fill pad acts as an insulative layer on the native ground, and permafrost aggrades under the center of the water tank. Note that freeze/thawing may occur at about -1.1°C due to the presence of pore water salinity.

Below the outer edge of the water tank there is some thawing of the granular pad and the maximum seasonal thaw extends about 0.2 m below the original ground surface.

4.2 Long-Term Thermal Performance – Climate Warming

To assess the effect of long-term climate warming of 0.1°C/year over 25 years the same model geometry and boundary conditions as described in Section 4.1 were used, except that climate warming rate was applied.

Figure 4.2 shows the temperature isotherms under the engineered fill embankment and original ground surface. In the long-term, the 0°C isotherm is at about 1 m and 0 m below original ground surface at the tank edge and under the centre of the tank, respectively. The -1°C isotherm reaches a depth of approximately 1 m to 1.5 m below original ground surface at the edge of the tank.

Figure 4.3 presents the same climate warming conditions as in Figure 4.2 but with 200 mm of insulation in the gravel pad. In this case, the 0°C isotherm under the water tank is located at the underside of the rigid insulation under the entire water tank. The -1°C isotherm is also located along the underside of the rigid insulation to within about 0.15 m from the outer edge of the tank.

5.0 DISCUSSION OF MODELLING RESULTS AND IMPLICATION TO WATER TANK DESIGN

Sections 3 and 4 described the various geothermal model setup and results that were obtained for this study, respectively. This section provides a discussion of the implications of the modelling results to the tank design.

One of the objectives of this geothermal study was to assess the influence of rigid insulation on the late-summer thaw depth under the water tank. Figure 5.1 presents this relationship. It is seen that with climate warming and approximately 10 cm of rigid insulation, long-term thawing does not extend into the native subgrade under the central area of the water tank, and with 20 cm of insulation the long-term thawing does not extend into the native subgrade at the edge of the water tank.

For design purposes, it is prudent to incorporate conservatism to account for uncertainty in the model input parameters. For example, conservatism may be incorporated by using a colder design temperature than would be normally needed. In this case the controlling parameter is the thawing temperature of the soils, which has been taken to be -1°C on account of an assumed pore water salinity of about 20 ppt. The geothermal modelling reported in Section 4 suggests that the -1°C isotherm is controlled to the similar extent as the 0°C isotherm and that an average insulation thickness of 15 cm (10 cm under the central area and 20 cm under the outer area) may represent a suitable design solution for this project.

There is one additional issue worthy of discussion relative to the reported geothermal model results; that is, the potential thaw settlement of the water tank. The geotechnical data provided by **exp** suggests that the native soils comprise a thick stratum of gravel and sand with some silt and an average water content of 8 percent. The engineered granular embankment is also assumed to have a water content of about 8 percent.

Hanna, Sanders, Lem and Carlson (1983) present thaw strain correlations for a wide range of soils, including gravelly soils (Unified soil classification symbols: GP, GW, SW, GM). The estimated thaw strain for granular soils (in order from the top of the engineered fill embankment) for 8 and 10 percent water content is 0% and 2%, respectively. Also, the thaw strain within the active layer would be 0%, as it would be ice-free. The active layer is estimated to be about 2.3 m below original ground surface.

Based on the expected thawing (assuming applied insulation), the amount of anticipated thaw settlement will be minimal to low.

The geothermal modelling reported herein is based on some uncertain input parameters. For example, the presence of massive ice within the native granular deposits may result in thaw settlement or creep deformation not considered in this study.

6.0 CLOSURE

This report has been prepared for the exclusive use of **exp** Services Inc. for the specific application and project described herein. The use of this report by third parties or for an application not described in this report is at the sole risk and responsibility of those parties.

If at any time, site conditions, such as the soil or climatic conditions, or project geometry or other factors be found to be different from what has been assumed in this report, Naviq should be notified and given the opportunity to examine the different conditions and the effect they may have on the analyses and recommendations reported herein.

This report is subject to the Terms and Conditions provided in Appendix A.

Prepared by:
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NAPEG Permit to Practice: P611

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APPENDIX A

TERMS AND CONDITIONS

TERMS AND CONDITIONS

The following Terms and Conditions form part of this Report. Acceptance of the report by the Client shall be interpreted as acknowledgement and agreement by the Client with the Terms and Conditions provided herein. Acceptance of the Report means that the Client has not objected to the Report or these Termas and Conditions in writing within seven days of receipt of this document.

1. STANDARD OF CARE: Naviq Consulting Inc. (Naviq) will strive to perform Services in a manner consistent with that level of care and skill ordinarily exercised by other members of Naviq's profession currently practicing in the same locality under similar conditions.

   No other representation, guarantee, or warranty, express or implied, is included or intended in these terms and conditions, or in any communication (oral or written), report, opinion, document, or instrument of service.

2. CHANGES: Client may order changes within the general scope of the Services by altering, adding to, or deleting from the Services to be performed. Further, if Naviq believes any subsurface or physical condition at or contiguous to the site is of an unusual nature and differs materially from conditions generally encountered or generally recognized as inherent in the character of Services provided in these Terms and Conditions, a change exists. If any such change causes an increase or decrease in Naviq's cost of, or the time required for, the performance of any part of the Services, a mutually acceptable equitable adjustment shall be made to the price and performance schedule.

3. FORCE MAJEURE: Should performance of Services by Naviq be affected by causes beyond its reasonable control, Force Majeure results. Force Majeure includes, but is not restricted to: acts of God; acts of a legislative, administrative or judicial entity; acts of contractors other than contractors engaged directly by Naviq; fires; floods; labor disturbances; and unusually severe weather. Naviq will be granted a time extension and the parties will negotiate an equitable adjustment to the price for the Services, where appropriate, based upon the effect of the Force Majeure on performance by Naviq.

4. INSTRUMENTS OF SERVICE: All reports, drawings, plans, or other documents (or copies) furnished to Naviq by the Client, shall at Client's written request, be returned on completion of the Services hereunder; provided, however, that Naviq may retain one copy of all such documents. All reports, drawings, plans, documents, software, source code, object code, field notes and work product (or copies thereof) in any form prepared or furnished by Naviq under these Terms and Conditions are instruments of service. Exclusive ownership, copyright and title to all instruments of service remain with Naviq. Client's right of use of instruments of service, if any, is limited to that use reasonably considered necessary for performance of the Client's duties and obligations. The instruments of service are not intended or represented to be suitable for reuse by Client or others on extensions of the work or on any other project.

5. CLIENT'S RESPONSIBILITIES: Client agrees to: (i) provide Naviq all available material, data, and information pertaining to the Services, including, without limitation as appropriate, the composition, quantity, toxicity, or potentially hazardous properties of any material known or believed to be present at any site, any hazards that may be present, the nature and location of underground or otherwise not readily apparent utilities, summaries and assessments of the site's past and present compliance status, and the status of any filed or pending judicial or administrative action concerning the site; (ii) convey and discuss such materials, data, and information with Naviq; and (iii) ensure cooperation of Client's employees.

   Client shall indemnify, defend, and save Naviq harmless from and against any liability, claim, judgment, demand, or cause of action arising out of or relating to: (i) Client's breach of these Terms and Conditions; (ii) the negligent acts or omissions of Client or its employees, contractors, or agents; (iii) any allegation that Naviq is the owner or operator of a site, or arranged for the treatment, transportation or disposal of hazardous materials, including all adverse health effects thereof and (iv) site access or damages to any subterranean structures or any damage required for site access.

In addition, where the Services include preparation of plans and specifications and/or construction oversight activities for Client, Client agrees to have its construction contractors agree in writing to indemnify and save harmless Naviq from and against loss, damage, injury, or liability attributable to personal injury or property damage arising out of or resulting from such contractors' performance or nonperformance of their work.

6. LIMITATION OF LIABILITY: As part of the consideration Naviq requires for provision of the Services, Client agrees that any claim for damages filed against Naviq by Client or any contractor or subcontractor hired directly or indirectly by Client will be filed solely against Naviq or its successors or assigns and that no individual person shall be made personally liable for damages, in whole or in part.

   Client's sole and exclusive remedy for any alleged breach of Naviq's standard of care hereunder shall be to require Naviq to re-perform any defective Services.

   Notwithstanding any other provision of these Terms and Conditions, the total liability of Naviq, its officers, directors and employees for liabilities, claims, judgments, demands and causes of action arising under or related to the Services or these Terms and Conditions, whether based in contract or tort, shall be limited to the total compensation actually paid to Naviq for the Services or $10,000, whichever is less. All claims by Client shall be deemed relinquished unless filed within one (1) year after substantial completion of the Services.

   Naviq and Client shall not be responsible to each other for any special, incidental, indirect, or consequential damages (including lost profits) incurred by either Naviq or Client or for which either party may be liable to any third party, which damages have been or are occasioned by Services performed or reports prepared or other work performed hereunder.

7. DISPUTE RESOLUTION: If a claim, dispute, or controversy arises out of or relates to the interpretation, application, enforcement, or performance of Services under these Terms and Conditions, Naviq and Client agree first to try in good faith to settle the dispute by negotiations between senior management. If such negotiations are unsuccessful, the parties agree to attempt to settle the dispute by good faith mediation. If the dispute can not be resolved through mediation and unless otherwise mutually agreed, the dispute shall be settled by litigation in an appropriate court in the Province of Alberta. Client hereby waives the right to trial by jury for any disputes arising out of these Terms and Conditions.

   The non-prevailing party in any litigation shall reimburse the prevailing party for the prevailing party's documented legal costs (including reasonable attorneys' fees), in addition to whatever other judgments or settlement sums may be due.

8. WAIVER OF TERMS AND CONDITIONS: The failure of either Naviq or Client in any one or more instances to enforce one or more of these Terms and Conditions or to exercise any right or privilege in these Terms and Conditions or the waiver by Naviq or Client of any breach of the these Terms and Conditions shall not be construed as thereafter waiving any such terms, conditions, rights, or privileges, and the same shall continue and remain in force and effect as if no such failure to enforce had occurred.

9. SEVERABILITY: Notwithstanding any possible future finding by a duly constituted authority that a particular term or provision is invalid, void, or unenforceable, these Terms and Conditions have been made with the clear intention that the validity and enforceability of the remaining parts, terms, and provisions shall not be affected thereby.

10. GOVERNING LAWS: This Agreement shall be governed and construed in accordance with the laws of the Province of Alberta.

FIGURES

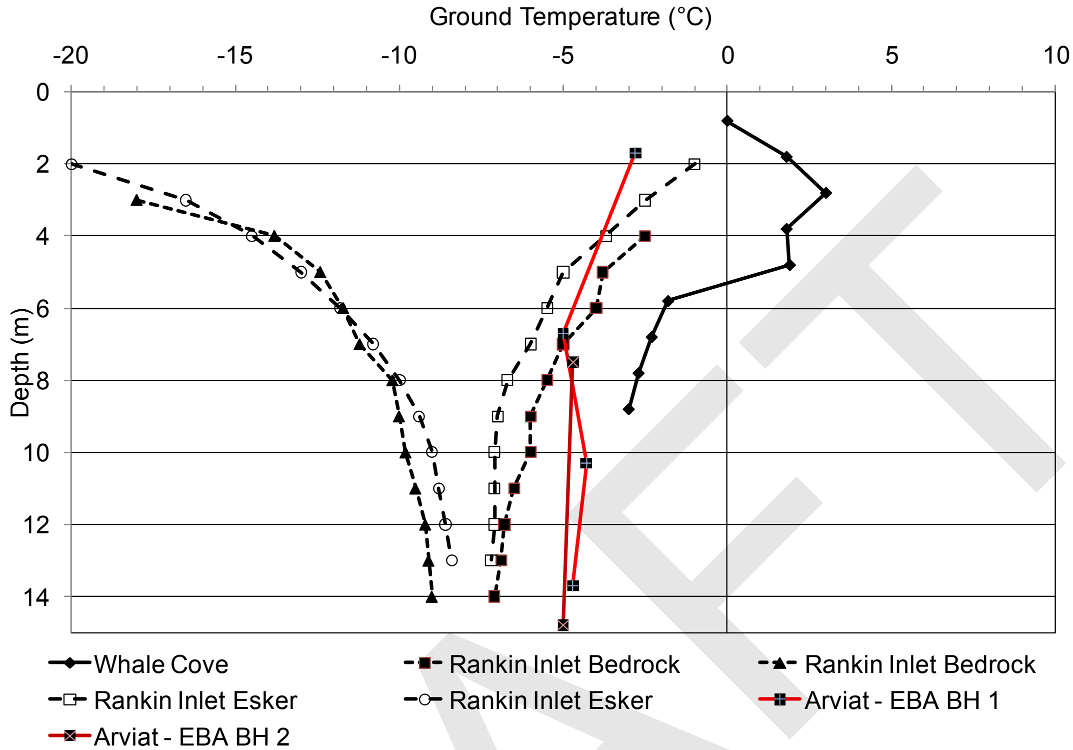

Figure 2.1. Ground temperature data for Arviat area and near-by communities.

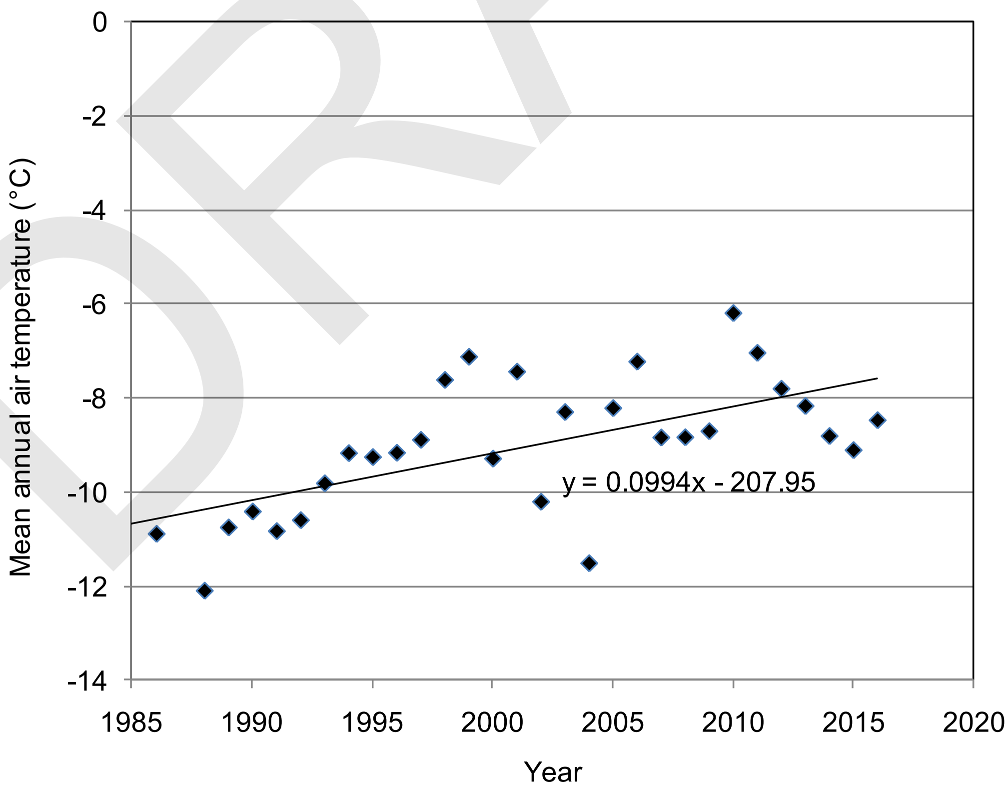

Figure 3.1. Long-term air temperature data for Arviat, NU.

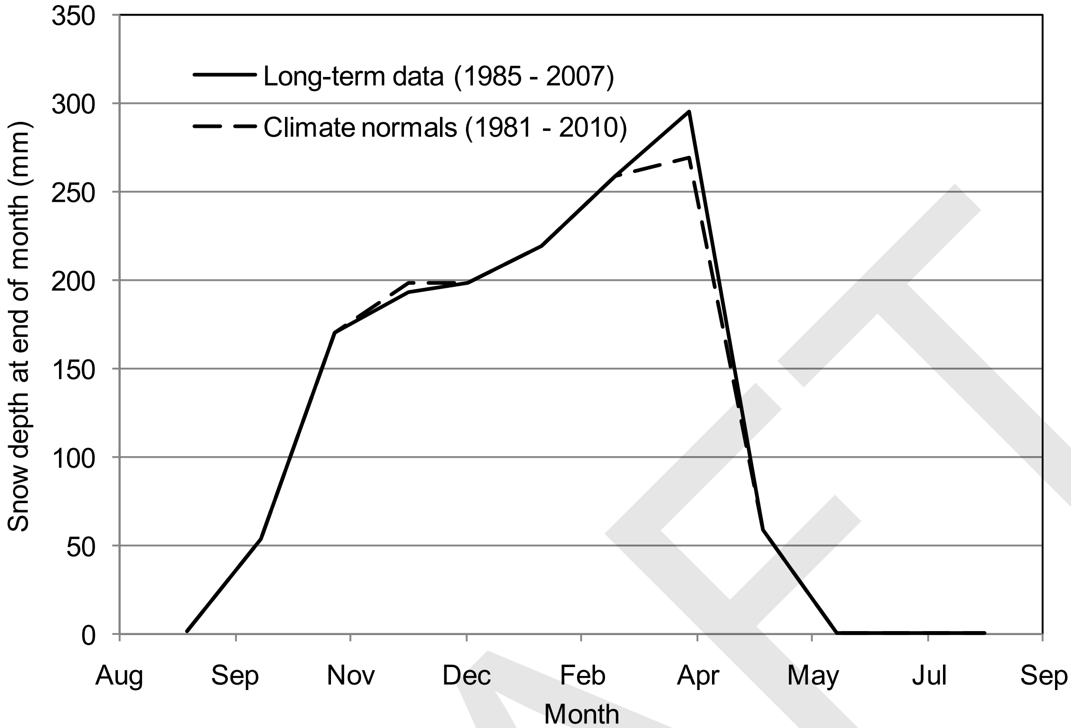

Figure 3.2. Snow depth at month end, generated for Arviat, NU.

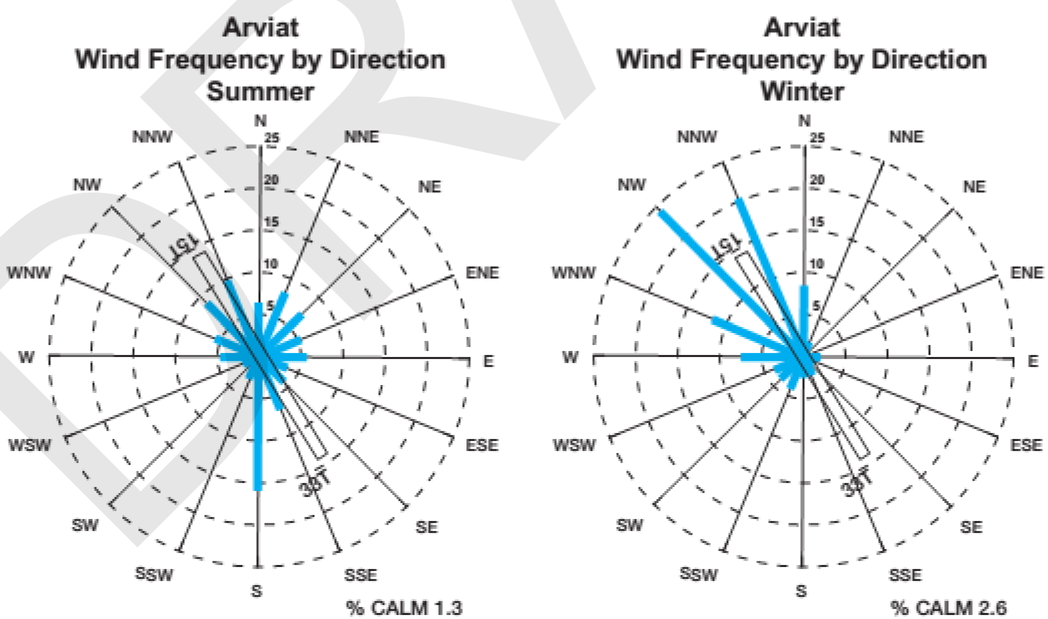

Figure 3.3. Wind rosettes for Arviat airport (NavCanada, 2010).

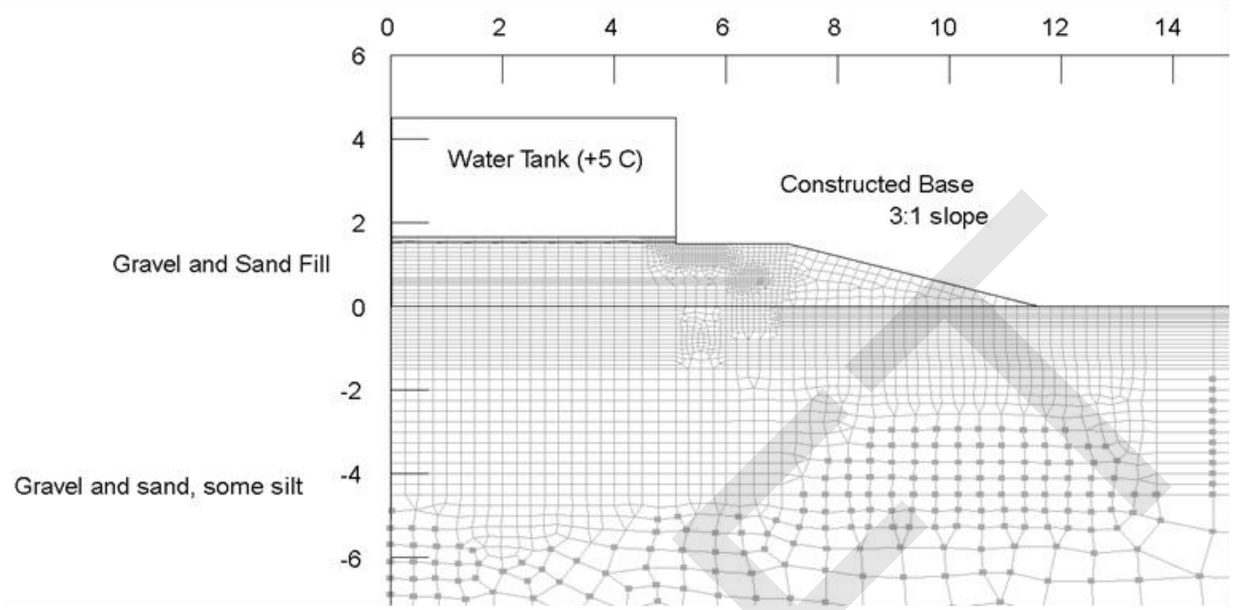

Figure 3.4. Two-dimensional finite element mesh (in vicinity of the water tank) used for the geothermal modelling.

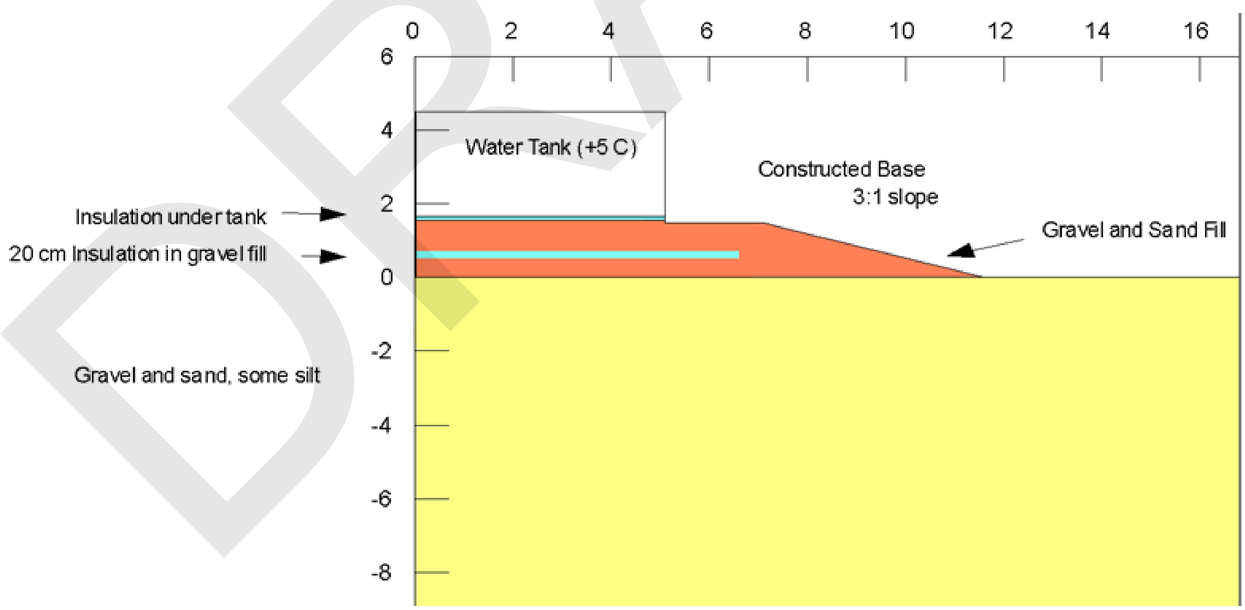

Figure 3.5. Geothermal modelling domain in the vicinity of the water tank showing the case with 20 cm thick insulation in the gravel pad.

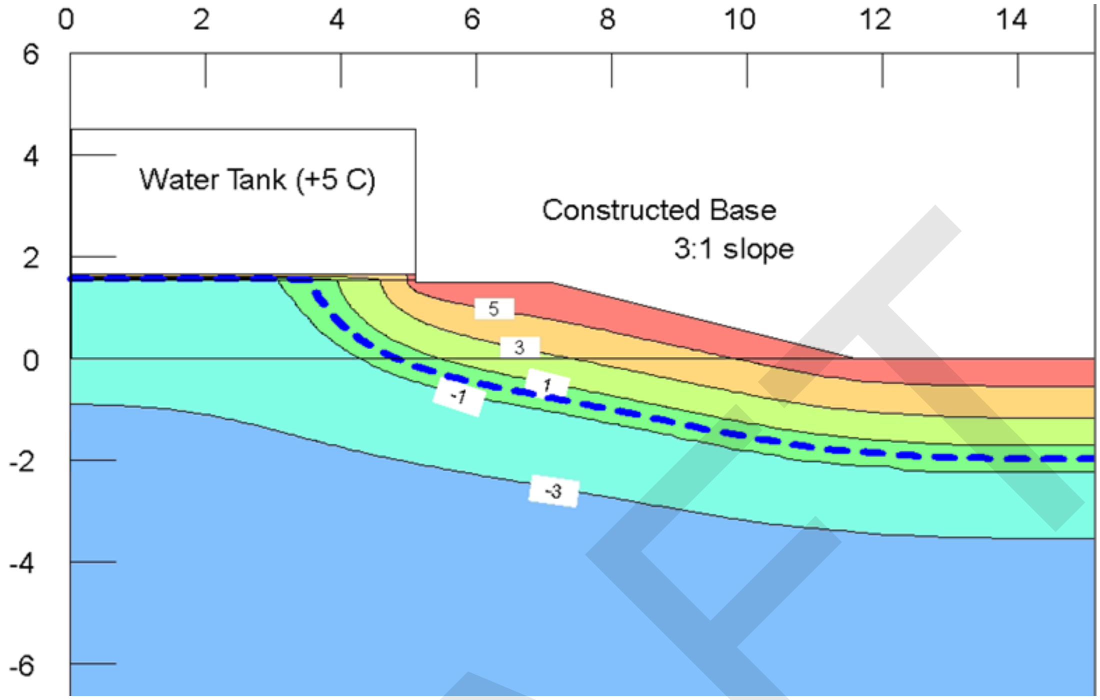

Figure 4.1. Long-term temperature isotherms beneath the water tank with no climate warming and no insulation. The dashed blue line represents the 0°C isotherm, but freeze/thaw actually may occur at about -1.1°C, due to pore water salinity.

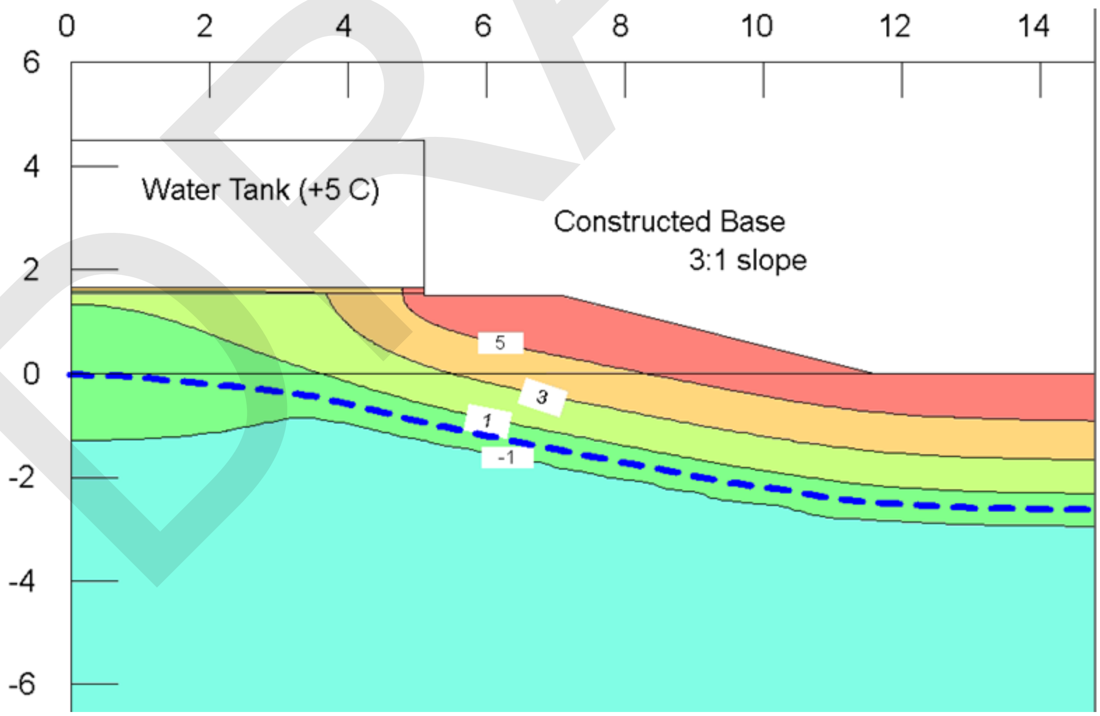

Figure 4.2. Long-term temperature isotherms beneath the water tank with 200 mm insulation. The dashed blue line represents the 0°C isotherm, but freeze/thaw actually may occur at about -1.1°C, due to pore water salinity.

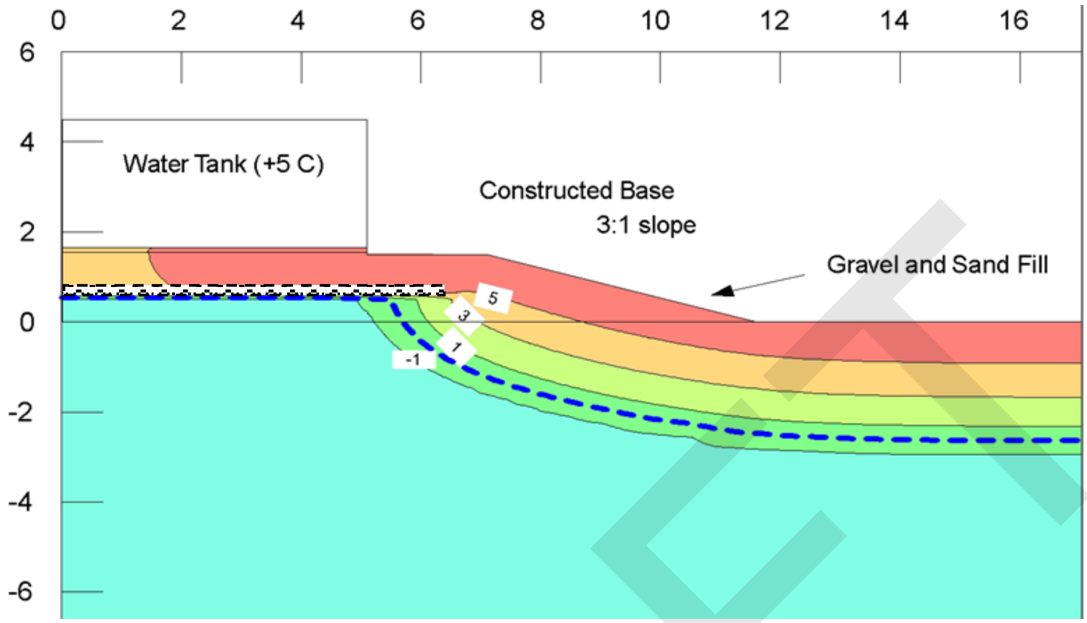

Figure 4.3. Long-term temperature isotherms beneath the water tank with 200 mm insulation and climate change. The dashed blue line represents the 0°C isotherm, but freeze/thaw actually may occur at about -1.1°C, due to pore water salinity.

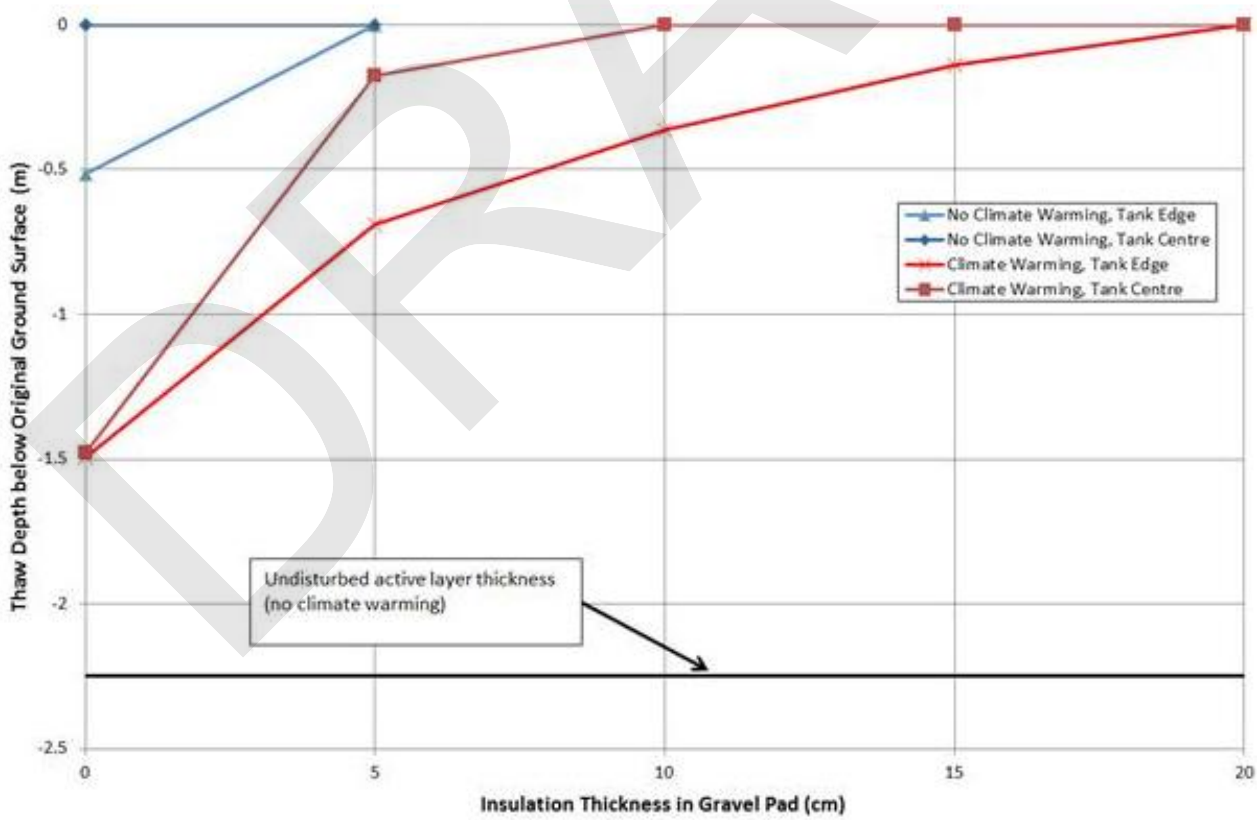

Figure 5.1. Effect of insulation thickness on thaw depth under the centre and edge of the water tank for the non-climate warming and climate warming cases.

Appendix B:
AGAT Laboratories Report

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
2650 QUEENSVIEW DRIVE, UNIT 100
OTTAWA, ON K2B8H6
(613) 688-1899

ATTENTION TO: Jason Smith

PROJECT: OTT-236239-AO

AGAT WORK ORDER: 17Z195005

SOIL ANALYSIS REVIEWED BY: Amanjot Bhela, Inorganic Coordinator

DATE REPORTED: Mar 16, 2017

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

All samples will be disposed of within 30 days following analysis. Please contact the lab if you require additional sample storage time.

AGAT Laboratories
5835 COOPERS AVENUE
MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
http://www.agatlabs.com

Certificate of Analysis

AGAT WORK ORDER: 17Z195005
PROJECT: OTT-236239-AO

CLIENT NAME: EXP SERVICES INC
SAMPLING SITE:

ATTENTION TO: Jason Smith
SAMPLED BY:

Inorganic Chemistry (Soil)

DATE RECEIVED: 2017-03-10

DATE REPORTED: 2017-03-16

Parameter	Unit	G / S	RDL	BH#1 S-2 6-7m	BH#2 S-2 7-8m	BH#2 S-4 13-14m	BH#4 S-2 6-7m	BH#5 S-2 6-7m	BH#5 S-4 12-13m	BH#6 S-2 6-7m	BH#8 S-2 5-6m
SAMPLE TYPE:				Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
DATE SAMPLED:				2017-02-28	2017-02-28	2017-02-28	2017-02-28	2017-02-28	2017-02-28	2017-02-28	2017-02-28
				8243558	8243559	8243560	8243561	8243564	8243565	8243566	8243567
pH, 2:1 CaCl2 Extraction	pH Units		NA	8.22	8.13	8.10	8.37	8.29	8.14	8.13	7.98
Electrical Conductivity	mS/cm		0.005	0.453	0.270	0.379	0.930	0.646	0.180	0.422	0.645
Sulphate (2:1)	µg/g		2	124	48	63	77	59	31	66	319

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

8243558-8243567 EC and Sulphate were 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).

Certified By: Amanjot Bhela

AGAT Laboratories

5835 COOPERS AVENUE
MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
http://www.agatlabs.com

Quality Assurance

CLIENT NAME: EXP SERVICES INC — AGAT WORK ORDER: 17Z195005

PROJECT: OTT-236239-AO — ATTENTION TO: Jason Smith

SAMPLING SITE: — SAMPLED BY:

Soil Analysis

RPT Date: Mar 16, 2017			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	8243558	8243558	8.22	8.28	0.7%	NA	101%	90%	110%	NA			NA		
Electrical Conductivity	8243558	8243558	0.453	0.456	0.7%	< 0.005	96%	90%	110%	NA			NA		
Sulphate (2:1)	8243558	8243558	124	121	2.4%	< 2	91%	70%	130%	96%	70%	130%	97%	70%	130%

Comments: NA signifies Not Applicable.

Certified By: Amanjot Bhela

5835 COOPERS AVENUE
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: OTT-236239-AO
SAMPLING SITE:

AGAT WORK ORDER: 17Z195005
ATTENTION TO: Jason Smith
SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
pH, 2:1 CaCl2 Extraction	INOR-93-6031	MSA part 3 & SM 4500-H+ B	pH METER
Electrical Conductivity	INOR-93-6036	McKeague 4.12, SM 2510 B	EC METER
Sulphate (2:1)	INOR-93-6004	McKeague 4.12 & SM 4110 B	ION CHROMATOGRAPH

AGAT Laboratories

1Lg

5835 Coopers Avenue
Mississauga, Ontario L4Z 1Y2
Ph: 905.712.5100 Fax: 905.712.5122
webearth.agatlabs.com

Laboratory Use Only

Work Order #: 17T195005

Cooler Quantity: One - no ice

Arrival Temperatures: 20.2 | 21.5 | 20.1
4.6 | 4.1 | 3.6

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 intended for human consumption)

Report Information:

Company: exp Services Inc. Ottawa

Contact: Jason Smith

Address: 2650 Queensview dr. Unit 100
Ottawa, ON, K2B 8H6

Phone: 613-769-3832 Fax:

Reports to be sent to:

1. Email: jason.smith2@exp.com
2. Email:

Regulatory Requirements: ☐ No Regulatory Requirement

(Please check all applicable boxes)

☐ Regulation 153/04
Table ____ *Indicate One*
☐ Ind/Com
☐ Res/Park
☐ Agriculture

Soil Texture *(Check One)*
☐ Coarse
☐ Fine

☐ Sewer Use
☐ Sanitary
☐ Storm

Region ____ *Indicate One*

☐ Regulation 558
☐ CCME
☐ 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 ☑ 5 to 7 Business Days

Rush TAT (Rush Surcharges Apply)

☐ 3 Business Days ☐ 2 Business Days ☐ 1 Business Day

OR Date Required (Rush Surcharges May Apply):

Please provide prior notification for rush TAT
**TAT is exclusive of weekends and statutory holidays*

Project Information:

Project: OTT-236239-A0

Site Location: Arviat Water Reservoir

Sampled By: exp

AGAT Quote #: 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 (Please Circle) Y / N	Metals and Inorganics	Metal Scan	Hydride Forming Metals	Client Custom Metals	ORPs: ☐ B-HWS ☐ Cl ☐ CN ☐ Cr6+ ☐ EC ☐ FOC ☐ NO3/NO2 ☐ Total N ☐ Hg ☐ pH ☐ SAR	Nutrients: ☐ TP ☐ NH3 ☐ TKN ☐ NO3 ☐ NO2 ☐ NO3/NO2	Volatiles: ☐ VOC ☐ BTEX ☐ THM	CCME Fractions 1 to 4	ABNs	PAHs	Chlorophenols	PCBs	Organochlorine Pesticides	TCLP Metals/Inorganics	Sewer Use	pH	Sulphate	Electrical Conductivity
BH#1 S-2 6-7m	Feb. 2017		1	S																		✓	✓	✓
BH#2 S-2 7-8m			1																			✓	✓	✓
BH#2 S-4 13-14m			1																			✓	✓	✓
BH#4 S-2 6-7m			1																			✓	✓	✓
BH#5 S-2 6-7m			1																			✓	✓	✓
BH#5 S-4 12-13m			1																			✓	✓	✓
BH#6 S-2 6-7m			1																			✓	✓	✓
BH#8 S-2 5-6m			1																			✓	✓	✓

Samples Relinquished By (Print Name and Sign):	Date	Time	Samples Received By (Print Name and Sign):	Date	Time
Jeff McMillan	March 10/17	2:34pm	Bertrelet	10-Mar-17	14h34
Samples Relinquished By (Print Name and Sign): KBD to Purolator	10-Mar-17	16h00	Samples Received By (Print Name and Sign): Sima	17/3/17	9:36
Samples Relinquished By (Print Name and Sign):	Date	Time	Samples Received By (Print Name and Sign):	Date	Time

Page 1 of 1

Nº: T 025698

List of Distribution

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