Drainage Report

Government of Nunavut

Type of Document:
Final Report

Project Name:
Geotechnical Investigation and Drainage Planning Services in Sanikiluaq, NU

Project Number:
OTT-00255134-A0

Submitted By:
EXP
100-2650 Queensview Drive
Ottawa, ON K2B 8H6
t: +1.613.688.1899
f: +1.613.225.7337

Date Submitted:
2020-03-27

Table of Contents

Appendices

1 INTRODUCTION

1.1 General

EXP Services Inc. (EXP) was contracted by the Government of Nunavut (GN) – Department of Community and Government Services (CGS) to conduct geotechnical evaluations and drainage planning for the Hamlet of Sanikiluaq, Nunavut (the Hamlet). It has been requested that EXP be guided by the methodology and deliverables of a 2018 study for geotechnical evaluation and drainage planning for a specified subdivision in Clyde River, Nunavut (completed by others). The exception is, this study shall be inclusive of the entire Hamlet and its surrounding area, rather than a specific parcel of land. The objective of this study is to provide data and recommendations to CGS which will be utilized to aid in future planning and construction projects within the Hamlet. These recommendations will focus on the following subjects:

- The existing terrain and permafrost conditions within the Hamlet.
- Future land development in the vicinity of the Hamlet, based on terrain mapping, permafrost conditions, and geohazards.
- Current drainage within the existing Hamlet and how it can be improved.
- How drainage works should proceed in planned future developments.

This analysis was conducted through a two-part approach. The first via a desktop review of readily available information relative to soils, terrain, permafrost conditions, geohazards, and drainage conditions. The other means of gathering and interpreting data was completed by a field investigation program that was conducted in late September 2019.

1.2 Background Data

Sanikiluaq was incorporated as a hamlet in 1976 to serve as an administrative centre for Inuit people living in the Belcher Islands. It is currently home to about 800 people. Sanikiluaq's economy relies on fishing and trapping. The area is famous for its soapstone carvings and intricately etched basketry.

Sanikiluaq is located on Flaherty Island which is part of the Belcher Islands as seen in Figure 1 below. It is the southern-most community in Nunavut at N56-33 and W79-13. Flaherty Island is about 70 km from north to south and up to 40 km wide. The island has several fjords and gentle hills. Flaherty Island is the only island that is permanently settled with communities in Sanikiluaq and South Camp.

Figure 1. Location of Belcher Islands

The Belcher Islands are an archipelago in the southeast part of Hudson Bay. The Belcher Islands peak at 155 m above sea level and some cliffs rise 50 m to 70 m. They support several polynyas (water open year-round surrounded by sea ice). No trees grow on Belcher Islands and, except in valleys, only a thin layer of topsoil covers the ground.

1.2.1 Surficial Geology

Well-developed cliff coasts and headlands occur on Belcher Islands. Underlain by discontinuous permafrost, these coasts are well-drained relative to the low-lying coasts to the south and west. The soils of these islands are often rocky and have a shallow active layer that supports tundra vegetation. The exception to this is in the valleys where the thickness of the overburden can vary up to 20 m.

1.2.2 Bedrock Geology

The rock basin that holds the Hudson and James Bay were formed over a very long time by various geological processes. It is situated in an area that has been depressed relative to the surrounding shield regions since at least the last Paleozoic time and consists of portions of three of Canada's geological provinces. These provinces, the Superior and the Churchill provinces of the Canadian Precambrian Shield and the Hudson Platform are distinguished from one another based on age, composition and structure of their rock strata. These rocks form the bedrock that underlies the loose surface materials in different areas of the basins.

The crystalline rocks of the Superior Province formed first and underly the entire basin. It constitutes the bedrock beneath the eastern Gulf of James Bay. Elsewhere in the basin, it forms a sialic crust beneath the younger sedimentary, metamorphic and volcanic rock of the Churchill Province and the sedimentary rocks of the Hudson Platform.

Younger crystalline rock of the Churchill Province overlies the older rock of the Superior Province throughout much of the basin. It constitutes the bedrock of the Quebec Coast north of Korak Bay and in the Richmond Gulf area, the Ottawa, Belcher and Nastapoca islands and the west coast of Hudson Bay.

Three geological subdivisions of the Churchill Province underlie the southeastern Hudson Bay, Richmond Gulf Embayment, Nastapoca Homocline, and the Belcher Fold Belt. The Richmond Gulf Embayment surrounded by sea ice extends inland to underlie Richmond Gulf and form most of the coastline. It consists of fluvial reed beds and associated terrestrial basalt that has been gently folded, faulted, and eroded. The Nastapoca Homocline is a broad pericratonic belt of younger deformed and partly metamorphosed sedimentary and volcanic rock that follows the arcing coastline of Hudson Bay. It also underlies coastal waters of southeastern Hudson Bay offshore to the Belcher Fold Belt, which underlies the offshore waters and forms the offshore island groups of southeastern Hudson Bay. This latter pericratonic belt is comprised of deformed and unmetamorphosed to slightly metamorphosed sedimentary and volcanic rock. Unmetamorphosed Proterozoic strata, folded into doubly plunging folds, are well exposed in the Belcher.

1.2.3 Permafrost and Geohazards

Sanikiluaq is located in a region of extensive discontinuous permafrost. The percentage of the land area underlain by permafrost is 10 to 50 percent. The ground ice content in the upper 10 m to 20 m of the ground as a percentage of visible ice is nil to low (0-3%). The mean annual temperature is 0 to -2° C.

Detailed mapping of the permafrost area of the Belcher Islands is not available. Therefore, development in Sanikiluaq presents some difficulty as the extent of the permafrost areas cannot be readily determined. Also, because of the relatively high mean annual temperature, permafrost is susceptible to degradation at a rapid rate compared to the other areas in Nunavut where the mean annual temperatures are much lower. Therefore, it appears that the construction of foundations on permafrost should not be relied upon. Also, the overburden soils are expected to be weak as they would lose their strength due to degradation of the permafrost and may not be suitable for supporting the foundation of structures. It appears that a prudent approach is to set the foundations of the structures on bedrock. Spread footings on bedrock are feasible in areas where the bedrock is present at a shallow depth. In areas where the bedrock is present at depth, end bearing piles socketed into bedrock would provide satisfactory foundations for structures.

The geotechnical investigation undertaken in the proposed development area has revealed that the majority of the soils are highly frost susceptible and are subject to heave on freezing and loss of strength on thawing. These soils are also susceptible to erosion. Consequently, seasonal heave and settlements of structures founded on soils at shallow depth should be anticipated. Also, the construction of the roadways may require a thicker pavement structure compared to areas where coarse materials are present. Similarly, culverts may require additional granular bedding and headwalls or rip rap for erosion control. Steep slopes in the hamlet are susceptible to surface erosion and frost creep.

1.2.4 Drainage Assessment and Planning

All drainage systems change over extended periods and with changes in climate, this is noticeable at an increased rate in Canada’s North. In northern communities, surface drainage issues generally occur during the spring snowmelt and rain events throughout the short summer season. Unlike many southern regions, surface water is primarily conveyed above ground as opposed to underground sewer systems. Typical conveyance infrastructure includes the use of ditches, swales, and culverts to displace surface water. The most common and reoccurring drainage problems include road washouts, road trafficability issues, water ponding, and poorly designed and/or constructed culverts Standards Council of Canada (2015). Thus, the development, implementation, and maintenance of the drainage plan will mitigate and even prevent some of these problems from re-occurring. The Standards Council of Canada (2015) provides a typical drainage planning flow chart which is a powerful guide on how to develop a drainage plan. This chart is included in Appendix A.

However, prior to the development of a drainage plan, a thorough assessment of the existing conditions must be conducted. Gathering information relating to existing soil conditions, satellite imagery and mapping, climate data, weather records, historical surface water levels, existing drainage systems & infrastructure, as well as catchment areas, and drainage patterns will aid in preparing a drainage baseline. Additionally, there is great value in observing the drainage issues during the spring snowmelt runoff as well as the summer and fall conditions. The data captured during this observation period provides critical data used for the development of a drainage plan.

2 Methodology

2.1 Background Review

The following documents were reviewed as part of a literature review:

- National Atlas of Canada, 5th Edition.
- Geology, Belcher Islands, Nunavut, by Jackson, G.D.
- Geological Provinces, and Geology of the Hudson and James Bay, Douglas, 1973.
- CSA Community Drainage System Planning, Design, and Maintenance in Northern Communities, CSA S503:15 reaffirmed 2019
- From Science to Policy in the Western and Central Canadian Arctic, Stern and Gaden 2015.

2.2 Terrain Mapping

2.2.1 Surficial Geology

The Hudson Bay region was glaciated most recently by the Laurentide Ice Sheet, comprised of glaciers that emanated from centres around rather than in Hudson-James Bay. Thick ice covered the entire marine area including the coasts and affected most of the present-day features. Ice loading depressed the earth's surface so that the present-day coast was inundated by marine water following glaciation. Isostatic rebound continues at a rate of 0.7 to 1.3 m per century, so most coastlines exhibit a variety of emergent glacial deposits.

There are three basic coastal types: low-lying, cliff and headland, and complex. Well-developed cliff coast and headlands occur on the Ottawa and Belcher Islands. Elevations seldom exceed 200 m above sea level in the Belcher and Ottawa Islands where relief is generally low and the coastline is dry. Continuous permafrost underlies the surface except along the Hudson Bay Arc and in the Belcher and Ottawa Islands, where it is discontinuous. These coastlines are dry relative to the low-lying coasts, with decreasing organic cover and vegetation moving northward on the islands and a shallow active layer of soil that is often rocky. These coasts have superb examples of emergent features, particularly the flights of raised marine beaches.

Bottom sediment distribution in Hudson Bay is controlled primarily by the last Wisconsin glacier. The sediment consists primarily of till, fine-grained, glaciomarine deposits and post-glacial mud (Figure 3). Postglacial sedimentation, which involves the reworking of glacially derived sediments by rivers and/or marine currents, is restricted largely to the shallow marine environments. These sediments are thin (<5 m) and selectively deposited near entire estuaries and in localized depressions.

Sediments in the Hudson Bay grade from coarse Precambrian or Paleozoic gravels near shore to fine silt and clay with considerable organic carbon content offshore. Coarse sediments are rare offshore.

2.2.2 Drainage

A watershed describes an area of land that catches snow and rain which eventually drains into a single larger body of water such as a lake, river, or ocean. Watersheds can vary greatly in size; some may be only a few acres whilst others are many thousands of hectares. The use of a computer to create a Stormwater Management Model (SWMM) is a common approach to analyzing drainage systems within a watershed. PCSWMM software was used to develop a hydrologic model that can be used to understand drainage paths, tributary drainage areas and sub-catchments. The model was prepared using a DTM (digital terrain model) file which was provided to EXP by GN. The modelled drainage maps identify the locations within a set boundary where major and minor overland flow routes exist. This imagery provides a visual tool in the form of a map illustrating the existing drainage patterns as well as sub-catchment areas through a region. Figure 1 and Figure 2 in Section 3.2 illustrate the baseline drainage map showing the existing drainage system within the Hamlet of Sanikiluaq. It should be noted that the accuracy or level of detail portrayed in the SWMM model is a function of the accuracy and level of detail of the terrain model.

This model is a powerful tool that can provide a user with all kinds of key drainage information. For example, one can easily identify:

- Areas where major drainage corridors exist.
- Areas at greater risk of damage during peak runoff events.
- It can determine the contributing areas to a drainage corridor, or
- It can determine a level of effort associated with selecting and developing a new parcel of land (from a drainage perspective).

Ultimately, there are many applications for which this model provides valuable data. In the case of Sanikiluaq, the model indicates that a large catchment area drains into the Sanikiluaq Lake, which then drains through certain parts of the community and ultimately into the ocean.

2.2.3 Construction Suitability Rating

The suitability of a study area for development is based on the overall terrain conditions. Common constraints include both geological and environmental constraints. Typical terrain constraints that have the potential to drastically affect the design, construction and maintenance of the development can include; slope steepness, natural drainage conditions, flooding, erosion, surficial materials and permafrost.

Sea level is another consideration for the development of lands near the coastline. Relative sea level has been falling in many areas of Nunavut due to the unloading caused by the thinning and retreat of the ice sheets at the end of the last Ice Age. This vertical land movement effect counteracts the effect of global sea-level rise. James, Simon, Forbes, Dyke and Mate (2011) provided a range of sea-level changes expected by the year 2100 for five communities in Nunavut. The estimates were derived from an assessment of published projected sea-level change and an evaluation of vertical land motion. Unfortunately, Sanikiluaq was not covered in this study, but conservative consideration of this information is suggested when determining appropriate setbacks from all major shorelines, streams, ponds and lakes.

When considering the existing terrain within a potential development area, slopes above 15% should be avoided due to an increased level of effort to develop and maintain the lands. New roads within a development area should be designed to have a maximum slope of 8.0%, although some roads constructed in Nunavut have been constructed with a 10.0% slope. Where heavy melt patterns are anticipated within a potential Development Area, it is recommended to align roads in these areas perpendicular to the slope of the land to encourage drainage along the roadside ditches.

Poor to very poor soil drainage conditions present within the development area can lead to the pooling of surface water. The permafrost is partially responsible for this process, by preventing the downward drainage below the active layer. This, in turn, causes saturation of the active layer and water ponding on the ground surface.

2.3 Field Reconnaissance

The purpose of the field reconnaissance was to confirm the preliminary findings derived through the analysis of mapping, contour, and geological data. After reviewing all pertinent information, the field representative would identify any gaps and discuss any missing information with Hamlet staff.

EXP conducted a field review of all existing and newly developed road and drainage infrastructure during a September 18-20, 2019 field visit. During the time of inspection, two field staff traversed the Hamlet on foot to analyze the existing conditions of all roads, ditches/swales and visible culverts. After a preliminary walkthrough, more detailed analysis and geotechnical investigations took place by a qualified civil and geotechnical technician, including soil sampling.

Local staff provided valuable information and raised concerns about existing drainage and soil conditions, which were then analyzed by field staff, and preliminary field data was collected, and possible solutions were discussed. EXP field staff also noted several other problem areas that could lead to issues or could be improved upon throughout the Hamlet. All visible culverts were identified and existing dimensions, conditions and issues (if applicable) were recorded. Staff also noted areas that could potentially benefit from a new culvert or other drainage construction.

2.4 Local Concerns

2.4.1 General Observations

During the field walkthrough, EXP staff noted several areas of concern regarding Hamlet drainage or other soil conditions. Visible damage to roads and culverts, or potential damage that may occur if no action is taken, was how staff identified these areas.

Firstly, there is a lack of general drainage throughout the Hamlet. Most roads have little to no ditching, and so, water either ponds in low lying areas, or is forced to travel either along the road surface or through residential yards, which could lead to washouts and undesired erosion. It was noted that most of the existing ditching, swales and culverts are in fair to poor condition. That is, swales and ditching were observed to be blocked by driveways and pathways without appropriate culverts installed or they were impeded by debris. Existing culverts were found to be partially or fully buried, crushed, collapsed, or impeded by debris. These were primarily noted in Area 4. The results related to poor drainage can be road/culvert washouts and ponding/flooding which may lead to early permafrost melting and ultimately additional/increased erosion. Washouts and increased erosion can vary in severity, however, the impacts will normally lead to higher maintenance costs and additional staffing and/or equipment requirements to regrade or rebuild sloped surfaces.

2.4.2 Area 1

Concerns noted by local staff were primarily located in Area 1 and tended to focus on the apparent poor soil conditions and inadequate drainage. Area 1 is said to be made up of very silty soil discovered through multiple excavations completed previously by Hamlet staff and contactors. Silty soils can lead to structural and stability concerns with roads, building foundations and erosion control.

Additionally, concern was raised with the major drainage crossings and the inadequacy of the existing culvert conditions, sizing and ability to convey water. Specific locations are noted in Appendix B (culvert location EC-01A/B, EC-02A/B, EC-03A/B/C, and EC-04A/B/C/D/E) and were identified as problem areas by Hamlet staff for several different reasons (refer to culvert inventory in Appendix C). One of the main concerns was the back up of water and the effect of flooding on the adjacent developments. For example, local staff expressed concern over drainage at culvert EC-03A/B/C, as ice and debris tends to build up around the outlet of the lake and inlet of the culverts, which in turn causes lake water levels to migrate northwesterly towards Area 1 due to the minor difference in elevation between the lake water surface elevation and the road surface in Area 1.

2.4.3 Area 1 and 3

Secondly, there is a concern associated with sheet drainage in the community. Some areas of Hamlet, such as Area 1 and 3, appear to drain through the process of sheet drainage, as there is little or no roadside ditching currently present and the land is a fairly consistent grade. Water tends to drain across roads and properties gradually (not localized) and spread across the entire area to an outlet (creek/ocean/etc.). Looking at Area 3, sheet drainage has had little to no negative impact as there was no significant erosion or ponding visible, however, this may not always be the case. During quick spring melts combined with heavy rainfall events, the drainage may become more channelized and ultimately lead to significant erosion. It should be noted that most of the existing residential houses are on block foundations and not piles, which raises serious concerns with undesired erosion around the foundations and the possibility of washouts. With a lack of existing ditching, there is no way to prevent this natural drainage and erosion. Some evidence of this erosion can already be seen in Area 1. This is a concern, as by looking at the contour data, the highest elevation of this area is relatively close to the surface elevation of the lake. Local staff expressed that in previous years, one or more house foundations in Area 1 have been close to being washed out from channelized drainage and erosion through the development. Certain drainage measures should be implemented to help alleviate potential damage from erosion, such as the construction of roadside swales/ditches to reroute any overland flow to designated drainage points, and/or possibly a rock berm with a liner at the lake's edge to protect the lower-lying infrastructure from any additional overland flow.

Almost all of the Hamlet of Sanikiluaq is constructed on the northern shoreline which slopes towards the ocean, and as a result, some of the roads running in the north/south direction tend to have higher slopes. During the field walkthrough, it was noted that a number of these roads tended to have visible erosion along the roadside and through resident driveways caused by drainage. These roads did not have any swales or ditching present, apart from the minor grade change from the cross fall of the road to the resident’s driveway. Due to trucked services such as water and wastewater requiring access to each household, it is critical that these driveways and roadside access points are maintained at all times, and are not negatively impacted by erosion or standing water.

Improper conveyance of water to a culvert can lead to road washouts and sediment buildup within or around the culvert. This was observed at road crossings X-01 and X-02, as water drains from the south to north towards the ocean, and accumulates along the Airport Road. With no exiting ditching, water is forced to travel along the south side of the Airport Road to culverts EC-01A/B or EC-02A/B, and in doing so, both the road surface and sloping adjacent to the culverts begin to washout.

2.4.4 Area 5

In addition to existing infrastructure, EXP staff also visited the area located at the eastern limits of the Hamlet currently under construction (approximately 80% complete), identified as Area 5. A geotechnical investigation was conducted by completing test pits and obtaining soil samples for lab analysis (refer to section 4.21 for geotechnical findings). By reviewing contour data and current drainage from adjacent lands, it was observed that the new roads have negatively impacted the flow path of the northern watershed. There was no ditching observed, and as a result, water has ponded along the inside of the radius and the south side of the road. Ponding can lead to a poor road structure and possible washouts in the future. During the spring melt, it is very likely that water levels in this area will increase, and begin to flow overland across the road surface towards the ocean, leading to erosion, possible road closures, and additional negative impacts to resident housing and properties. Additionally, It was observed that there were large rock outcrops present directly adjacent to the roadway.

The final set of observations was based on road conditions and materials. EXP field staff noted that throughout the Hamlet, most road surfaces appear to be constructed with a round river-type stone that does not interlock very well. Any fine granular material generally gets washed out, leaving only the larger round stones that tend to be pushed out of the high traffic areas and into the less travelled areas. This material is unsuitable for road construction, resulting in uneven and uncomfortably riding road surfaces. Increased road maintenance and proper granular material are required to ensure proper drainage and road cross-section.

3 Results

3.1 Surficial Geology

Available surficial geological information indicates that the overburden in the Sanikiluaq area is generally shallow. The exception to this is in the valleys where the thickness of the overburden may be up to 30 m. Therefore, the depth to bedrock is variable in the Hamlet which was confirmed by the Hamlet representatives during the fieldwork. The overburden in the coastal areas at the north end of the Flaherty Island is expected to be coarse-grained glacio-marine. In the central portion of the island, the surficial soils have been deposited as fine-grained glacio-marine. The overburden over the majority of the remainder of the island has not been identified.

3.2 Existing Drainage

Figure 2 below illustrates the existing major overland flow paths in and around the Hamlet developed using the PSCWMM software as described in Section 2.2. The major overland flow paths in and around the Hamlet are shown in red, and the minor paths are shown in blue.

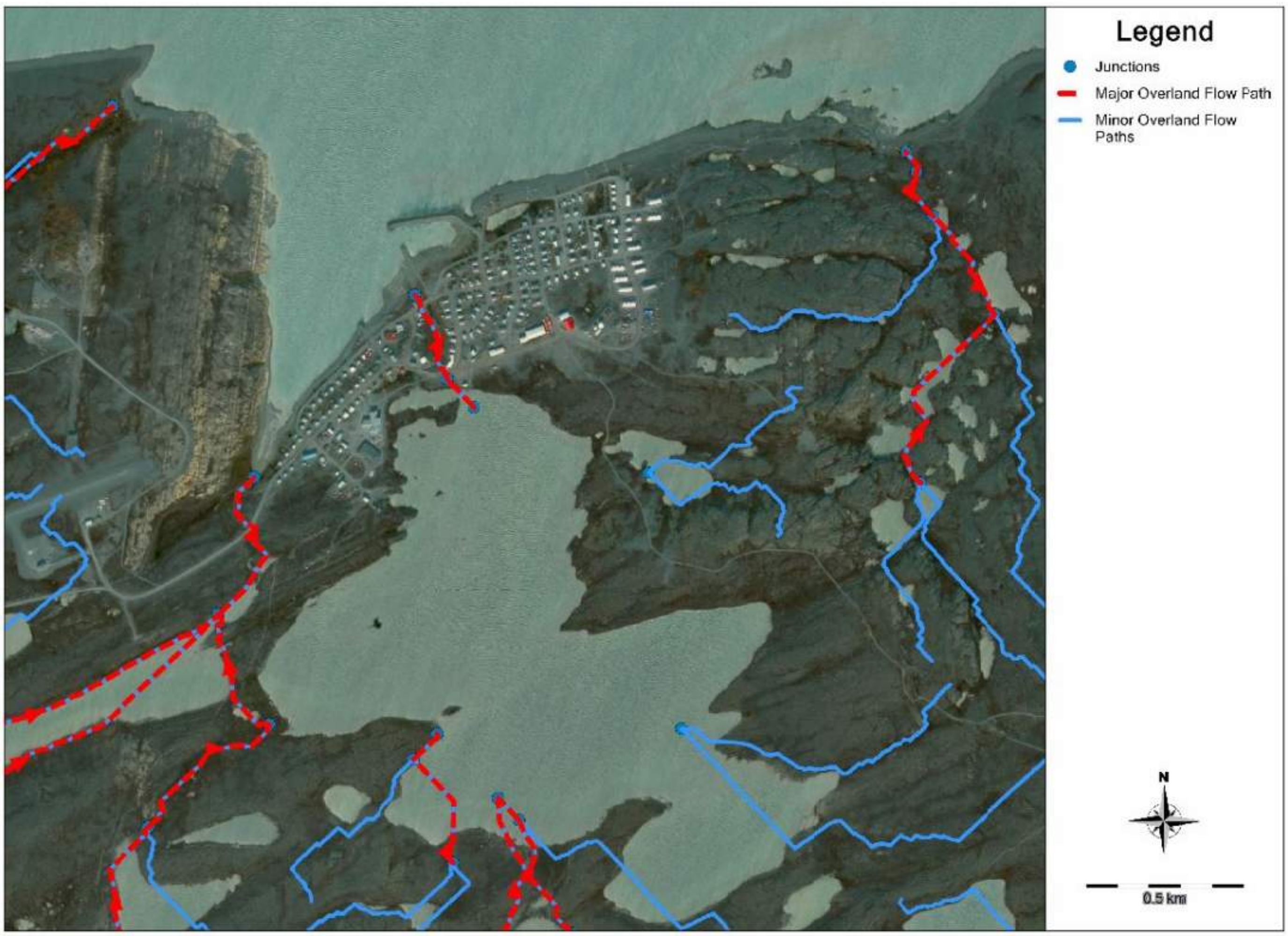


Figure 2. Existing major overland flow paths in and around Sanikiluaq.

As seen in this figure, Sanikilliaq Lake drains through the Hamlet out into the ocean. The other two major overland flow paths occur to the west of Area 1, and the east of the new development area. No major flow paths are travelling through the new development area. Figure 3 below is a closer view of the area which shows the locations of minor overland flow routes through Area 5.

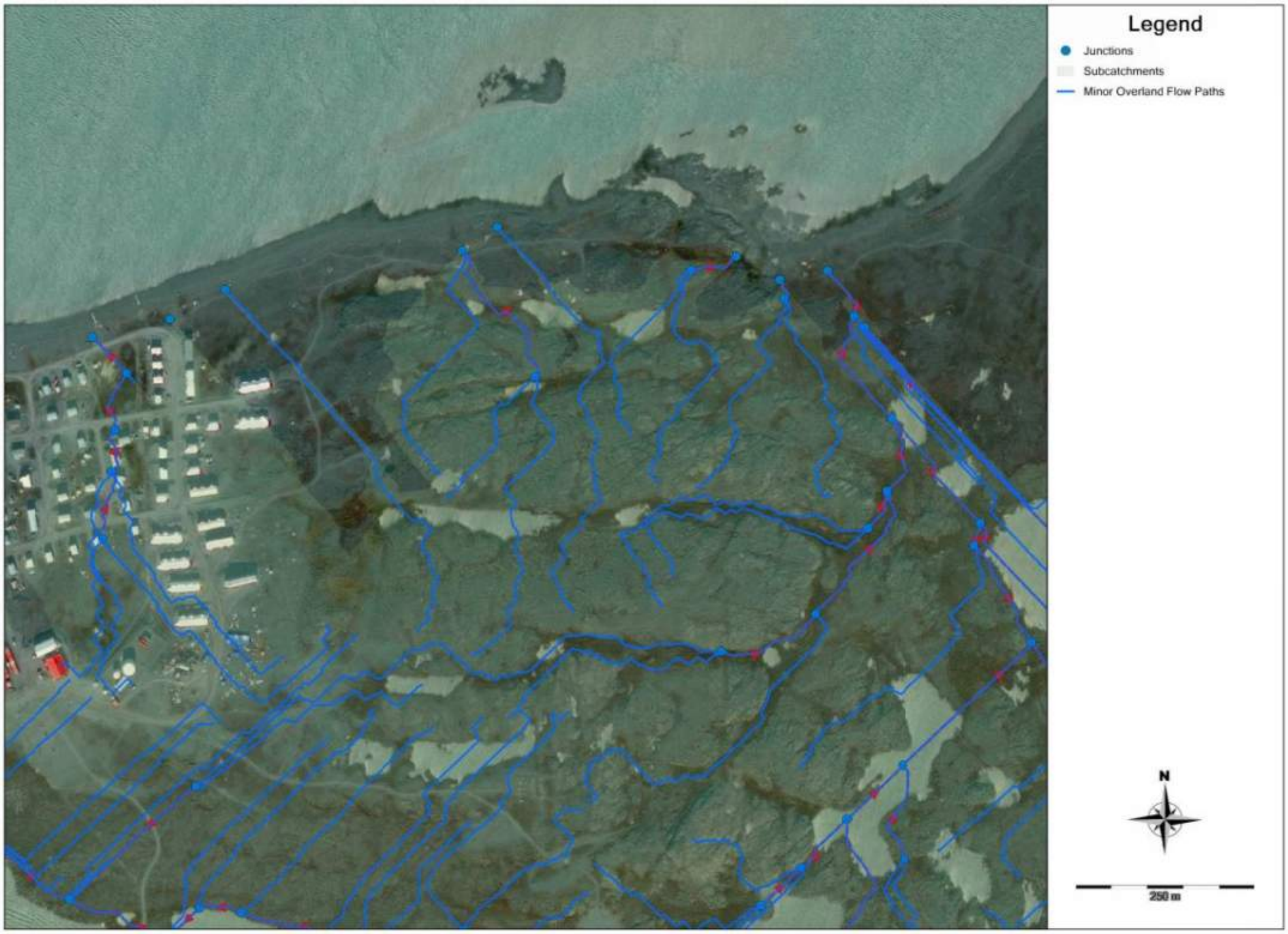


Figure 3. Minor overland flow routes through Area 5.

3.3 Existing Drainage Infrastructure

The culvert inventory catalogued all the existing culverts in the Hamlet and included the following information:

- Code/Picture
- Diameter, Length (If Known), Type
- Material Condition (Interior/Exterior)
- End Conditions
- Cover/End Protection (Material)/ Bedding/Etc
- Comments, Recommend Repair/Replace, Ok? Etc.

The various problems with the existing individual culverts are presented in this inventory.

4 Conclusion and Recommendations

The following section summarizes key findings during the field program and offers solutions to solve the Hamlet's drainage problems.

4.1 Summary of Key Findings

4.1.1 Permafrost

Flaherty Island is located in a region of discontinuous permafrost. The percentage of the land area underlain by permafrost is 10 to 50 percent. Information regarding permafrost areas in the Hamlet is not available. According to the representatives of the Hamlet, to date, they have not encountered permafrost anywhere in the Hamlet where they have undertaken civil works.

4.1.2 Future Construction

Based on the above information and considering that in the future permafrost is likely to degrade further due to global warming, it would be prudent to design the civil engineering works in the Hamlet assuming non-permafrost conditions, especially as it relates to the stability of slopes, bedding for concrete, drainage requirements, erosion protection, etc.

4.1.3 Frost Susceptibility of on-site Soils

The limited testing has indicated that the coarse gravel glaciomarine deposits are generally free draining and not frost susceptible whereas the fine-grained glaciomarine deposits are frost susceptible. The design of the structural and civil works should consider the frost susceptibility of the soils to minimize the detrimental effects of frost heave, etc.

4.2 Recommendations

4.2.1 Proposed Development

4.2.1.1 Field Work

The investigation work in Area 5 consisted of excavating test pits and sampling stockpiles of materials used for civil engineering work.

(a) Test Pit Excavation

A preliminary geotechnical assessment was undertaken in this area. The assessment comprised of excavating four pits (Test Pits 1 to 4 inclusive) with a backhoe to a depth of 0.8 m to 2.5 m. The test pits were logged and representative soil samples were obtained. Water level observations were made in the test pits during the fieldwork. The test pits were backfilled on completion of the fieldwork.

(b) Surface Sample

A surface sample (S1) was obtained from the upstream end of a culvert located at the southwest extremity of the developed area in the Hamlet (see Figure 2 for location) to perform grain size analysis. The culvert at this location is set at a shallow depth and freezes during the cold months. It is also small and would likely need replacement.

(c) Stockpile Sampling

Also, samples of the materials from stockpiles located close to the proposed development were obtained. It is understood that these stockpiles of material are currently used for the construction of the roads. These samples were identified as road gravel, crushed sand and washed gravel. It is understood that it is the first time that the Hamlet has crushed sand. Washed gravel is understood to be a by-product of the crushing of the sand. Recommendations are required regarding the potential uses of these materials.

4.2.1.2 Soil Description and Test Pit Samples

The test pit logs for the four test pits excavated in the area of future development are given in Table 1. A review of this table indicates that the site is covered with approximately 200 mm of tundra. Beneath the tundra, silty sand with rock fragments extends to the entire depth investigated in Test Pit 1, i.e. 0.8 m. Refusal to excavation with the backhoe was encountered at this depth. The refusal to excavation is considered to have occurred on the bedrock.

A grain size analysis performed on the sample of soil obtained from Test Pit 1 yielded a soil composition of 15 percent silt and clay, 65 percent sand, and 20 percent gravel Appendix D.

Table 1: Test Pit Logs

Test Pit #	Depth (m)	Soil Description	Sample Depth (m)`	Moisture Content (%)	Organic Content (%)
1	0-0.2	Tundra			
	0.2-0.8	Silty sand with rock fragments	0.3	8.0	0.5
	0.8	Refusal to excavation on bedrock			
	Water level on completion of test pit = 0.4 m				
2	0-0.2	Tundra and organics			
	0.2-2.5	Clayey sandy silt with seashells, large rock fragments	1.2	39.5	-
	2.5	Test pit terminated due to extensive cave-in of sides			
	Water level on completion = 1.0 m				
3	0-0.2	Organics and rock fragments			
	0.2-1.1	Clayey silt, with gravel, cobbles and boulders	0.6	18.4	-
	1.1	Test pit terminated due to refusal to excavation on a boulder or bedrock			
	Water level at 0.6 m depth on completion				
4	0-0.2	Organics and rock fragments			
	0.2-0.4	Rock fragments			
	0.4-1.2	Sandy clayey silt, trace gravel	0.9	20.0	-
	1.2	Refusal to excavation on bedrock			
	Water level at 1.0 m depth on completion.				
Surface Sample S1	0.0	Poorly graded silty sand	0	21.3	0.6

In the other test pits, the tundra is underlain by sandy silt to clayey silt with trace to some gravel. This stratum extends to the entire depth investigated in Test Pits 2 to 4. Test Pit No 2 was terminated at 2.5 m depth due to water inflow into the test pit and extensive cave-in of the sides of the test pit. Test Pits 3 and 4 met refusal at a depth of

1.1 m and 1.2 m respectively. This refusal is considered to have been met on the bedrock surface. It is noted that at the time of the investigation, the soil was not frozen in any of the test pits. All the test pits were backfilled on completion.

One soil sample from each of Test Pits 2 to 4 was subjected to grain size analysis. The results of these tests are given in Appendix A. A review of these figures indicates that the soil comprises of 51 to 72 percent silt and clay, 24 to 30 percent sand, and 4 to 22 percent gravel. The test results have been summarized in Table 2.

4.2.1.3 Soil Description of Surface Sample

The surface sample obtained from the southwest end of the developed area of the Hamlet consisted of poorly graded sand. Its composition consisted of 28 percent silt and clay, 72 percent sand, and 0 percent gravel (Figure 10 and Table 2).

Table 2: Grain Size Analyses of Soils from Test Pits and of Surface Sample

Test Pit #	Depth (m)	Grain Size Analysis (%)			Liquid Limit * (%)	Plastic Limit (%)
		Clay & Silt	Sand	Gravel		
1	0.3	15	65	20	Non-plastic	
2	0.8	55	30	15	30.1	23.5
3	0.3	51	27	22	-	-
4	0.9	72	24	4	-	-
Surface Sample	0.0	28	72	0	Non-plastic	

4.2.1.4 Frost Susceptibility of On-Site Soils

Frost susceptibility of soils refers to the propensity of the soil to grow ice lenses and heave during construction. The frost susceptibility of the on-site soils was assessed using the U.S. Corp of Engineers Frost Design Soil Classification. The soils are listed in four categories, F1 to F4, in approximately increasing order of frost susceptibility and loss of strength during a thaw. Based on U.S. Corp of Engineers criteria, the soils from the four test pits excavated in the area of the proposed development and the surface sample obtained from near a culvert located in the southwest part of the community were classified for frost susceptibility. The results are given in Table 3.

Table 3: Frost Susceptibility Assessment of some On-site Soils

Test Pit or Sample #	Depth (m)	Soil Description	Percentage fewer than 0.02 mm by Weight	Frost Creep Classification
1	0.3	Poorly graded sand, some gravel (SG)	8	F1
2	0.8	Clayey sandy silt (ML)	41	F4
3	0.3	Sandy clayey silt (CL)	42	F4
4	0.9	Sandy clayey silt (CL)	55	F4
S1	0.0	Poorly graded silty sand (SP)	6	F1

4.2.1.5 Stockpiled Materials

The stockpiles located in the northeast part of the Hamlet were sampled. The samples from the stockpiles were identified as road gravel, crushed sand, and washed gravel. Road gravel is the natural pit run material. Crushed sand is produced by crushing gravel and cobbles. Washed gravel is a by-product of crushing the sand. Grain size analyses were performed on the samples from the stockpiles and the results have been listed in Table 4 and plotted in Appendix D.

Table 4: Results of Grain Size Analysis of Stockpiled Samples

Sample Identification	Grain Size Analyses (%)		
	Clay & Silt	Sand	Gravel
Road Gravel	3	32	65
Crushed Sand	10	86	4
Washed Gravel	0	0	100

The gradation of the road gravel meets the gradation requirements for base material and is considered suitable for this purpose.

The crushed sand is considered suitable for use as a granular sub-base for the construction of the roads.

The washed gravel may be used as a filter material around sub-surface drains, and as 19mm clear stone under slab-on-grade floors, etc.

4.2.1.6 Foundation Considerations for the Proposed Development

Based on a review of the surficial and bedrock geology of the proposed development area, and the limited geotechnical investigation undertaken in the proposed development area, it is considered that the following foundation alternatives are feasible:

1. Spread and strip footings on bedrock; and,
2. End bearing piles.

Spread Footings on Bedrock

Footings placed directly on bedrock are quite common in the arctic. In this case, spread and strip footings may be used. The foundations normally consist of conventional reinforced concrete footings and piers.

End Bearing Piles

Pile foundations, especially end bearing piles socketed into bedrock, are considered to be the most reliable and preferred foundation system for permafrost regions. Based on a review of the geological information in the Hamlet, it is considered that the bedrock in the Hamlet is present at a shallow depth below the ground surface. The exception to this is in the valleys where the thickness of the overburden may vary up to 30 m.

Normal practice is to use round hollow section (HSS) piles as opposed to pipe casings. The piles are normally grouted a minimum of 2 m into the sound bedrock provided that the annulus between the pile boring and the pile is 25 mm or more. If the annulus is less than 25 mm, the piles are normally grouted 2.5 m into bedrock.

Steel piles installed according to the above recommendations can normally be designed for SLS bearing pressure of 5 MPa over the full base area of the grouted pile. Also, it may be possible to use the bond between the grout and the bedrock for design purposes. The allowable bond between the grout and the bedrock is normally taken as 1.0 to

1.5 percent of the unconfined compressive strength of the grout. The minimum unfounded compressive strength of the grout used is normally specified as 20 MPa.

4.2.2 Areas of Concern

The following section identifies specific locations in the Hamlet where drainage issues must be addressed.

4.2.2.1 Lake Drainage

As seen above in Figure 1 in Section 3.2 some of the major concerns noted during the site visit and described by local Hamlet staff were the major drainage courses traversing through the community, specifically in Area 1. Figure 2 in Section 3.2 shows a significant portion of the southern overland flow route drains northernly through the Hamlet of through crossings X-01, X-03 and X-04. Due to the extent of the drainage area, it is critical to maintain adequate flow through these culvert crossings at all times, and most importantly during the seasonal spring melt. From discussions with Hamlet staff, it is EXP's understanding that during these melting periods with increased flow, large masses of ice and snow tend to build up around the crossing X-03, resulting in increased lake water levels and minor to moderate flooding of adjacent properties. Crossing locations are shown in on the Site Plan in Appendix B. By reviewing the contour data provided by GN sources, there appears to be less than one meter of elevation difference between the typical lake water level, and the airport road surface (i.e. the highest elevation in Area 1). That is, if the lake drainage outlet is blocked and water levels rise, it is more than likely that water will begin to drain westerly through the Hamlet. The results of this will vary in severity depending on the duration of the blockage and peak flow rates, but can range from standing water and minor erosion along roadsides and residential properties, to major erosion and washouts of road surfaces and building block footings.

Three scenarios to reduce the potential of flooding, or protect against it, would be:

1. Consider upgrading road crossings X-03 and X-04;
2. Install a berm along the western lake shoreline; and/or,
3. Constructing swales and ditches within the right-of-way in Area 1.

Some of the issues with the road crossing X-03, and possible reasons for blockages, are likely due to the size of the existing culvert EC-03A. This culvert is 1800mm diameter CSP and is likely adequate to handle the annual peak flows, however, due to the widespread and shallow drainage from the lake, it may be advantageous to consider installing a road crossing with an increased span to allow for a wider flow of water and ice debris. This should ultimately reduce the chance of buildup and blockages. One option would be to install one or more precast concrete box culverts instead of typical CSP culverts. Box culverts can be manufactured in a range of different dimensions, and so, one or more culverts with an opening span of 1800-2400mm, and a rise of approximately 1200mm will help convey larger masses of ice and debris and may reduce the chance of blockages. Additionally, using a concrete product increases the end durability, minimizing damage from ice flow, or from heavy machinery, in the event a blockage does occur, and maintenance staff are required to clear it. Unlike concrete, CSP will bend, tear, and/or unravel when struck by maintenance equipment, where concrete may only chip and can be easily repaired without full section replacement. Another option for the road crossing upgrade could be to install a bridge, as it can allow for greater spans for significantly increased water and ice conveyance, minimizing the chance of blockages and buildups. Some considerations that may outweigh the benefits of a bridge would be the initial installation costs, maintenance requirements and resulting costs, and overall required size and capacity.

The second option that may be considered to reduce the potential negative impacts to Area 1 in the event of increased lake water levels would be the installation of a berm along the northwestern shoreline of the lake. Although extensive investigation would be required before deciding the size and type of berm, it is thought that a rock berm with internal liner approximately 600-900mm in height would be able to help reduce overland flow through Area 1 from the lake. The berm would likely run from the Airport Road to the rock outcrop directly east of the school, with access points available for pedestrian and snowmobile crossing throughout the year. Further investigations may also suggest incorporating additional protection from groundwater seepage, and so, other methods such as sheet piling could also be incorporated into the berm design if required.

The third approach would be an inexpensive yet effective solution to help reduce washouts throughout Area 1 and would entail constructing drainage ditches and swales alongside the roads within the right-of-way. The contours show that it would be feasible to convey water southwest along the Airport road to the intersection with approximately two road crossing culverts required. Water would then travel northwest towards the shoreline, where a third road crossing culvert would be required. It is recommended to complete a full topographical survey of the shoreline road to check if there are any additional areas where outlet culverts would be required.

4.2.2.2 Airport Road

With the airport being a critical lifeline within any northern community, it is imperative to ensure the road to the airport is always properly maintained and protected from potential erosion and washouts. Discussions with Hamlet staff and observations noted during the field walkthrough suggest that the existing road culverts and current drainage should be improved upon.

It is evident in Figure 1 in Section 3.2 that there is a large area of land that ultimately drains through culverts EC-01A and EC-01B. Hamlet staff have explained that they have not had any issues with these culverts and that their size appears adequate for the resulting flow. Although that may be the case, it has been determined that repairs would be difficult and costly, and so, a full replacement is recommended. Both culverts exhibit moderate to severe signs of corrosions, with EC-01A showing full corrosion penetration along its bottom, and both the upstream and downstream ends require extensive repair and lengthening. Attempting to repair these culverts would be infeasible. It would make the most sense (from a financial and constructability standpoint) to replace both culverts with a similar size and material, i.e. two 1500mm diameter CSP culverts, allowing for a minimum of 750mm of cover (0.5x Diameter – Iqaluit design guideline). The road embankments should be graded to between 2:1 to 3:1 slope, and the culvert ends should be extended to the toe of the finished slope. The embankments and culvert ends should then be protected with an appropriate rip rap apron as per Figure 4 in Section 4.2.5.

Additionally, another consideration to improve drainage along the Airport road would be to upgrade culverts EC-02A and EC-02B. After discussions with Hamlet staff and review of the culvert conditions, it is recommended to replace these two existing crossings with larger diameter CSP culverts. During the late winter and early spring months, it has been observed that due to the inadequate size and minimal cover, these culverts tend to fill with ice and snow, and freeze almost completely solid. Drainage is then almost impossible during the seasonal melt, and water tends to back up towards the adjacent buildings. Considering the poor soils witnessed in this area from previous excavations, standing water may contribute to early permafrost melting and cause unstable soil conditions. Erosion and washouts become a very likely outcome from this backup of water. To combat this seasonal issue, it is recommended to replace these culverts with one or more 750mm diameter CSP culverts. Taking advantage of the consistent slope towards the ocean, it is possible to lower the invert elevations of the culvert, upstream creek and downstream outlet to ensure adequate cover requirements are met. Embankments should be graded between 2:1 to 3:1, and culvert ends should be extended to the toe of the finished slope, and protected with appropriate rip rap aprons per Figure 4 in Section 4.2.5.

By reviewing the land contour along the Airport road, one can see that water tends to flow overland from south to north perpendicular to the Airport road. The roadway then impedes this flow, and water beings to run along the edge of the roadway towards crossings X-01 and X-02. During major melting and/or rainfall events, this flow of water has been observed to erode and washout the edge of the Airport road, as well as the embankments around the upstream ends of culverts EC-01A/B and EC-02A/B. To combat this erosion, it is recommended to construct a drainage ditch along the south side of the airport road which should be protected with rip rap stone along its base. An appropriate ditch outlet with rip rap apron should then be constructed to control the flow of water into culverts EC-01A/B and EC-02A/B. Annual maintenance should be completed along this ditch to ensure sediment buildups are removed efficiently.

4.2.2.3 Existing Hamlet Drainage

During the field walkthrough, it was observed that a large majority of existing drainage infrastructure was in a rather poor condition. Ditches and swales tended to be blocked or impeded by (after the fact) driveways, pathways or ramps, as well as several areas were blocked by sediment and debris buildup. Many culverts were observed to be severely damaged, crushed, filled in, collapsed or buried (partially or fully). A simple, yet effective solution to improve the drainage throughout the Hamlet would be to clean out any existing culverts that are blocked by debris or sediment and replace all culverts that are damaged or cannot be cleaned. Ditches and swales should be reshaped and regraded to ensure consistent and positive flow from higher elevations to designated outlet culverts. Refer to Appendix C for full detailed recommendations for individual culverts. Ditches and swales should be protected with rip rap wherever possible and in steep, high flowing areas.

4.2.2.4 Area 5 – New Subdivision

Most of Area 5 is currently vacant, apart from some new houses located on the west end. The road construction was estimated to be approximately 80% complete during the time of inspection, and several key observations were noted regarding the site drainage and ground conditions. Staff also noted that there were areas where the new road construction impeded overland flow paths from the south lands to the north shore. It was observed that the eastern radius within the right-of-way had staining present on the granular material from standing water, and there was significant standing water along the south side of the road, as well as within the radius. By impeding this flow path, water will accumulate in these areas, and begin to flood residential properties and buildings, and/or drain across the road surface increasing the chance of erosion and washouts. To protect against this, it is recommended to installing ditching or swales along both sides of the south road, with a culvert crossing from the south side of the road to the inside of the radius. A second culvert crossing should then be installed from the inside of the radius to the north side of the road, ultimately draining towards the shore. Due to the large rock outcrops present throughout this area, rock breaking will likely be required. It was observed that there are several ponds located between Area 5 and the shoreline, which will likely be the drainage outlet for this overland flow from Area 5. Another recommendation would be to modify the outlets of these ponds to either lower the water elevation within the pond to allow for more developmental land or to simply control the maximum elevation of the pond with a rock weir to reduce the risk of flooding between Area 5 and the shore. Other general recommendations would be to construct ditching or swales along the roadsides and to install culverts from low areas where standing water can accumulate to a lower outlet on the opposite side of the road. The construction suitability for the new development can be seen in Appendix B.

4.2.3 Culvert Design Considerations

Large volumes of water begin to run-off the land during the spring melt in northern climates. In the context of subdivision design, roads and gravel building pads typically act as barriers to the flow of water. without the proper installation and maintenance of culverts and ditches, drainage paths can become blocked which will lead to pools of standing water.

Drainage works should always be appropriately sized to ensure that they can adequately accommodate the volumes of water that are expected to flow through each portion of the subdivision. This section specifies minimum standards for typical drainage works within subdivisions in an Arctic environment. Culverts shall be sized to reflect the potential flow requirement and facilitate maintenance activities. The minimum recommended culvert size in a community drainage system should be 450mm diameter to facilitate access by maintenance personnel to thaw the culvert during spring runoff. Many Northern communities allow residential driveway culverts to be smaller than 450mm diameter. Upsizing culvert sizes to allow some icing to occur without completely blocking the flow of water is recommended to minimize intervention by thawing devices.

Roads crossing areas where high flows are expected are at greater risk of washout and should have multiple culverts installed for redundancy. The culverts should be positioned to reduce the risk of icing, this is done by placing the culverts at slightly different elevations to prevent the blockage of all culverts at the same time.

The following recommendations for culvert design apply to subdivision developments:

- Culverts shall be a new galvanized corrugated steel pipe with a minimum wall thickness of 1.6 mm.
- Minimum pipe sizes for various uses are as follows:
  - Residential Driveway Culvert 450mm diameter
  - Industrial Driveway Culvert 450mm diameter
  - Roadway Centreline Culverts 450mm diameter
- All culverts shall have appropriate end treatments depending on the application. End treatment recommendations are discussed further in Section 6, Erosion and Sediment Control. Inverts shall be extended to the toe of the side slope.
- The culvert grade shall not be less than the ditch grades at the inlet and outlet. The minimum recommended ditch grade of 0.5% will apply wherever possible, as recommended by the Nunavut Subdivision Design and Standards Manual.
- Culverts shall be designed and installed with a sufficient amount of coverage to protect against damage from the expected traffic loading. Minimum cover shall be 300mm or one-half the diameter of the culvert, whichever is greater as measured from the finished shoulder grade to the top of the culvert.

4.2.4 Conveyance Considerations

Surface drainage systems are constructed by grading the surface to create berms, swales and ditches that permit the conveyance of water by gravity. The drainage system design shall consider the major overflow path that the runoff will take when the capacity of the drainage system is exceeded. Ditches shall be constructed to a depth that ensures the road structure is adequately drained. The following recommendations for ditch design apply to subdivision developments:

- Ditches for roadways shall have back slopes no steeper than 3H:IV.
- Swale and ditch grades shall match the road grades wherever possible.
- Swale and ditch grades shall have a minimum grade of 0.5%.
- Ditches shall have a flat bottom, with a minimum 0.3m width.

4.2.5 Erosion Control Considerations

Erosion and sedimentation control measures should be included in subdivision design near natural drainage features such as streams as well as drainage infrastructure such as culverts. Materials to consider are geotextiles and rip-rap armouring. Geotextiles protect soil from the tractive forces of moving water, wind, or rainfall while minimizes the tractive forces by slowing the velocities. Rip-rap and geotextiles combined are the most common materials used for erosion control. Other materials include gabions, concrete structures, ditch blocks, wood cribbing and vegetation.

Rip-rap aprons should be used to mitigate potential erosion at drainage infrastructures such as embankment slopes and culvert outlets. The following Figure 4 provides details on typical culvert apron design.

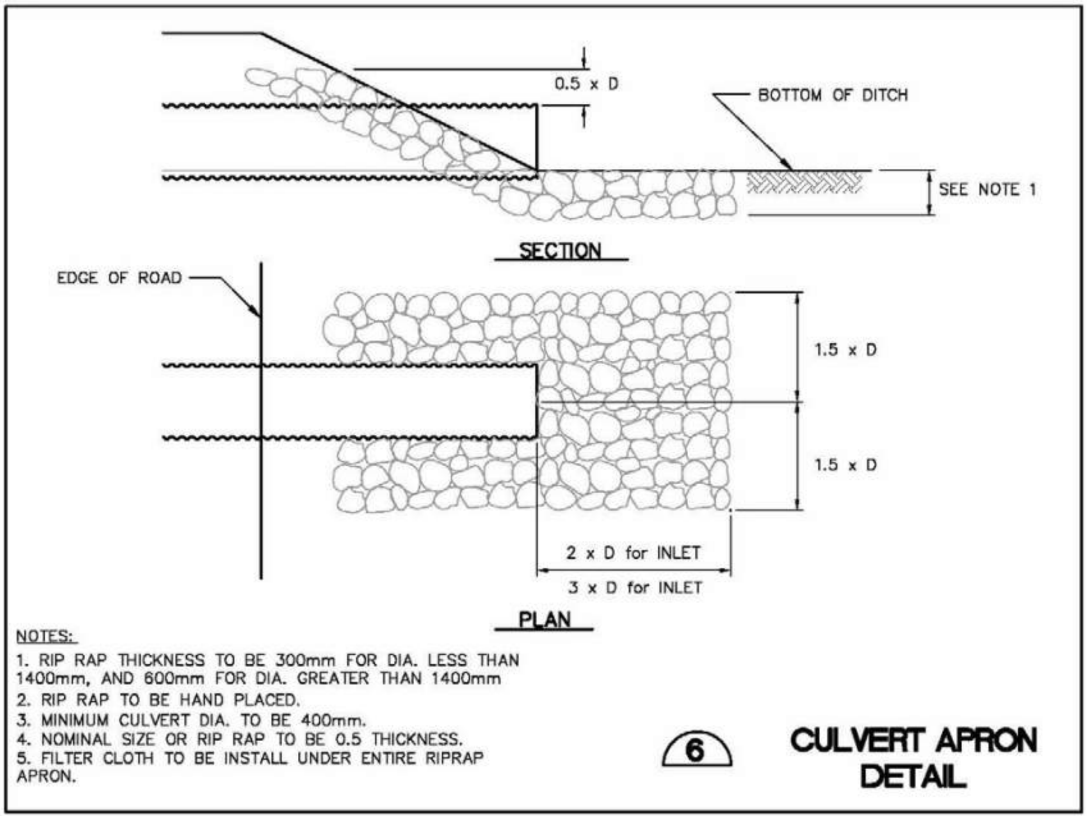


Figure 4. Typical Culvert Apron Design.

4.2.6 Operation & Maintenance Considerations

A drainage system must be maintained and monitored to ensure the long-term core functionality of the system. Inspection and maintenance personnel shall be responsible for maintaining the drainage system. An important first step is to have a map indicating the locations of all culverts throughout the community, including the size of the culvert, the direction of flow and end treatments provided.

As with any region which experiences freezing conditions there is a need for snow removal. It is not uncommon for road maintenance operations to unintentionally have negative impacts on the performance of the drainage system. It is suggested that the following components of the community drainage system be marked and identifiable before the first snowfall to notify snow removal equipment operators of their location:

- Outfalls
- Drainage ditches
- Culvert ends

The development and implementation of a snow management plan can also be very beneficial. Strategic placement of snow piling locations can reduce the impact on the drainage system during the spring melt.

Best practices suggest that the drainage infrastructure be inspected weekly during the melting season and/or after major rainfall events. Culvert ends shall be cleared when blocked with snow or ice. A hand tool is preferred to remove blockages to limit damage to the culvert. Blocked culverts shall be cleared to allow meltwater to flow freely. A steamer or pressure washer (hot) can be used to melt frozen blockage from the downstream end. It is also suggested that maintenance personnel begin at the downstream end of the drainage system and work upstream.

The following activities shall be included in the corrective action plan as a minimum:

- Ponding in ditches shall be documented and corrected by re-sloping the ditch or lowering the downstream culvert (if possible).
- Blocked culverts shall be flushed to remove sediment, rocks, ice, and other debris which impedes the flow.
- Damaged culvert ends shall be cut back, replaced, or bent open if collapsed; and
- Culverts that have shifted or that are damaged beyond repair shall be replaced or re-installed on a priority basis.

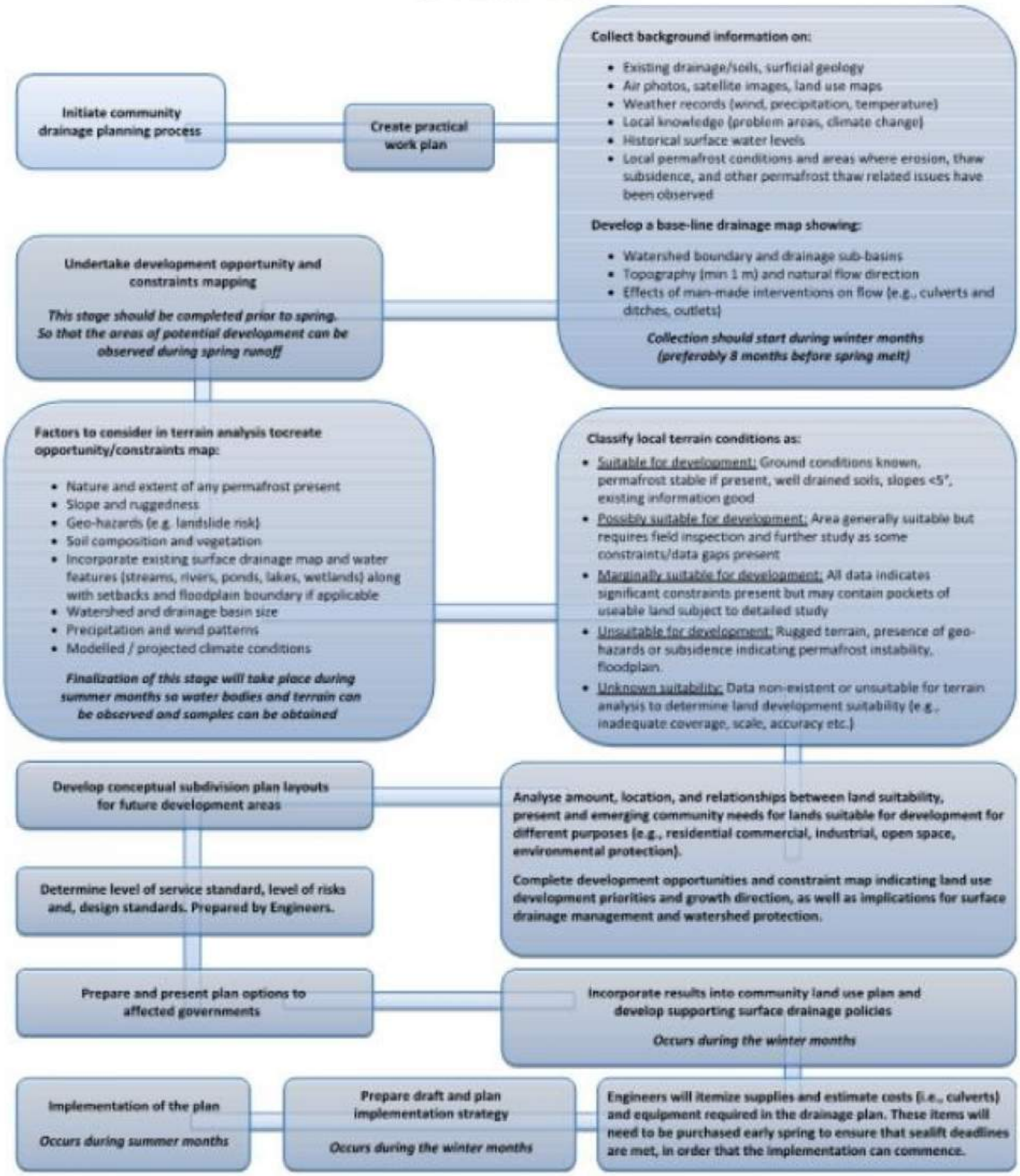
5 REFERENCES

James, T.S., Simon, K.M., Forbes, D.L., Dyke, A. s., & Mate, D.J. (2011). *Sea-Level Projections for Five Pilot Communities of the Nunavut Climate Change Partnership. Canada: Natural Resources Canada.*

Standard Council of Canada. 2015. Community drainage system planning, design, and maintenance in northern communities, National standard of Canada, CAN/CSA-S503-15.

Appendix A –
CSA Drainage Planning Flow Chart

Figure 6
Drainage planning flow chart
(See Clause 4.3.1.)



Note: *This flow chart acknowledges that the spring runoff and summer drainage issues must be observed before the drainage plan can be fully developed and, therefore, funding to support drainage system development might need to span two fiscal years. This ensures that the background research is complete the previous winter and the*

Appendix B –
Site Plan and Future Suitability

CAUTION
THE POSITION OF ALL POLE LINES, CONDUITS, WATERMAINS, SEWERS AND OTHER UNDERGROUND AND OVERGROUND UTILITIES AND STRUCTURES IS NOT NECESSARILY SHOWN ON THE CONTRACT DRAWINGS, AND WHERE SHOWN, THE ACCURACY OF THE POSITION OF SUCH UTILITIES AND STRUCTURES IS NOT GUARANTEED. BEFORE STARTING WORK, DETERMINE THE EXACT LOCATION OF ALL SUCH UTILITIES AND STRUCTURES AND ASSUME ALL LIABILITY FOR DAMAGE TO THEM.

SCALE
0 30m 60m 120m
HORIZONTAL 1:3000

NORTH

DESIGNED BY

REVIEWED BY

CLIENT
GOVERNMENT OF NUNANVUT
KUGLUKTUK, NU. P.O. BOX 272

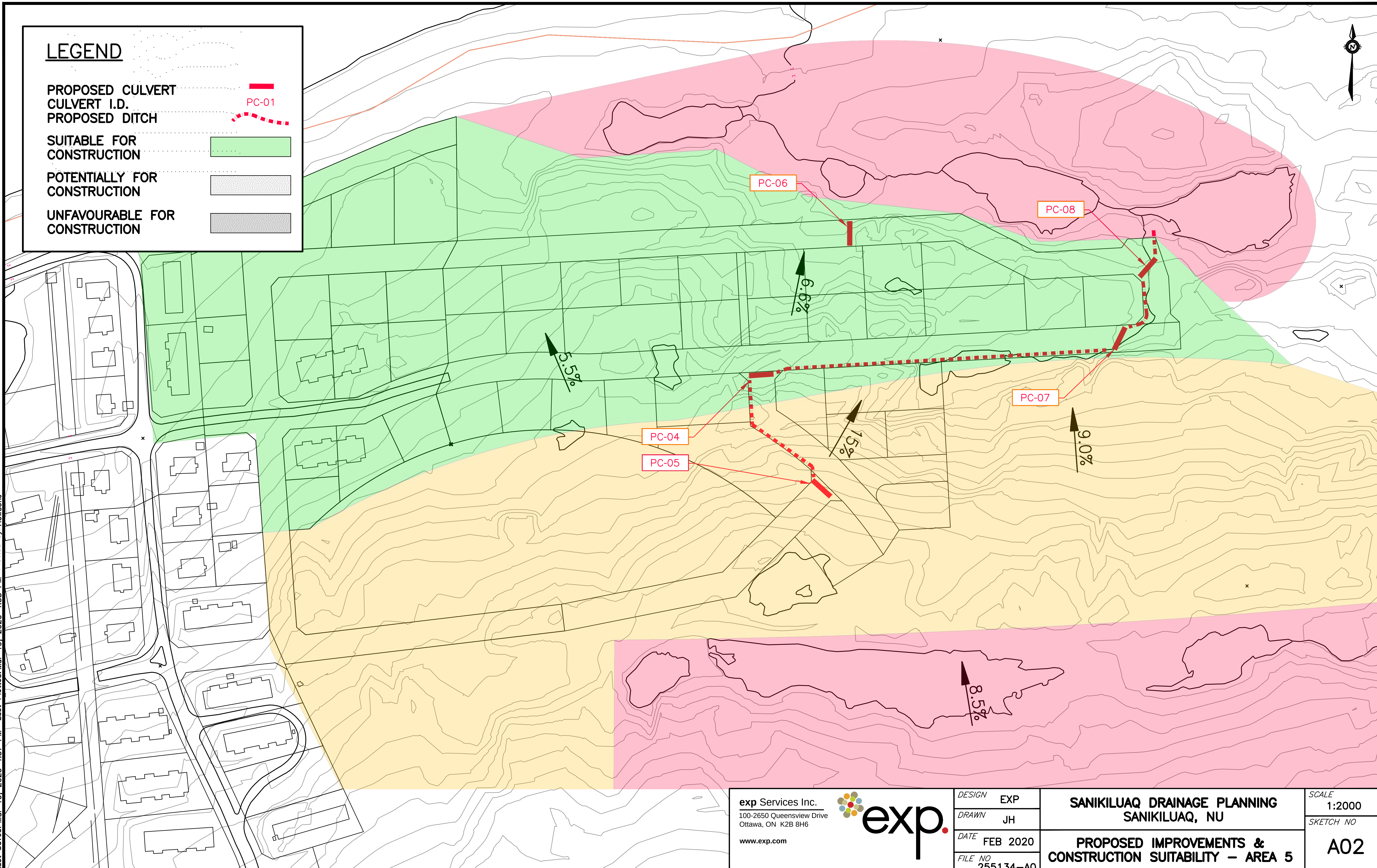
exp.
exp Services Inc.
t: +1.613.688.1899 | f: +1.613.225.7330
2650 Queensview Drive, Unit 100
Ottawa, ON K2B 8H6
Canada
www.exp.com
• BUILDINGS • EARTH & ENVIRONMENT • ENERGY •
• INDUSTRIAL • INFRASTRUCTURE • SUSTAINABILITY •

BASEPLAN	GN
DESIGN	EXP
CHECKED	IPC
CAD	JH
PROJECT MANAGER	SP
APPROVED	IPC

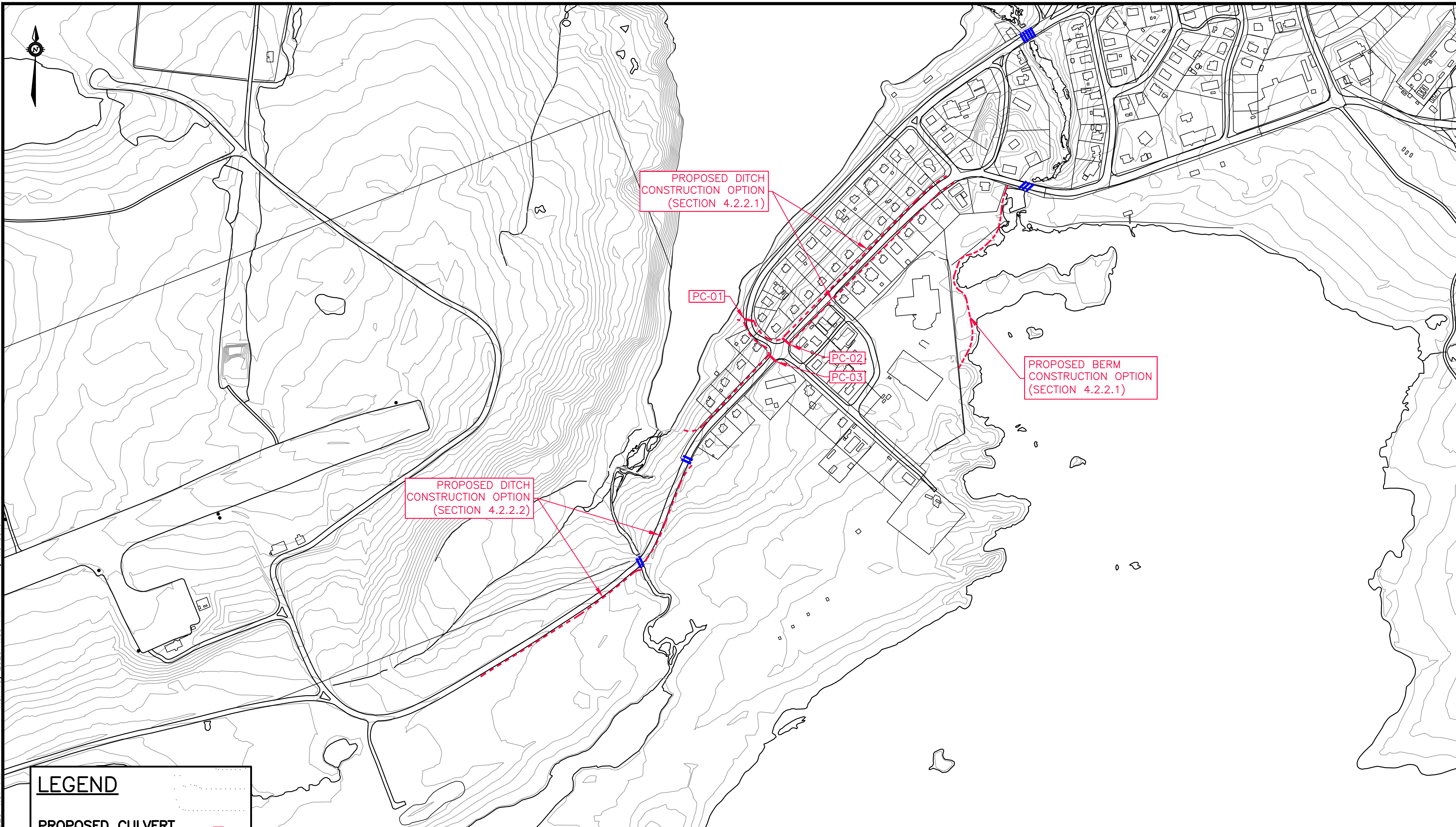
PROJECT
SANIKILUAQ DRAINAGE PLANNING
SANIKILUAQ, NU

TITLE
EXISTING CONDITIONS & DRAINAGE

PROJECT No.	OTT-255134-A0
SURVEY	---
DATE	SEP 2019
DRAWING No.	A02



Filename: P:\Projects\Civil\255000\OTT-00255134-A0 – Sanikiluaq Drainage Study – Sanikiluaq\60-EXECUTION\64-DWG\255134.dwg
Last Saved: Mar 19, 2020 4:57 PM Last Plotted: Mar 19, 2020 4:58 PM Plotted by: HewsonJ



LEGEND

PROPOSED CULVERT
CULVERT I.D. PC-01
PROPOSED DITCH
PROPOSED BERM

exp Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6
www.exp.com

exp.

DESIGN	EXP
DRAWN	JH
DATE	FEB 2020
FILE NO	255134-A0

SANIKILUAQ DRAINAGE PLANNING
SANIKILUAQ, NU

PROPOSED IMPROVEMENTS
AREA 1 & AIRPORT ROAD

SCALE 1:5000

SKETCH NO A02

Filename: P:\Projects\Civil\255000\OTT-00255134-A0 - Drainage Study - Sanikiluaq\60-EXECUTION\64-DWG\255134.dwg
Last Saved: Mar 19, 2020 4:57 PM Last Plotted: Mar 19, 2020 4:59 PM Plotted by: HewsonJ

Appendix C –
Culvert Inventory

Appendix 1 – Culvert Inventory

CROSSING: X-01

NORTHWEST OUTLET

SOUTHEAST INLET

Culvert I.D.	EC-01A
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 1500 mm
Interior Condition	Poor - Culvert bottom has severe rust penetration - Complete material failure
Exterior/End Condition	Poor - Northwest end is torn (CSP unravelling) - Northwest and southeast end do not extend far enough to protect embankment from erosion/collapse - North end is too high, resulting in creek bed erosion
Embankment Condition	Poor - Erosion present - Rock protection is too large and not adequate to protect bank (may also cause additional damage to culvert ends)
Ditch Conditions	Good - Minimal erosion present; only below outlet of culvert - Good vegetation (erosion control) along banks - Good stone bottom to protect from erosion upstream/downstream
Comments/Recommendations	Culvert is in working order and receives primary flow from creek, however, replacement is recommended due to poor interior condition. Extend new culvert sufficiently beyond toe of slope, and protect with 6" minus rip rap along embankment and creek bed.

NORTHWEST OUTLET

SOUTHEAST INLET

Culvert I.D.	EC-01B
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 1500 mm
Interior Condition	Fair - Culvert bottom has moderate corrosion - No visible penetration
Exterior/End Condition	Poor - Both ends are torn/bent (CSP unravelling) - Northwest and southeast end do not extend far enough to protect embankment from erosion/collapse - Northeast end is too high, resulting in creek bed erosion
Embankment Condition	Poor - Erosion present - Rock protection is too large and not adequate to protect bank (may cause additional damage to culvert ends)
Ditch Conditions	Good - Minimal erosion present; only below outlet of culvert - Good vegetation (erosion control) along banks - Good stone bottom to protect from erosion upstream/downstream
Comments/Recommendations	Inverts are higher than EC-01A, and so culvert receives secondary flow (overflow). Interior condition is fair, however, due to EC-01A requiring replacement, EC-01B is also recommended to be replaced simultaneously for long term financial and operational benefits. Extend new culvert sufficiently beyond toe of slope, and protect with 6” minus rip rap along embankment and creek bed.

CROSSING: X-02

NORTHWEST OUTLET

SOUTHEAST INLET

Culvert I.D.	EC-02A
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 600 mm
Interior Condition	Fair - Culvert bottom has minor corrosion - No visible penetration - Good conveyance of water
Exterior/End Condition	Poor - Both ends are torn/damaged - Northwest and southeast end do not extend far enough to protect embankment from erosion/collapse
Embankment Condition	Poor - Erosion present due to minimal cover and inadequate end extension - Granular material is too small for proper erosion protection
Ditch Conditions	Poor - Silty material has built up near culvert inlet - No rip-rap material upstream to control sediment - Good stone bottom to protect from erosion downstream
Comments/Recommendations	Culvert appears to be inadequate size, and does not meet proper cover requirements. Culverts should be removed, and new culverts should have a minimum 900mm diameter. Invert elevations should be lowered to allow for 500-600mm of cover below road surface. Extend new culvert sufficiently beyond toe of slope, and protect with 6" minus rip rap along embankment and creek bed.

NORTHWEST OUTLET

SOUTHEAST INLET

Culvert I.D.	EC-02B
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 600 mm
Interior Condition	Poor - Culvert bottom has minor corrosion - No visible penetration - Lots of granular/sediment blocking flow
Exterior/End Condition	Poor - Both ends are torn/damaged - Northwest and southeast end do not extend far enough to protect embankment from erosion/collapse - Lots of granular/sediment blocking flow
Embankment Condition	Poor - Erosion present due to minimal cover and inadequate end extension - Granular material is too small for proper erosion protection
Ditch Conditions	Poor - Silty material has built up near culvert inlet - No rip-rap material upstream to control sediment - Good stone bottom to protect from erosion downstream
Comments/Recommendations	Culvert appears to be inadequate size, and does not meet proper cover requirements. Culverts should be removed, and new culverts should have a minimum 900mm diameter. Invert elevations should be lowered to allow for 500-600mm of cover below road surface. Extend new culvert sufficiently beyond toe of slope, and protect with 6” minus rip rap along embankment and creek bed.

CROSSING: X-03

SOUTHWEST INLET

INTERIOR

Culvert I.D.	EC-03A
Upstream / Downstream	Southwest / Northeast
Material / Size	CSP / 1800 mm
Interior Condition	Fair - Culvert bottom has minor corrosion - No visible penetration, and no debris/sediment
Exterior/End Condition	Fair - Both ends have deformation, but not significant damage/tearing - Southwest inlet extends well beyond toe of slope. Northeast outlet could be extended. - Large boulders surround ends; could cause further damage/deformation
Embankment Condition	Fair - Large boulders surround culvert ends, and do not adequately protect against erosion - Embankment is fairly steep
Ditch Conditions	Fair - Upstream could be channelized to reduce spread of flow (reduce chance of ice buildup in the winter) - Good stone bottom to protect from erosion upstream and downstream - Outlet could be built up with rip-rap to protect against further erosion
Comments/Recommendations	Culvert appears to be adequate size for water conveyance and is in overall fair condition and does not require any immediate repairs. Granular cover below the road surface should be increased if culvert is replaced. Outlet end could be extended to protect from embankment erosion. Embankment could be protected with 6" minus rip-rap surrounding the culvert ends.

NORTHWEST OUTLET

SOUTHEAST INLET

Culvert I.D.	EC-03B
Upstream / Downstream	Southwest / Northeast
Material / Size	CSP / 750 mm
Interior Condition	Poor - Appears to be collapsed / full of debris - Corrosion penetration / material failure
Exterior/End Condition	Poor - Appears to be out of place; southwest inlet has been pulled up out of position
Embankment Condition	NA (See EC-03A)
Ditch Conditions	NA (See EC-03A)
Comments/Recommendations	Culvert has completely failed and appears to be collapsed/full of debris. Due its size compared to EC-03A, this culvert does not appear to be required for regular flow rates. Replacement is recommended if culvert EC-03A is ever replaced in the future.

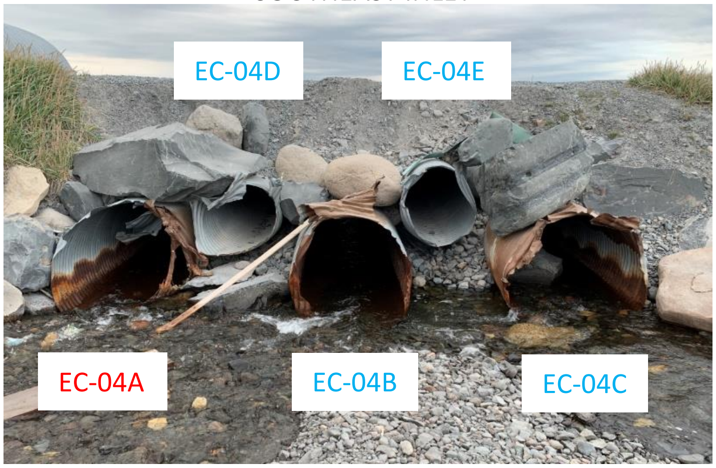
NORTHWEST OUTLET

SOUTHEAST INLET

Culvert I.D.	EC-03C
Upstream / Downstream	Southwest / Northeast
Material / Size	CSP / 750 mm
Interior Condition	Poor - Appears to be collapsed / full of debris - Corrosion penetration / material failure
Exterior/End Condition	Poor
Embankment Condition	NA (See EC-03A)
Ditch Conditions	NA (See EC-03A)
Comments/Recommendations	Culvert has completely failed and appears to be collapsed/full of debris. Due its size compared to EC-03A, this culvert does not appear to be required for regular flow rates. Replacement is recommended if culvert EC-03A is ever replaced in the future.

CROSSING: X-04

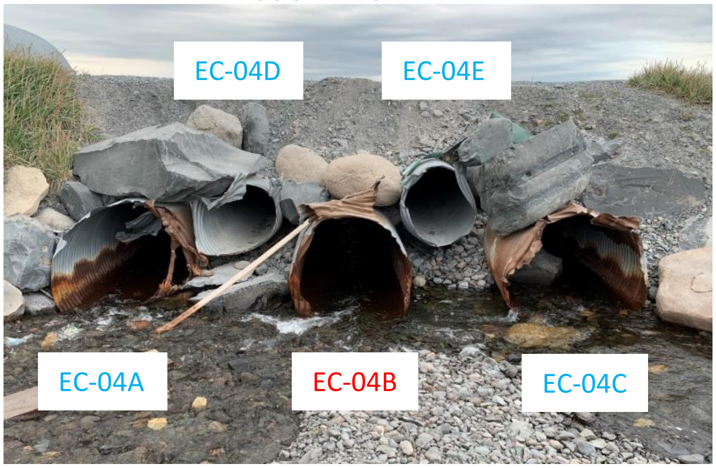
SOUTHEAST INLET



SOUTHEAST INLET

Culvert I.D.	EC-04A
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 1200 mm
Interior Condition	Fair - Moderate to severe corrosion (possible penetration) - Minor debris/sediment
Exterior/End Condition	Poor - Both ends are damaged/torn (CSP unravelling)
Embankment Condition	Poor - Erosion present on northwest side - Embankment appears to be too steep (minor collapse) - Large boulders surround culvert ends; could cause further damage and do not protect against erosion well
Ditch Conditions	Good - Good stone bottom to protect from erosion upstream and downstream - Some debris present
Comments/Recommendations	Culvert is in working order and does not impede water flow. Condition is deteriorating and may require replacement soon. Recommend replacement simultaneously with adjacent culverts.

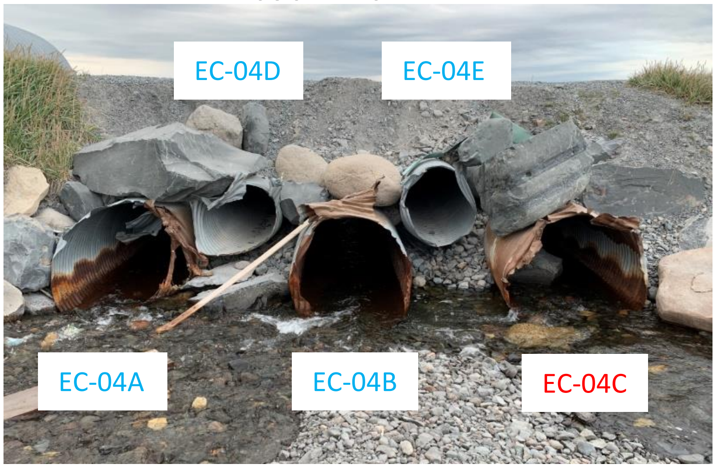
SOUTHEAST INLET



SOUTHEAST INLET

Culvert I.D.	EC-04B
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 1200 mm
Interior Condition	Fair - Moderate to severe corrosion (possible penetration) - Minor debris/sediment
Exterior/End Condition	Fair - Both ends are damaged/torn - End extension appears adequate
Embankment Condition	Poor - Erosion present on northwest side - Embankment appears to be too steep (minor collapse) - Large boulders surround culvert ends; could cause further damage and do not protect against erosion well
Ditch Conditions	Good - Good stone bottom to protect from erosion upstream and downstream - Some debris present
Comments/Recommendations	Culvert is in working order and does not impede water flow. Condition is deteriorating and may require replacement soon. Recommend replacement simultaneously with adjacent culverts.

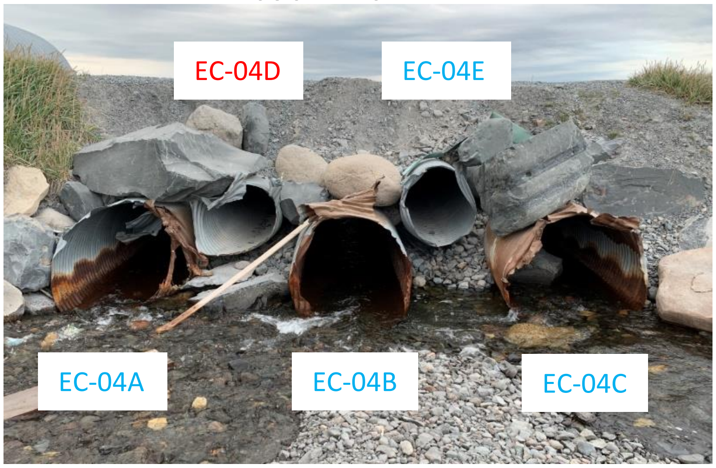
SOUTHEAST INLET



NORTHWEST OUTLET

Culvert I.D.	EC-04C
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 1200 mm
Interior Condition	Fair - Moderate to severe corrosion (possible penetration) - Minor debris/sediment
Exterior/End Condition	Poor - Both ends are damaged/torn (CSP unravelling) - End extension appears adequate
Embankment Condition	Poor - Erosion present on northwest side - Embankment appears to be too steep (minor collapse) - Large boulders surround culvert ends; could cause further damage and do not protect against erosion well
Ditch Conditions	Good - Good stone bottom to protect from erosion upstream and downstream - Some debris present
Comments/Recommendations	Culvert is in working order and does not impede water flow. Condition is deteriorating and may require replacement soon. Recommend replacement simultaneously with adjacent culverts.

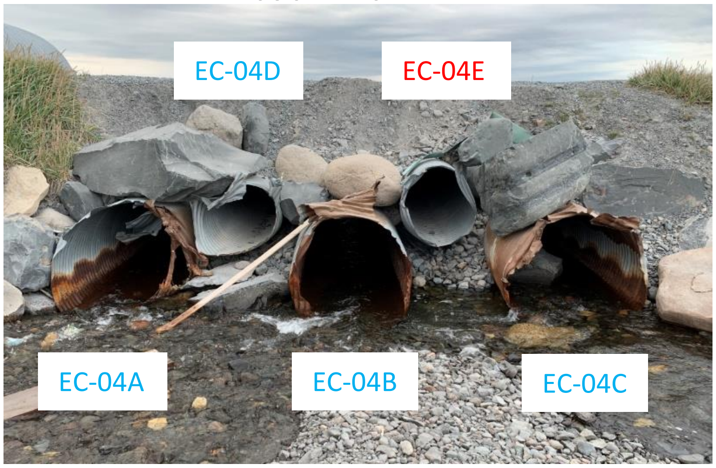
SOUTHEAST INLET



SOUTHEAST INLET

Culvert I.D.	EC-04D
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 800 mm
Interior Condition	Good - No corrosion or sediment/debris present
Exterior/End Condition	Poor - Both ends are damaged/torn (CSP unravelling) - End extension appears adequate - Portion of North outlet end has been bent upwards (may impede flow)
Embankment Condition	Poor - Erosion present on northwest side - Embankment appears to be too steep (minor collapse) - Large boulders surround culvert ends; could cause further damage and do not protect against erosion well
Ditch Conditions	Good - Good stone bottom to protect from erosion upstream and downstream - Some debris present
Comments/Recommendations	Culvert is in working order and appears to be used for secondary overflow. Material is in good condition and does not require replacement at this time, however, replacement is recommended simultaneously with adjacent culverts for ease of construction and consistency. Culvert ends could be repaired in the short term to help in the event of an overflow/back up.

SOUTHEAST INLET



SOUTHEAST INLET

Culvert I.D.	EC-04E
Upstream / Downstream	Southeast / Northwest
Material / Size	CSP / 800 mm
Interior Condition	Good - No corrosion or sediment/debris present
Exterior/End Condition	Poor - Both ends are damaged/torn (CSP unravelling) - End extension appears adequate - Portion of North outlet end has been bent upwards (may impede flow)
Embankment Condition	Poor - Erosion present on northwest side - Embankment appears to be too steep (minor collapse) - Large boulders surround culvert ends; could cause further damage and do not protect against erosion well
Ditch Conditions	Good - Good stone bottom to protect from erosion upstream and downstream - Some debris present
Comments/Recommendations	Culvert is in working order and appears to be used for secondary overflow. Material is in good condition and does not require replacement at this time, however, replacement is recommended simultaneously with adjacent culverts for ease of construction and consistency. Culvert ends could be repaired in the short term to help in the event of an overflow/back up.

CROSSING: X-05

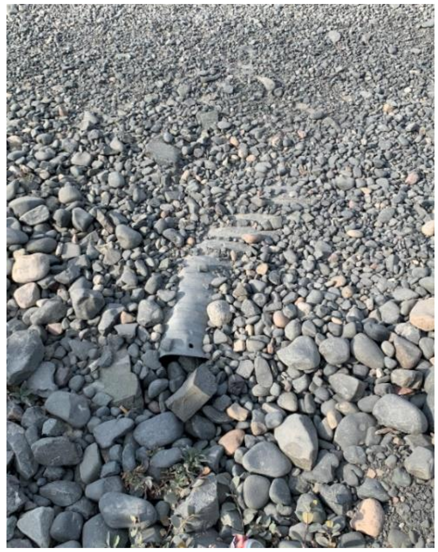
SOUTH END MISSING

Culvert I.D.	EC-05
Upstream / Downstream	South / North
Material / Size	CSP / 600 mm
Interior Condition	NA - Culvert is buried and/or possibly collapsed - South culvert end location is unknown
Exterior/End Condition	Poor - End extensions are not adequate - North outlet partially buried - South inlet completely buried - Likely damaged from vehicular traffic
Embankment Condition	NA
Ditch Conditions	Poor - Ditch is blocked by driveways - Some debris present
Comments/Recommendations	Roadside ditch should be regraded, and existing culverts should be replaced. Culvert should have adequate cover, and ends should be protected from vehicular traffic.

CROSSING: X-06

SOUTH INLET

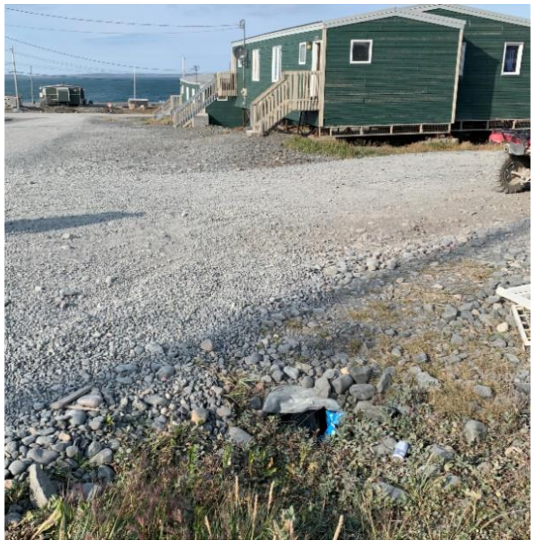
SOUTH INLET



Culvert I.D.	EC-06
Upstream / Downstream	South / North
Material / Size	CSP / Unknown
Interior Condition	NA - Culvert is 95-100% buried and/or possibly collapsed - South culvert end is visible and north end is unknown
Exterior/End Condition	Poor - Cover does not appear to be adequate - End extensions are not adequate - North outlet completely buried - South inlet almost completely buried - Likely damaged from vehicular traffic
Embankment Condition	NA
Ditch Conditions	Poor - Ditch likely ponds due to lack of drainage - Some debris present - Not adequate for proper water conveyance
Comments/Recommendations	Roadside ditch should be regraded, and existing culverts should be replaced. Culvert should have adequate cover, and ends should be protected from vehicular traffic.

CROSSING: X-07

SOUTH INLET



Culvert I.D.	EC-07
Upstream / Downstream	South / North
Material / Size	CSP / 600 mm
Interior Condition	NA - Culvert is 95-100% buried and/or possibly collapsed - South culvert end is visible and north end is unknown
Exterior/End Condition	Poor - Cover does not appear adequate - End extensions are not adequate - North outlet completely buried - South inlet almost completely buried - Likely damaged from vehicular traffic
Embankment Condition	NA
Ditch Conditions	Poor - Ditch likely ponds due to lack of drainage - Some debris present - Not adequate depth for water conveyance
Comments/Recommendations	Roadside ditch should be regraded, and existing culverts should be replaced. Culvert should have adequate cover, and ends should be protected from vehicular traffic.

CROSSING: X-08

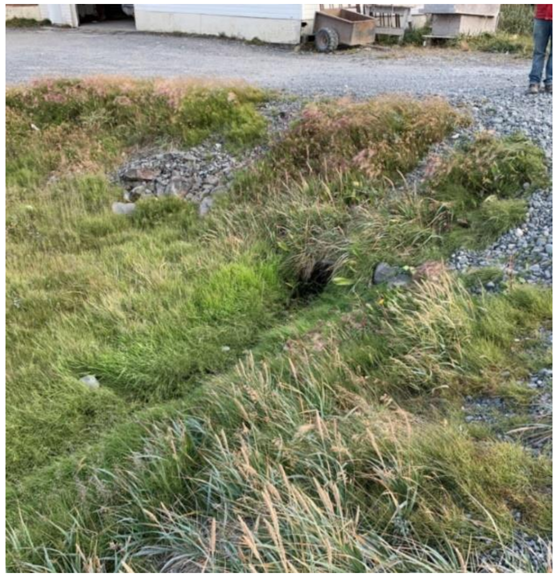
SOUTH INLET

Culvert I.D.	EC-08
Upstream / Downstream	South / North
Material / Size	CSP / 600 mm
Interior Condition	NA - Culvert is approximately 75% buried on the north outlet - South culvert end is visible but crushed from vehicular traffic
Exterior/End Condition	Poor - Cover does not appear adequate - End extensions are not adequate - South inlet crushed from vehicular traffic - North outlet partially buried
Embankment Condition	NA
Ditch Conditions	Poor - Ditch likely ponds due to lack of drainage - Some debris present - Not adequate depth for water conveyance
Comments/Recommendations	Roadside ditch should be regraded, and existing culverts should be replaced. Culvert should have adequate cover, and ends should be protected from vehicular traffic.

CROSSING: X-09

SOUTH INLET

NORTH OUTLET



Culvert I.D.	EC-09
Upstream / Downstream	South / North
Material / Size	CSP / 600 mm
Interior Condition	Fair - Culvert appears to be in working order - Some sediment and debris present
Exterior/End Condition	Fair - Cover does not appear adequate on the north end - End extensions are adequate but could be improved - Thick vegetation could cause blockages at culvert ends
Embankment Condition	Fair - Vegetation is present and will protect against erosion
Ditch Conditions	Fair - Vegetation is present and will protect against erosion - Appears to be adequate depth for water conveyance
Comments/Recommendations	Culvert is in fair condition and working order, and does not require replacement at this time. Replacement is recommended simultaneously with other driveway culvert replacements. Ditch should be protected with rip-rap or vegetation.

CROSSING: X-10

SOUTH INLET

INTERIOR

NORTH OUTLET

Culvert I.D.	EC-10
Upstream / Downstream	South / North
Material / Size	CSP / 900 mm
Interior Condition	Good - Some debris/sediment present - Material appears to be in good condition
Exterior/End Condition	Fair - Cover appears to be adequate but could be increased - South inlet is in good condition - North outlet is in poor condition; severe corrosion/penetration, and deformation
Embankment Condition	Good - Sloping is adequate to protect embankment - Rip-rap does not appear to be required
Ditch Conditions	Poor - Downsteam ditch is not well defined - Could be regraded to improve water conveyance
Comments/Recommendations	Culvert is in overall good condition and does not require replacement at this time, however, the north outlet should be repaired by removing the portion of corroded CSP and replaced with a new extension.

CROSSING: X-11

SOUTH INLET

SOUTH DITCH

NORTH OUTLET

Culvert I.D.	EC-11
Upstream / Downstream	South / North
Material / Size	CSP / 600 mm
Interior Condition	Good - Material shows little to no signs of corrosion or damage - Some sediment. Should not impede flow.
Exterior/End Condition	Good - Cover to road surface could be increased - Ends are in good condition with no signs of damage
Embankment Condition	Good - Sloping is adequate to protect embankment - Rip-rap does not appear to be required
Ditch Conditions	Poor - Downstream ditch is not well defined - Upstream ditch is not graded properly, and is filled with debris and blocked by a resident pathway
Comments/Recommendations	Culvert is in overall good condition and does not require replacement at this time. Ditches upstream and downstream should be repaired/regraded to ensure proper conveyance of water.

CROSSING: X-12

SOUTH INLET

NORTH OUTLET

Culvert I.D.	EC-12
Upstream / Downstream	South / North
Material / Size	CSP / 600 mm
Interior Condition	Fair - Minimal corrosion with some damage and sediment present
Exterior/End Condition	Poor - Cover appears to be adequate - North outlet is in good condition with only minor deformation - South inlet is crushed/damaged and possibly blocked with debris
Embankment Condition	Good - Sloping is adequate to protect embankment - Rip-rap does not appear to be required
Ditch Conditions	Poor - Downstream ditch is well defined - Upstream ditch is not graded properly, and is filled with debris and vegetation
Comments/Recommendations	Culvert inlet end is in poor condition. Replacement is likely not required, however, culvert ends should be repaired and extended. Ditching should be regraded, and debris should be removed. Culvert ends should be protected with rip-rap and markers should be installed to deter drivers from crushing the ends.

CROSSING: X-13

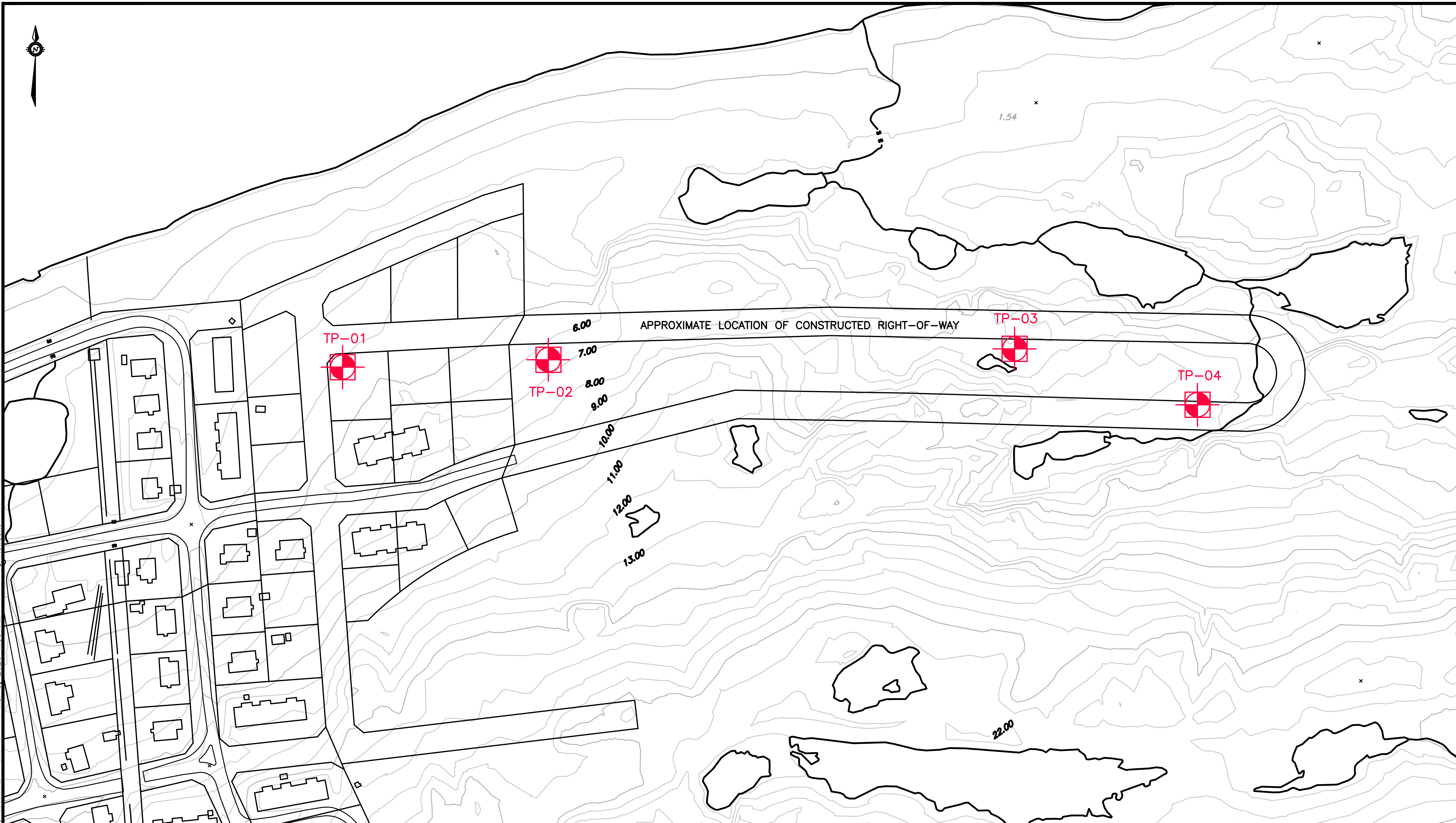
SOUTH DITCH

SOUTH INLET

INTERIOR

Culvert I.D.	EC-13
Upstream / Downstream	South / North
Material / Size	CSP / 800 mm
Interior Condition	Poor - Little to no corrosion, however, culvert is full of rocks, sediment and debris (approximately 40% full)
Exterior/End Condition	Fair - Cover appears to be adequate - End extensions are not adequate and may affect slope stability on the embankment
Embankment Condition	Fair - Sloping is fairly steep and may lead to minor collapse of the embankment - Rip-rap could help with slope protection
Ditch Conditions	Fair - Upstream and downstream ditches are well defined - Inlet ditches require cleaning due to build up of debris and sediment
Comments/Recommendations	Culvert is in working order with adequate cover, and material appears to be in good condition. Highly recommend cleaning out the full length of the culvert, extending the ends, protecting the embankments with rip rap and cleaning the upstream and downstream ditches. Due to the effort required to clean the culvert, replacement is recommended. Replace with 900mm size culvert minimum to be consistent with upstream culvert sizes.

Appendix D –
Geotechnical Mapping and Test Pit Data



exp Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

www.exp.com

DESIGN	EXP
DRAWN	JH
DATE	FEB 2020
FILE NO	255134-A0

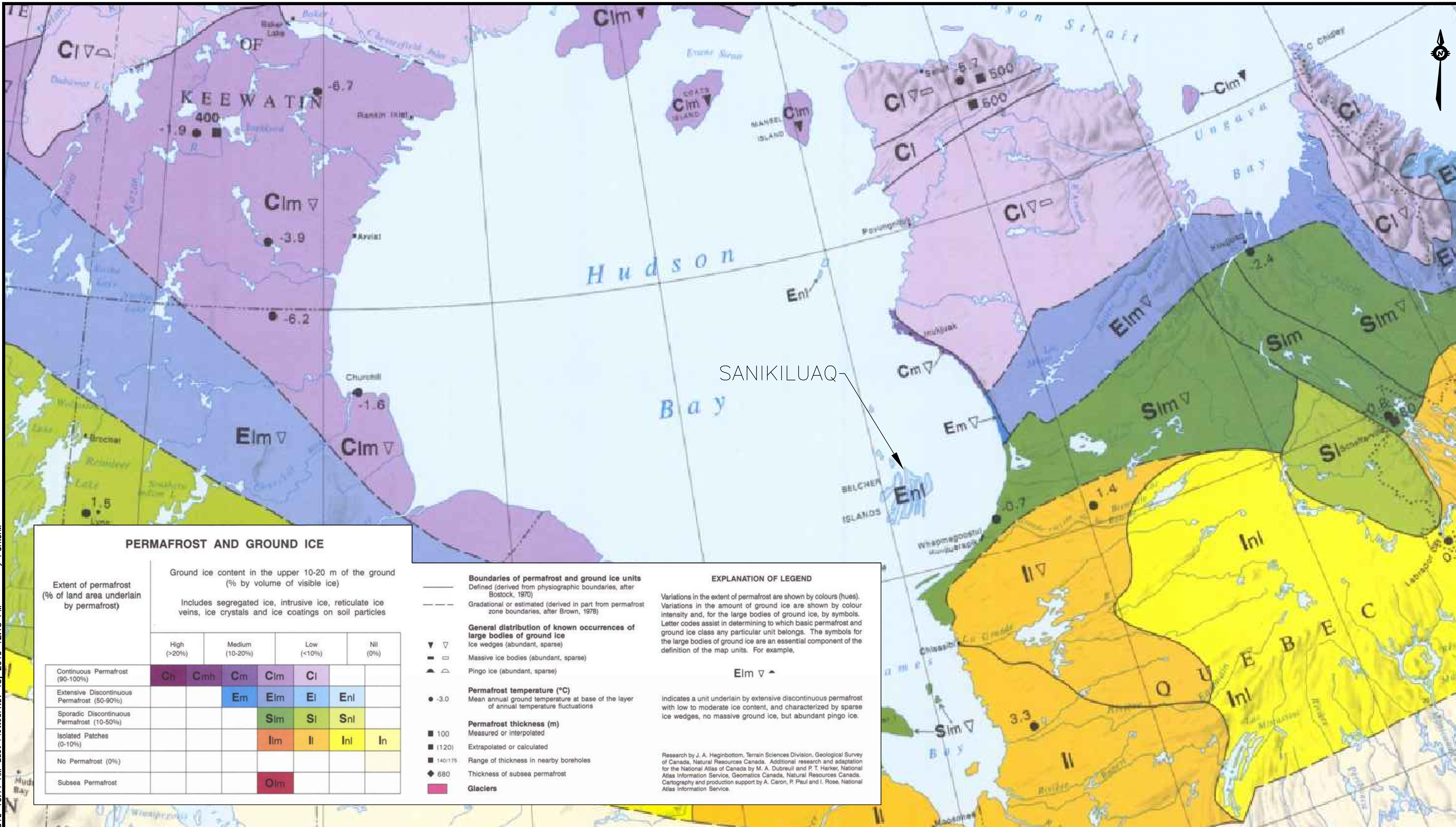
SANIKILUAQ DRAINAGE PLANNING
SANIKILUAQ, NU

TEST PIT LOCATION

SCALE 1:2000

SKETCH NO A02

Filename: P:\Projects\Civil\255000\OTT-00255134-A0 - Drainage Study - Sanikiluaq\60-EXECUTION\64-DWG\255134.dwg
Last Saved: Mar 5, 2020 1:47 PM Last Plotted: Mar 5, 2020 1:50 PM Plotted by: HewsonJ



PERMAFROST AND GROUND ICE

Ground ice content in the upper 10-20 m of the ground (% by volume of visible ice)

Includes segregated ice, intrusive ice, reticulate ice veins, ice crystals and ice coatings on soil particles

Extent of permafrost (% of land area underlain by permafrost)	High (>20%)		Medium (10-20%)		Low (<10%)		Nil (0%)	
Continuous Permafrost (90-100%)	Ch	Cmh	Cm	Clm	Cl			
Extensive Discontinuous Permafrost (50-90%)			Em	Elm	El	Enl		
Sporadic Discontinuous Permafrost (10-50%)				Slm	Sl	Snl		
Isolated Patches (0-10%)				Ilm	Il	Inl	In	
No Permafrost (0%)								
Subsea Permafrost				Olm				

Boundaries of permafrost and ground ice units

—— Defined (derived from physiographic boundaries, after Bostock, 1970)

— — — Gradational or estimated (derived in part from permafrost zone boundaries, after Brown, 1978)

General distribution of known occurrences of large bodies of ground ice

▼ ▽ Ice wedges (abundant, sparse)

▬ ▭ Massive ice bodies (abundant, sparse)

Pingo ice (abundant, sparse)

Permafrost temperature (°C)

● -3.0 Mean annual ground temperature at base of the layer of annual temperature fluctuations

Permafrost thickness (m)

■ 100 Measured or interpolated

■ (120) Extrapolated or calculated

■ 140/175 Range of thickness in nearby boreholes

◆ 680 Thickness of subsea permafrost

Glaciers

EXPLANATION OF LEGEND

Variations in the extent of permafrost are shown by colours (hues). Variations in the amount of ground ice are shown by colour intensity and, for the large bodies of ground ice, by symbols. Letter codes assist in determining to which basic permafrost and ground ice class any particular unit belongs. The symbols for the large bodies of ground ice are an essential component of the definition of the map units. For example,

Elm ▽

indicates a unit underlain by extensive discontinuous permafrost with low to moderate ice content, and characterized by sparse ice wedges, no massive ground ice, but abundant pingo ice.

Research by J. A. Heginbottom, Terrain Sciences Division, Geological Survey of Canada, Natural Resources Canada. Additional research and adaptation for the National Atlas of Canada by M. A. Dubreuil and P. T. Harker, National Atlas Information Service, Geomatics Canada, Natural Resources Canada. Cartography and production support by A. Caron, P. Paul and I. Rose, National Atlas Information Service.

exp Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6
www.exp.com

DESIGN	---	SANIKILUAQ GEOTECHNICAL INVESTIGATION AND DRAINAGE PLAN	SCALE N.T.S.
DRAWN	MNP		SKETCH NO
DATE	NOV 2019	CANADA PERMAFROST THE NATIONAL ATLAS OF CANADA 5TH EDITION	FIG 1
FILE NO	OTT-00255134-A0		

LEGEND

QUATERNARY

Q — Reworked glacial ground moraine: mud, silt, sand, and gravel, rare outcrops; abundant raised beaches, some in well-sorted stacks of cobbles or boulders with no matrix; scattered lenses of marine shells, rows of ice-shoved boulders-blocks outline former shoreline; abundant crag and tail and roche moutonnée structures; glacial erratics mostly Belcher Group-type lithologies, a few Paleozoic-, rare gneiss- and mafic-ultramafic-clasts; rare medial moraines and short eskers.

MIDDLE PALEOPROTEROZOIC

BELCHER GROUP

LOAF FORMATION (Molasse) (PBLl–PBL)

PBL — *Undivided (cross-section only).*

PBLu — *Upper Member: Mostly pink to red and grey arkose, thin- to very thick-bedded, abundant crossbeds, minor red shale; minor grey to olive green arkosic- and feldspathic-greywacke, siltstone, shale, argillite, undifferentiated siltstone and sandstone mostly in lower part; minor intraformational pebble- to boulder-conglomerate; minor ferruginous dolostone and dolostone conglomerate, increase upward in abundance; ripple marks; local slumps, small folds, channels, truncations.*

PBLl — *LowerMember: Mostly intergradational light- to medium-grey and grey-green, arkose, subarkose, arkosic wacke, feldspathic wacke, abundant crossbeds; minor shale, argillite, siltstone, pebble- to boulder-intraformational conglomerate lenses; dolostone and dolostone conglomerate, concretions common to locally abundant, scattered shale (clay?) fragments; local breccia; some interbeds and blotchy areas of pink to red shale and conglomerate in the upper part of the member, one conglomerate contains red sandstone boulders in a drab brownish olive green matrix; rare black sandstone and siltstone; some ripple marks, channels; rare anthraxolite. May include upper Omarolluk strata in some places.*

OMAROLLUK FORMATION (turbidite flysch) (PBOl–PBO)

PBO — *Undivided (cross-section only).*

PBOu / PBOud — *Upper (transition) Member: Similar lithiogies and colours to those of the lower member, but the ratio of sandstone to interbedded shale- argillite-silstone is commonly 1:1 or less in the easternmost islands; minor dolostone, dolostone breccia-conglomerate; a few thin, folded and/or brecciated, disturbed zones, one about 26 km. long east of Innetalling Island; a few thick, massive to faintly layered, debris-flow beds (PBOud) with rare, irregular-shaped, argillite-siltstone blocks; common ripple marks.*

PBOl — *Lower Member: In part black pyritiferous shale, tuff, volcanic sandstone at base; the rest is mostly dark grey to dark green feldspathic- and lithic-graywacke, minor arkosic graywacke; laminated to very thick-bedded; cyclicly interbedded with thin shale, slate, argillite (ratio about 10 - 3:1), a few tuff beds in lower part, minor thin intraformational conglomerate, local limestone, dolostone, carbonate conglomerate; sandstones contain less mafic material and slightly lighter coloured upward; rare anthraxolite abundant partial to complete Bouma cycles; common to abundant flutes, concretions, flute- and groove-casts, parting lineations and ripple marks; some flat-clast imbrication in channel deposits.*

LATE MAFIC INTRUSIONS

PMB — *Basalt dykes and possible sills; massive, dark greyish green to black, aphanitic to very fine-grained, sparse plagioclase phenocrysts; much altered in places to epidote and sericitized plagioclase with minor chlorite; sparse, feldspar-phyric, massive, medium grained Haig gabbro inclusions; noted only in southern Churchill Sound.*

FLAHERTY FORMATION (PBFc–PBF)

PBF — *Undifferentiated; Dark green-grey to light grey, amygdaloidal, pillowed, massive, aphanitic to fine-grained, continental tholeiitic basalt flows; common ropy, bulbous, brecciated tops; some medium grained plagioclase-phyric flows; mineral assemblages from both Eskimo and Flaherty flows include prehnite and pumpellyite, Flaherty flows slightly lower grade; minor interbedded volcanic breccia, tuff, lapilli tuff, pyroclastic flows, volcanic breccia, volcaniclastic debris flows, turbiditic mud flows, argillite (locally red), black slates, volcanic sandstone, chert, hornfels, limestone; quartz-calcite veins, some with chalcopyrite traces, are common and concentrated locally along the Innetalling Island Anticline axis; small basalt dykes and Haig sills occur in the lower part of the formation; several anthraxolite occurrances occur east of Omarolluk Peninsula; the formation thickens westward.*

PBFm — *Mostly massive basalt.*

PBFp — *Mostly pillowed basalt.*

PBFc — *Undivided pyroclastic, volcaniclastic, and sedimentary rocks as noted above, solid line is defined, dashed line is approximate-assumed.*

PBFb — *Mostly volcanic breccia.*

PBFf — *Mostly pyroclastic flows.*

HAIG INTRUSIONS

PBH — *Massive gabbro-diabase sills and dykes as much as 275 m. thick; dark-grey to greenish grey; aphanitic to coarse grained with a subophitic texture; common plagioclase phenocrysts as large as 2.5 cm across; some pinkish quartz-feldspar granophyre pockets and/or arkose inclusions; common bifurcations and a few composite sills.*

PBK — *KIPALU FORMATION: Comprises several intergradational zones, each composed mostly of one or two of: (a) laminated grey and green micrite (siderite, dolomite, serpentine), (b) laminated and massive red, brown, and grey feruginous argillite, local very fine- to fine-grained sandstone, (c) aphanitic to granular grey, green, and black chert, or red jasper containing lenses and nodules of iron carbonate; as much as 50% iron locally; contains possible microfossils; oids occur in some micrite and together with pisoliths in chert and jasper; most uppermost units are chert or jasper, overlain locally by ferruginous argillite-tuff-greywacke that grades up into Flaherty pyroclastics.*

PBM — *MUKPOLLO FORMATION: Mostly white to light grey quartz arenite, shaly feldspathic sandstones thin upward and are rare in upper part; the lower part is well-bedded with minor dolomitic sandstone near the base, a chert bed near the middle, minor dolostone lenses and pods and grey and purple siltstone near the top of the lower part; the siltstone contains small channels of quartz arenite and of basal lag conglomerate with quartz, chert dolostone and ironstone pebbles: the upper part is massive quartz arenite with rare mudstone partings, veined locally at the top by brown weathering iron carbonate; crossbeds, ripple marks, scours are more abundant and distinct in the lower than in the upper part.*

ROWATT FORMATION (PBRl–PBR)

PBR — *Undivided south from Eskimo Harbour where upper member dolostones are absent; crossbeds, scours, channels, and other sedimentary structures, present in most of the formation, are especially variable in the lower member.*

PBRu — *Upper Member: Mostly well interbedded, buff, stromatolitic, sandy grainstone, beachrock, and stromatolitic dololutite, variously folded and brecciated in zones up to 10 m thick; grainstone clasts are mostly dolomicrite of variable grain size and chert; interbedded sandstone sequences in the upper part grade upward from basal quartz arenite through dolarenite into brecciated and bedded dolostone; some large channels filled with dolomitic sandstone, grainstone.*

PBRl — *Lower Member: The basal zone is mostly quartz arenite and thinly interbedded mudstone, lenticular grainstone, beach rock at the top. The middle zone is mostly thick, thinly bedded units of partially slumped grey-green mudstone with thin interbeds of fine-grained sandstone, a few channel lag conglomerate lenses, thick coarse sandstone beds. The upper zone is mostly dolarenite with associated dolostone conglomerate, dololutite, beach rock, and sandstone; large, isolated lenticular dolostone bodies in the top part.*

LADDIE FORMATION (PBLa–PBLal)

PBLa — *Undivided.*

PBLau — *Upper Member: Thinly interbedded grey, red and green argillite and shale with grey, or orange and mauve lutite beds in the lower part and with a few dolulite- and lenticular sandstone-beds and a local soft sediment slump zone in the upper part.*

PBLal — *Lower member: Thinly bedded red argillite; minor calcilutite interbeds (some white); calcitic pods decrease in abundance upward.*

PBMC — *Undivided McLeary or Tukarak to Costello formations; includes dolostone, sandstone, mudstone, and green argillite.*

PBMCa — *Undivided Mavor and Costello formations; mostly along Kasegalik anticline where rocks are sheared and intruded by numerous Haig gabbro sills.*

PBC — *COSTELLO FORMATION: The basal unit ranges from black and grey shale to calcareous shale containing a massive biostromal dolostone horizon with local barite crystals. The rest of the formation is mostly rhythmically bedded, varicoloured, dololutite, calcarenite, calcilutite with shale partings; some graded dolosiltite beds in lower part; a distinct zone in the middle part contains partial Bouma cycles containing variously dolomitized sand size lutite clasts in calcareous cement, channel intraformational conglomerate, slump folds; upper part of the formation is mostly red argillite with calcite pods and some basal channel pebble conglomerate.*

PBMa — *MAVOR FORMATION: Mostly interbedded fine- to coarse-grained grey, pink, and tan, pale buff weathering, stromatolitic dolostone, wavy and crinkly dolostone cryptalgal laminites; thin, shaly, laminated dololutite in upper part; mound structures are common; contained stromatolites are mostly digitate, columnar, domal, and spherical types. Distinct, widespread, varicoloured coarse dolostone near the base of the formation contains abundant, plastically deformed, soft-sediment slump folds, bed pull-aparts, and brecciated zones. The entire formation comprises an extensive biostromal complex containing giant mounds on eastern Tukarak Island; sandy-, argillaceous-, and varicoloured-dolarenite, dolomitic limestone, beachrock, rosettes, chert nodules, pisolites, and thrombolite mounds occur elsewhere.*

TUKARAK FORMATION

PBT — *Upper Member: (a) Mostly very thinly interbedded red-reddish brown mudstone, dolomitic mudstone and buff dololutite; wavy-, lenticular-, corrugated- and flaser-bedding; stone rosette pavement; the upper zone includes buff dolostone beds with stromatolitic mounds and a distinctive crinkly and wavy, stylolitic dolostone bed. (b) Kasegalik anticline – Interbedded lithologies noted above are scarce, the lower zone is stromatolitic dolostone as on Tukarak Island and includes the crinkly dolostone marker bed; the upper zone is mostly laminated fine grained sandstone-mudstone and green-grey argillite, the latter dominates in southern Kasegalik Lake area.*
Lower Member: Commonly fine grained sandstone, dolomitic sandstone, grey shaly mudstone; local stromatolite mounds near the base, draped by thinly interbedded red and buff dololutite and mudstone; local stone rosettes, chert; red colour mostly absent and green argillite dominates in southern Kasegalik Lake area.

MCLEARY FORMATION (PBML–PBMLl)

PBML — *Undivided.*

PBMLu — *Upper Member: Lower zone is mostly thin bedded buff dololutite and dolarenite with sandstone beds and lenses in the lower part; various cryptalgal laminates, with black chert lenses and pods, increase in abundance upwards from the middle of the zone; in the middle zone, grey dolostone (some containing cryptalgal laminates, stromatolites, and stromatolite domes), increase in abundance upward as buff dololutite, dolarenite, and sandstone decrease; the upper zone is grey stromatolitic dolostone with a variety of stromatolites in dololutites, sandy dolarenite; chert is minor; the top unit is a regionally developed buff dolostone biostrome complex.*

PBMLm — *Middle Member: Mostly dolomitic quartz-rich sandstone-dolarenite (includes dolograinstone) cycles capped by beachrock beds, grey colours increase upward, minor quartz arenite, a few beds of dololutite and stromatolitic dolostone; upper zone is mostly interbedded dololutite and quartzose dolarenite; sparse gypsum casts and sulphate molds,– some contain barite. Includes PBMLl south of Eskimo Harbour and possibly elsewhere west of Omarolluk Sound.*

PBMLl — *Lower Member: Basal unit is most commonly a buff grainstone beachrock bed with small stromatolites at the top; overlain by thin bedded dololutite (some gypsum casts) with lenses of intraformational conglomerate containing edgewise-stacked clasts and stone rosette structures, minor intercalated siltstone and sandstone; local gypsum casts, dark chert with traces of chalcopyrite and pyrite in middle beds; some quartzarenite beds near the top. Is present and included in PBMLm south of Eskimo Harbour, but may be rare elsewhere west of Omarolluk Sound.*

FAIRWEATHER FORMATION (PBFal–PBFa)

PBFa — *Undivided.*

PBFau — *Upper Member: Mostly red and green siltstone and fine grained sandstone, cut by channels of sublitharenite and quartz arenite; tabular-bedded sandstone is common in the upper 20 m on Tukarak Island and includes channel lag conglomerate and a few grit beds.*

PBFal — *Lower Member: Discontinuous lean, commonly red and green, ferruginous argillite and mudstone with thin bedded lean jasper iron-formation occur intermittently at the base on Tukarak Island and at the north end of Churchill Sound; a thin basalt flow or sill occurs locally near the base on the east side of the Tukarak Anticline; the rest of the lower part on Tukarak Island is mostly pisolitic dolostone with local algal mats and interbedded green and red mudstone, siltstone, sparse purple immature sandstone, local tuff; the upper part of the member contains shoaling up cycles, lower units are mostly basal quartz arenite and subarkose interbedded wit and overlain by siltstone, red shale; rare dolostone boulder conglomerate, truncated dololutite; the upper unit is distinctive buff pisolitic dolostone, with some mudstone and sandstone.*

ESKIMO FORMATION (PBEc–PBE)

PBE — *Mostly massive aphanitic to fine grained, aphyric, dark green to grey, amygdaloidal, continental, subaerial, tholeiitic basaltic flows; common red, brecciated tops; minor pillowed basalt (more common in the west), tuff, lapilli tuff, pyroclastics, agglomerate interbeds with local felsic and mafic bombs (some variolitic-spherulitic in the middle of the formation); minor sedimentary rocks include: red and green argillite in the lower and upper parts, chert, quartz arenite, fluvial arkosic graywacke, sandstone, conglomerate; local hyaloclastites; local iron-carbonate iron-formation below the top; gabbro sills (some plagiophyric) mostly at the base and near the top; volcanic prehnite-pumpellyite assemblages suggest subgreenschist metamorphic grade; the formation thickens north-northeastward.*

PBEm — *Mostly massive basalt.*

PBEp — *Mostly pillowed basalt.*

PBEc — *Mostly pyroclastics and tuffs and/or sedimentary rocks.*

PBKa — *KASEGALIK FORMATION: Five zones commonly present: (a) Lowermost zone contains grey dolostones with <20% interbedded red mudstones; minor dolomitic quartz sandstones, pink dolostones; (b) red mudstones >80% and grey dolostones. Zones (a) and (b) contain halite casts, sulphate molds; (c) light grey stromatolitic dolostones; (d) grey cherty stromatolitic dolostones, probable microfossils in dark grey-black chert; stromatolite mounds increase upward through zones (c) and (d) to 5 m in diameter; minor clastic dolostones include flat clast conglomerates, possible stone rosettes; (e) pink argillaceous dolostones with interbedded tuffs, red mudstones, limestones near top; green argillite at top in some places; brecciated, faulted, deformed along Kasegalik anticlinal axis.*

Geological contact (defined, approximate, assumed)

Primary layering, general trend (direction of dip known, unknown)

Sedimentary and primary igneous layering, tops known (inclined (tops up); vertical (tops always toward younger strata, away from axial plane of anticline, reverse in syncline); overturned (tops toward bend in tic line in anticline, reverse in syncline); horizontal (tops up))

Orientation of igneous contact

Generalized paleocurrent directions (from crossbeds (c), current ripple marks (r), volcanic flow tops (f))

Joint (inclined, vertical, horizontal)

Cleavage, shearing (inclined, vertical)

Plunge of small-scale parasitic drag folds (S, Z)

Plunge of small- to intermediate-scale fold axis

Axial plane of fold

Zone of contortion

Moraine

Lineament

Fault (defined, approximate, assumed) arrowheads indicate apparent relative horizontal separation

Axial trace of anticline, upright-inclined (defined, approximate) arrowhead indicates direction of plunge

Axial trace of syncline, upright-inclined (defined, approximate) arrowhead indicates direction of plunge

Positive aeromagnetic anomaly (nT nanotesla) — 7000 nT

Glacial striae (direction of movement indicated, undetermined)

Crossed striae (numbers indicate relative age, 1 being the oldest)

Rose diagram for glacial striae in the part of the map area indicated in the captions; N = number of measurements; those for which the direction of movement is known are shown individually — N = 38

Crag-and-tail (direction of movement indicated by bowed head)

Raised boashoe

Esker (arrowheads point in direction of flow)

Location for age determination sample 59JD58A = sample number and station number

Uranium-lead method — u

K-Ar whole rock method — WK

Haig sill — h

Pillow core — c

Rim — r

Younger dyke — d

Photograph location and figure number

Mineral occurrence — Cu

Anthraxolite (see Figure 49b) — a1-7

Barite — br

Copper minerals, mainly chalcopyrite, malachite; local bornite, covellite — Cu

Halite casts, molds — ha

Sulphides, mainly pyrite, minor pyrrhotite — s

Sulphate molds — sl

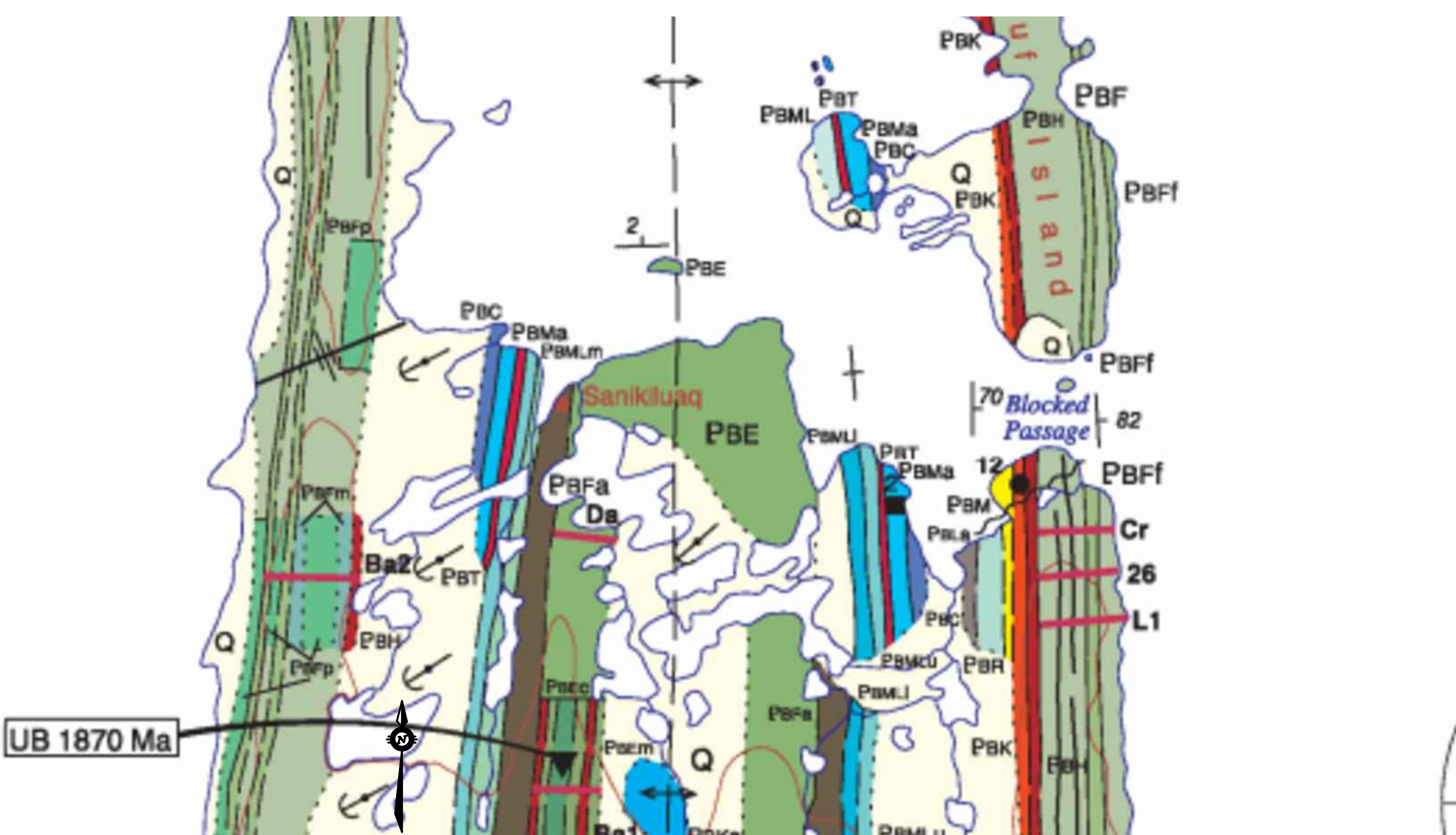
Cross-section line — A B

Kipalu Formation sections 1–13; see Tables 1 and 4, Figure 31, Figure 32, and Appendix 1; for chemical analyses see Appendix 2 Table 1

Sample sites of analysed Kipalu iron-formation samples (see Appendices 1–3, Table 4) — 56JD192

Eskimo and Flaherty sections referred to from the Literature or information used from (see also tables 1 and 4): Baragar, 2007 - Ba1, Ba2; Legault et al., 1994 - Jy, Ft, Da, Cr, Pw, Tk; Leggett, 1974 - L1; Ricketts, 1979; Ricketts et al., 1982 - 17, 20b, 20d, 26; Schenk, 1959 - S; Ware, 1978 and Ricketts, 1979 - W3, W5, W7a, W7b

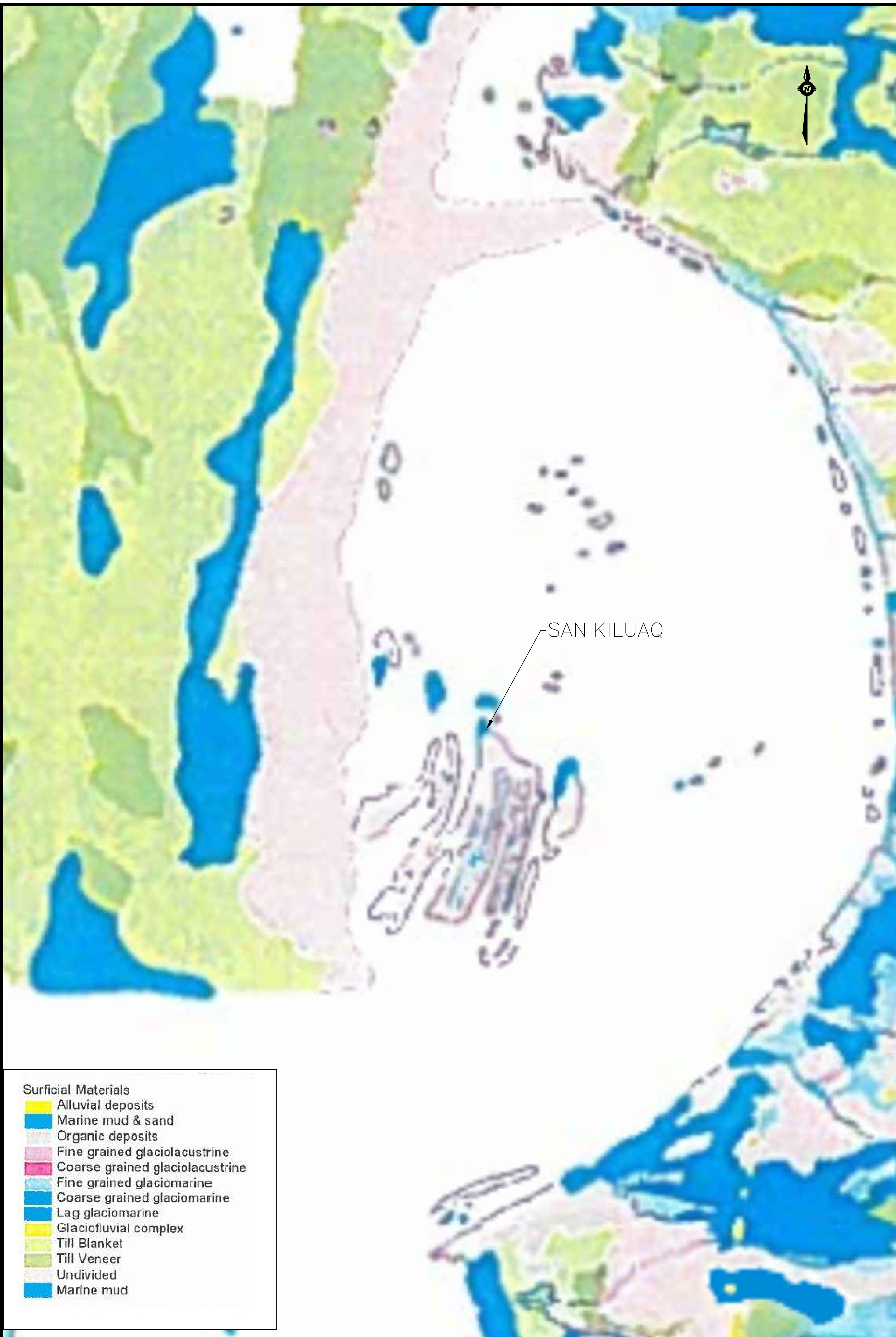
Note: Some structural symbols on the map have been placed over water, nearest possible to the actual location of measurements.



exp Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6
www.exp.com

DESIGN: ---	SANIKILUAQ		SCALE: N.T.S.
DRAWN: MNP	GEOTECHNICAL INVESTIGATION AND DRAINAGE PLAN		SKETCH NO
DATE: NOV 2019	BELCHER ISLANDS GEOLOGY MAP		FIG 2
FILE NO: OTT-00255134-A0			

Filename: C:\Users\ParkerM\Desktop\Sanikiluaq – Permafrost map.dwg
Last Saved: Nov 12, 2019 10:11 AM Last Plotted: Nov 13, 2019 11:39 AM Plotted by: ParkerM



exp Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6
www.exp.com

exp.

DESIGN	---
DRAWN	MNP
DATE	NOV 2019
FILE NO	OTT-00255134-A0

SANIKILUAQ
GEOTECHNICAL INVESTIGATION AND DRAINAGE PLAN

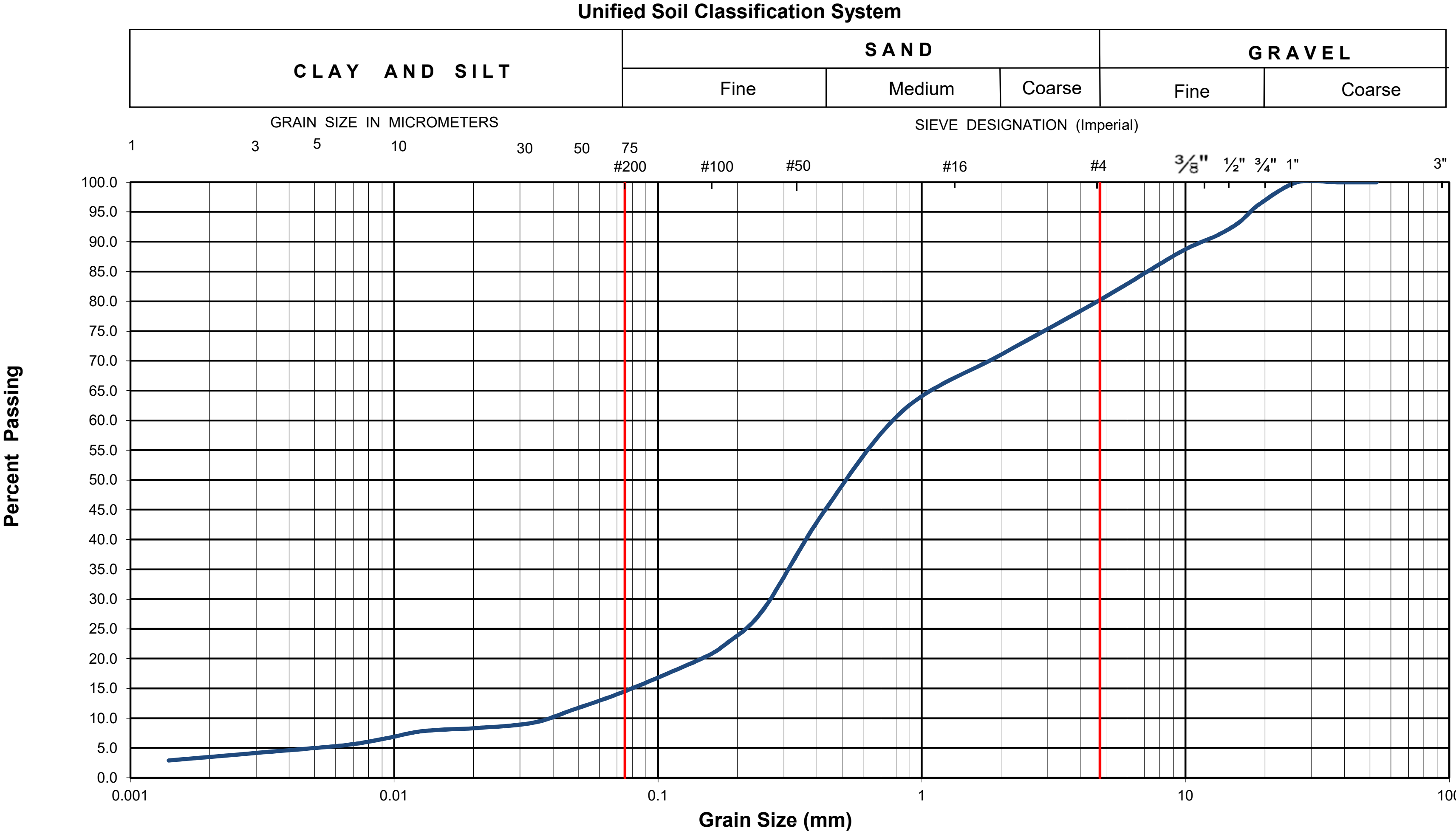
BELCHER ISLANDS SURFICIAL MAP

SCALE N.T.S.
SKETCH NO
FIG 3

Filename: C:\Users\ParkerM\Desktop\Sanikiluaq – Permafrost map.dwg Plotted by: ParkerM
Last Saved: Nov 12, 2019 10:11 AM Last Plotted: Nov 13, 2019 9:44 AM

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

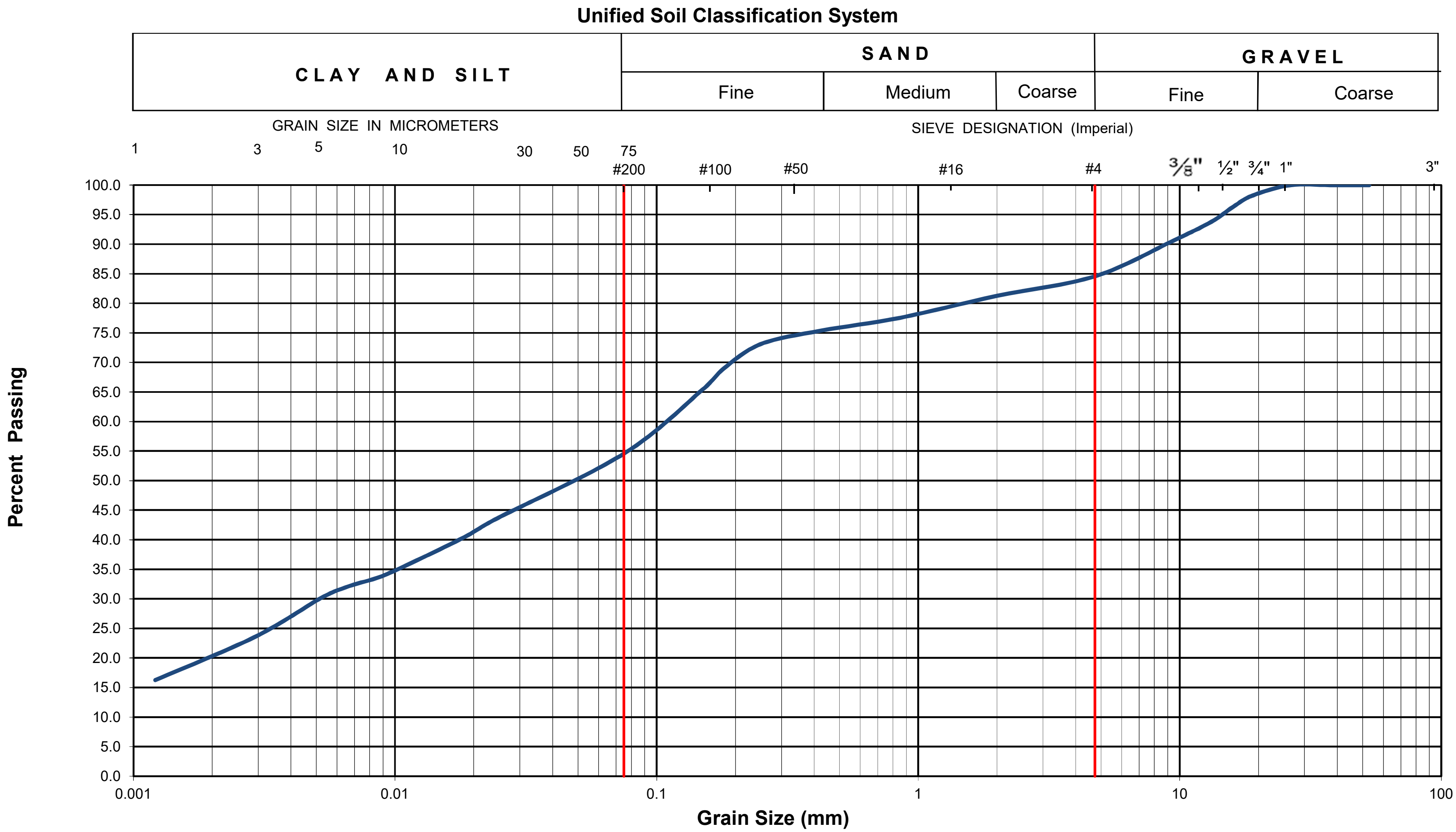
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-00255134	Project Name :	Geotechnical Investigation - Sanikiluaq				
Client :	N/S	Project Location :	Sanikiluaq				
Date Sampled :	October 7, 2019	Borehole No:	TP1	Sample No.:	S2	Depth (m) :	0.3
Sample Description :		% Silt and Clay 15	% Sand	65	% Gravel 20	Figure :	xxxx
Sample Description :	Silty Sand some Gravel (SM)						

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

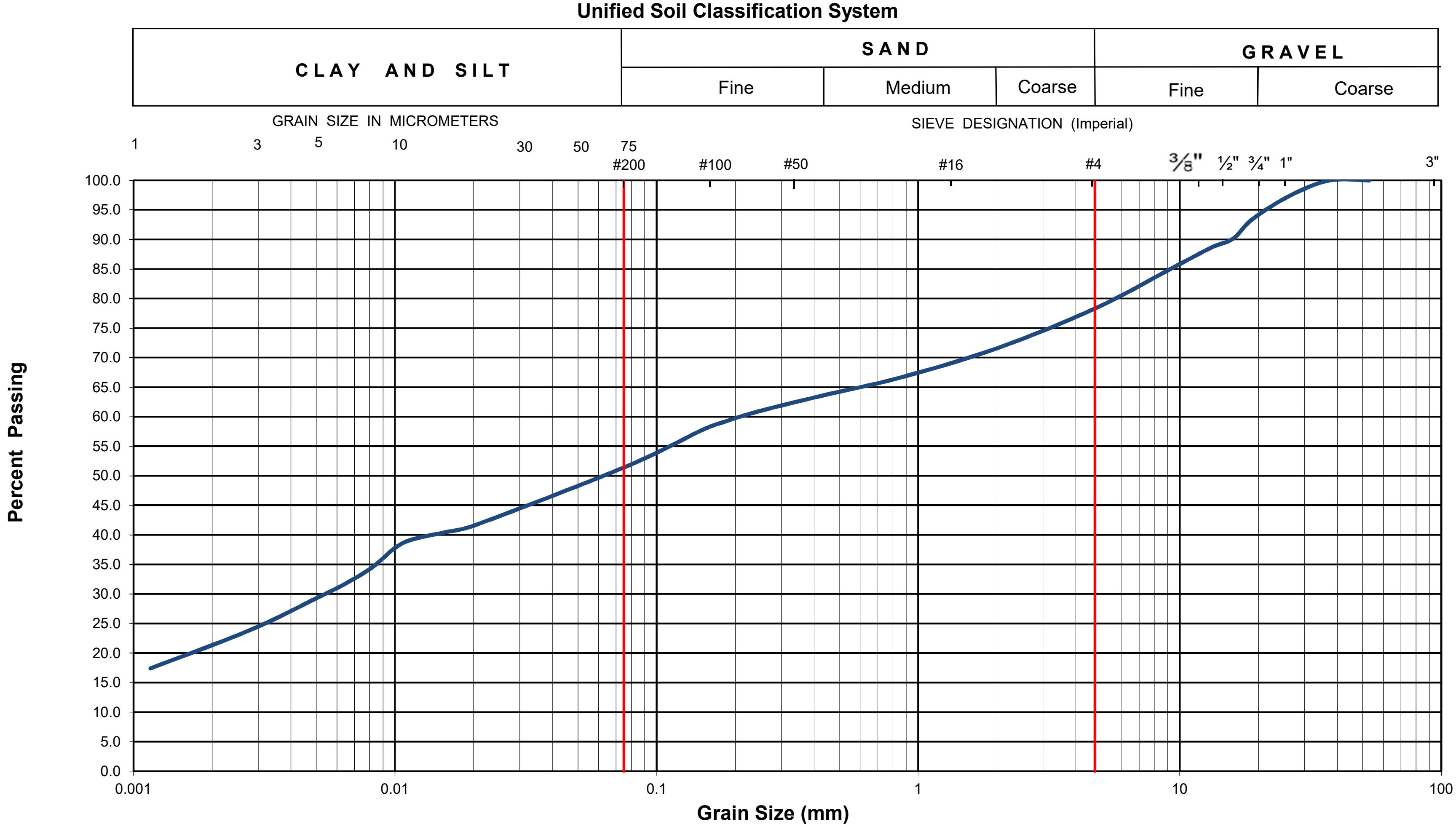
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-00255134	Project Name :	Geotechnical Investigation - Sanikiluaq				
Client :	N/S	Project Location :	Sanikiluaq				
Date Sampled :	October 7, 2019	Borehole No:	TP2	Sample No.:	SS3	Depth (m) :	0.8
Sample Description :		% Silt and Clay	55	% Sand	30	% Gravel	15
Sample Description :	Silty Clay, Low Plasticity (CL or ML)					Figure :	xxxx

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

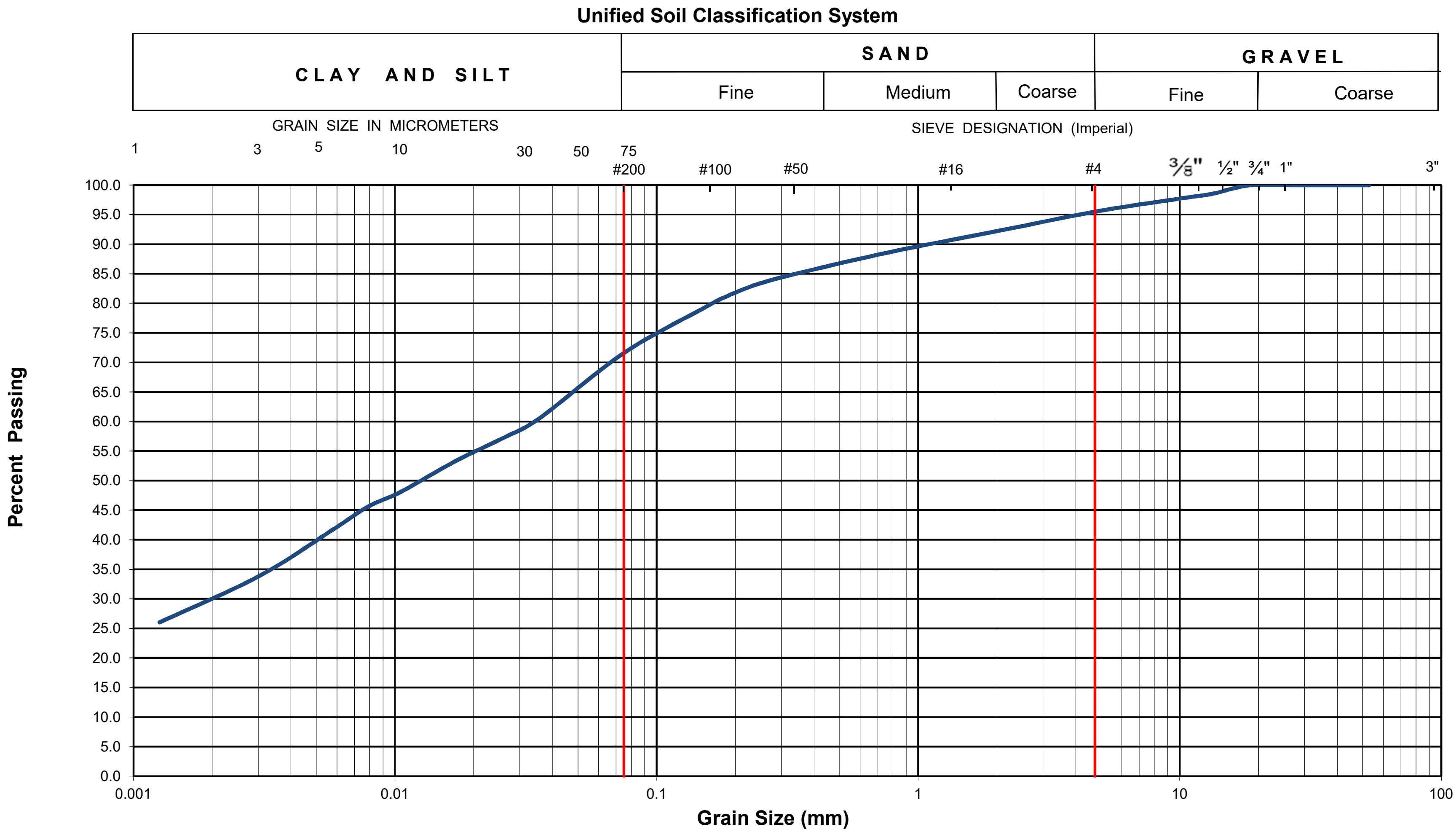
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	**OTT-00255134**	**Project Name :**	**Geotechnical Investigation - Sanikiluaq**				
Client :	**N/S**	**Project Location :**	**Sanikiluaq**				
Date Sampled :	**October 7, 2019**	**Borehole No:**	**TP3**	**Sample No.:**	**SS4**	**Depth (m) :**	**0.3**
Sample Description :		**% Silt and Clay** 51	**% Sand**	27	**% Gravel** 22	**Figure :**	**xxxx**
Sample Description :	**Low Plasticity Silt & Clay (CL)**						

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

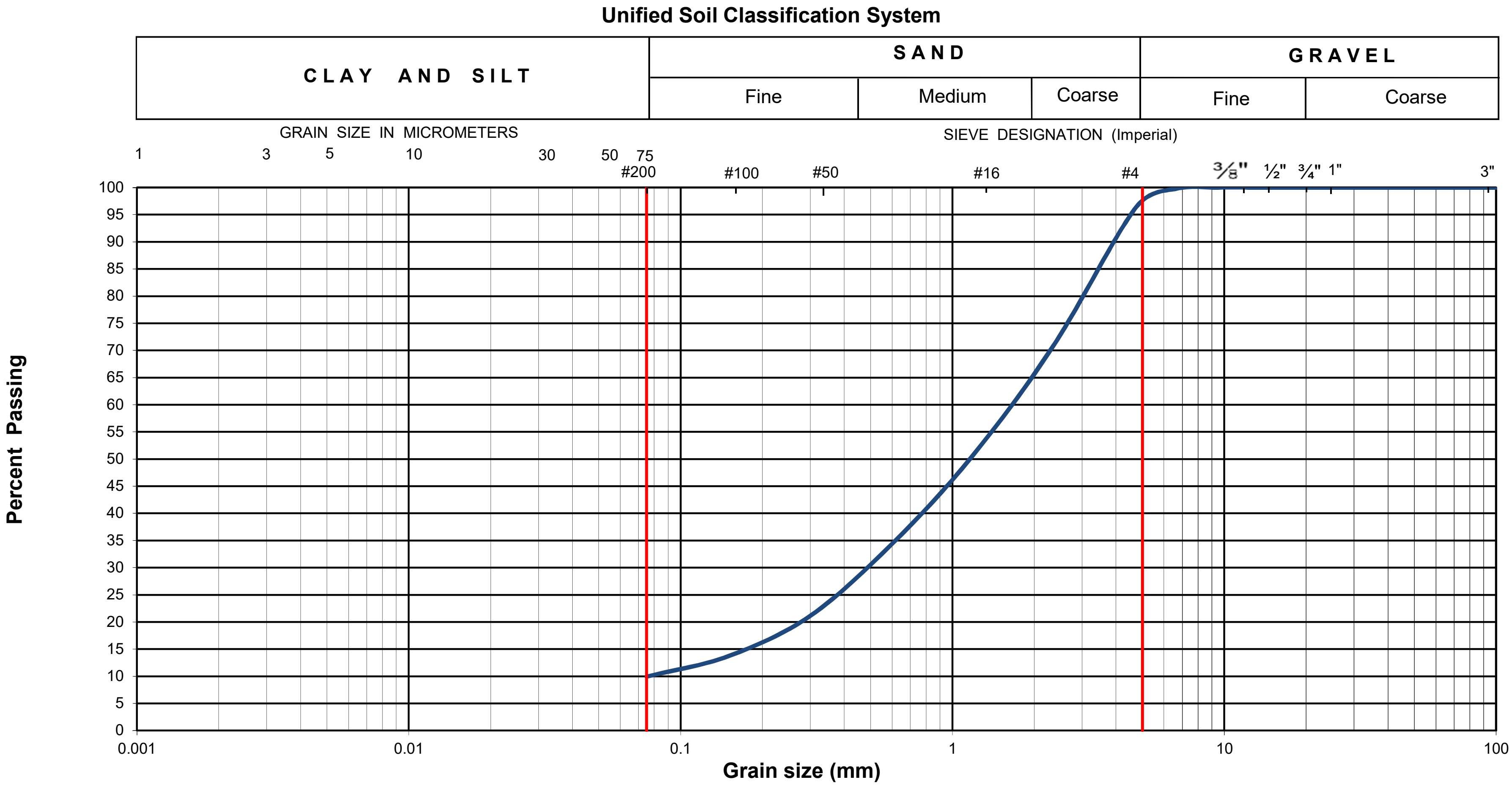
Grain-Size Distribution Curve
Method of Test For Particle Size Analysis of Soil
ASTM C-136/ASTM D422



EXP Project No.:	OTT-00255134	Project Name :	Geotechnical Investigation - Sanikiluaq					
Client :	N/S	Project Location :	Sanikiluaq					
Date Sampled :	October 7, 2019	Borehole No:	TP4		Sample No.:	SS5	Depth (m) :	0.9
Sample Description :		% Silt and Clay	72	% Sand	24	% Gravel	4	Figure : xxxx
Sample Description :	Low Plasticity Silt & Clay (CL)							

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

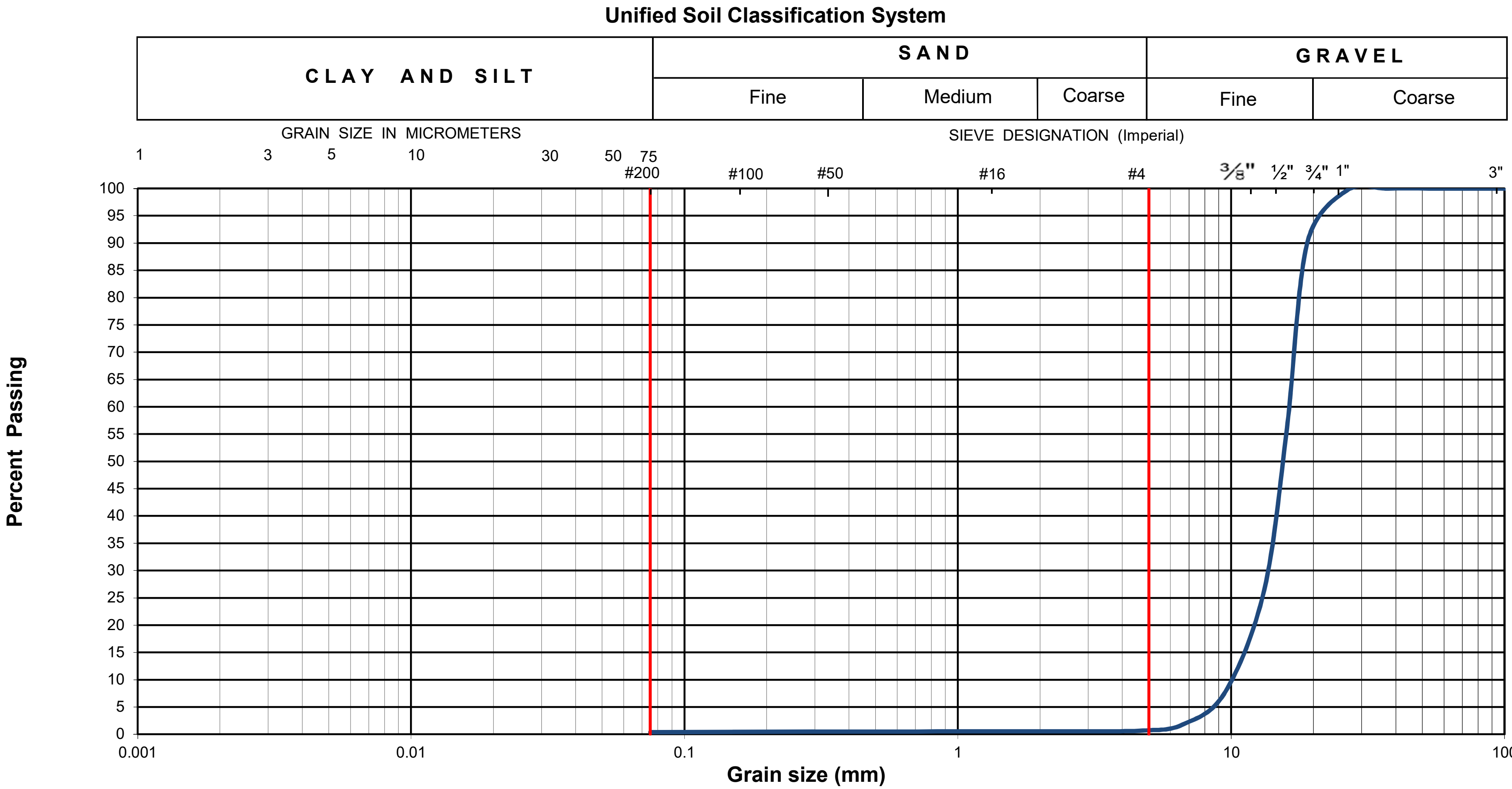
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	**OTT-00255134**	**Project Name :**	**Geotechnical Investigation Sanikiluaq**					
Client :	**N/S**	**Project Location :**	**Sanikiluaq**					
Date Sampled :	**September 19, 2019**	**Borehole No:**	**N/A**	**Sample:**	**N/A**		**Depth (m) :**	**0**
Sample Composition :		**Gravel (%)**	**4**	**Sand (%)**	**86**	**Silt & Clay (%)** **10**	**Figure :**	**xxx**
Sample Description :	**Well Graded Sand (SW)**							

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

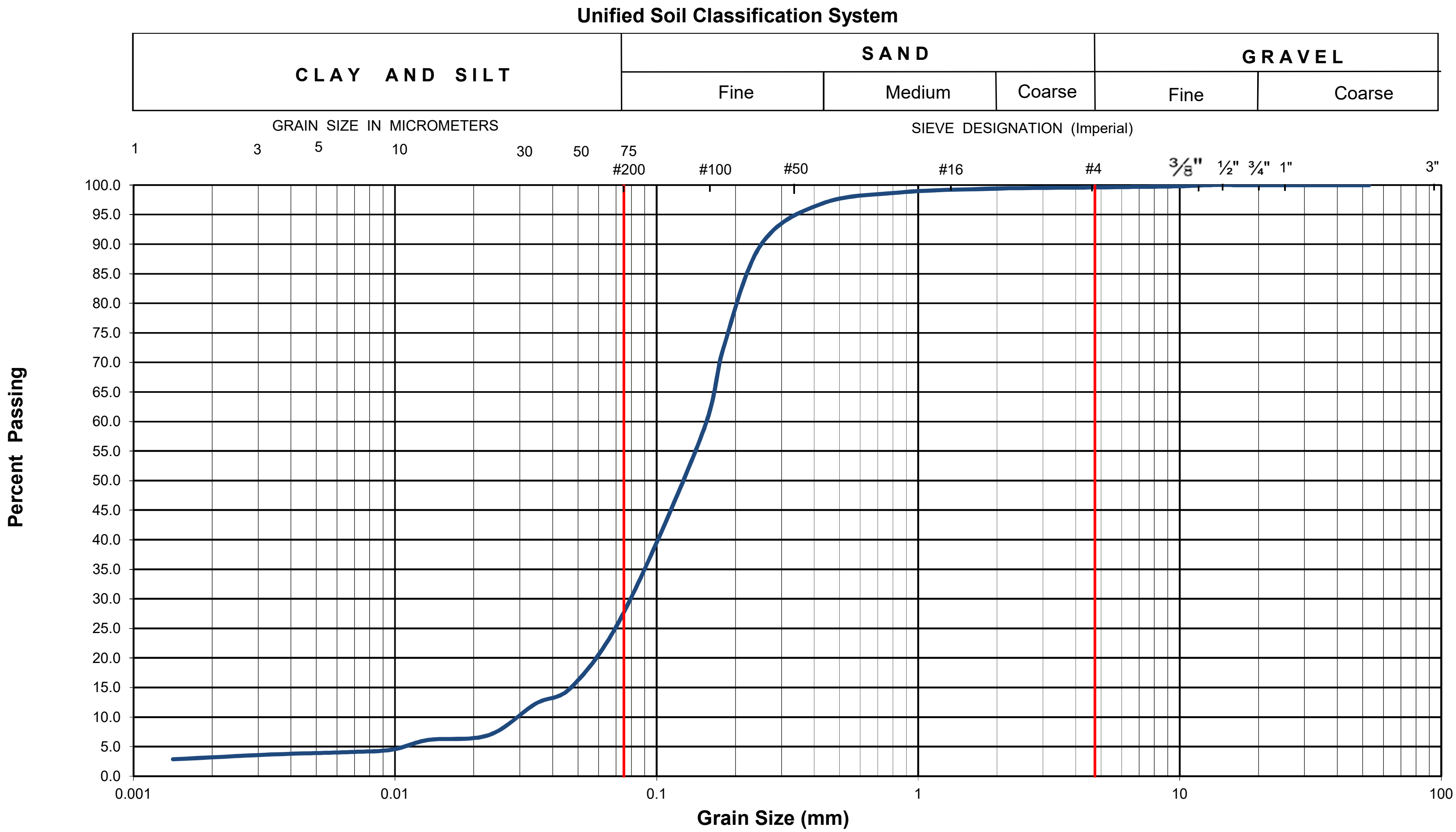
Grain-Size Distribution Curve
Method of Test For Sieve Analysis of Aggregate
ASTM C-136



EXP Project No.:	OTT-00255134	Project Name :	Geotechnical Investigation Sanikiluaq				
Client :	N/S	Project Location :	Sanikiluaq				
Date Sampled :	September 19, 2019	Borehole No:	N/A	Sample:	N/A	Depth (m) :	0
Sample Composition :		Gravel (%)	99	Sand (%)	1	Silt & Clay (%)	0
Sample Description :	Poorly Graded Gravel (GP)					Figure :	xxx

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

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



EXP Project No.:	OTT-00255134	Project Name :	Geotechnical Investigation - Sanikiluaq				
Client :	N/S	Project Location :	Sanikiluaq				
Date Sampled :	October 7, 2019	Borehole No:	Surface	Sample No.:	SS1	Depth (m) :	N/A
Sample Description :		% Silt and Clay	28	% Sand	72	% Gravel	0
Sample Description :	Silty Sand (SM)					Figure :	xxxx

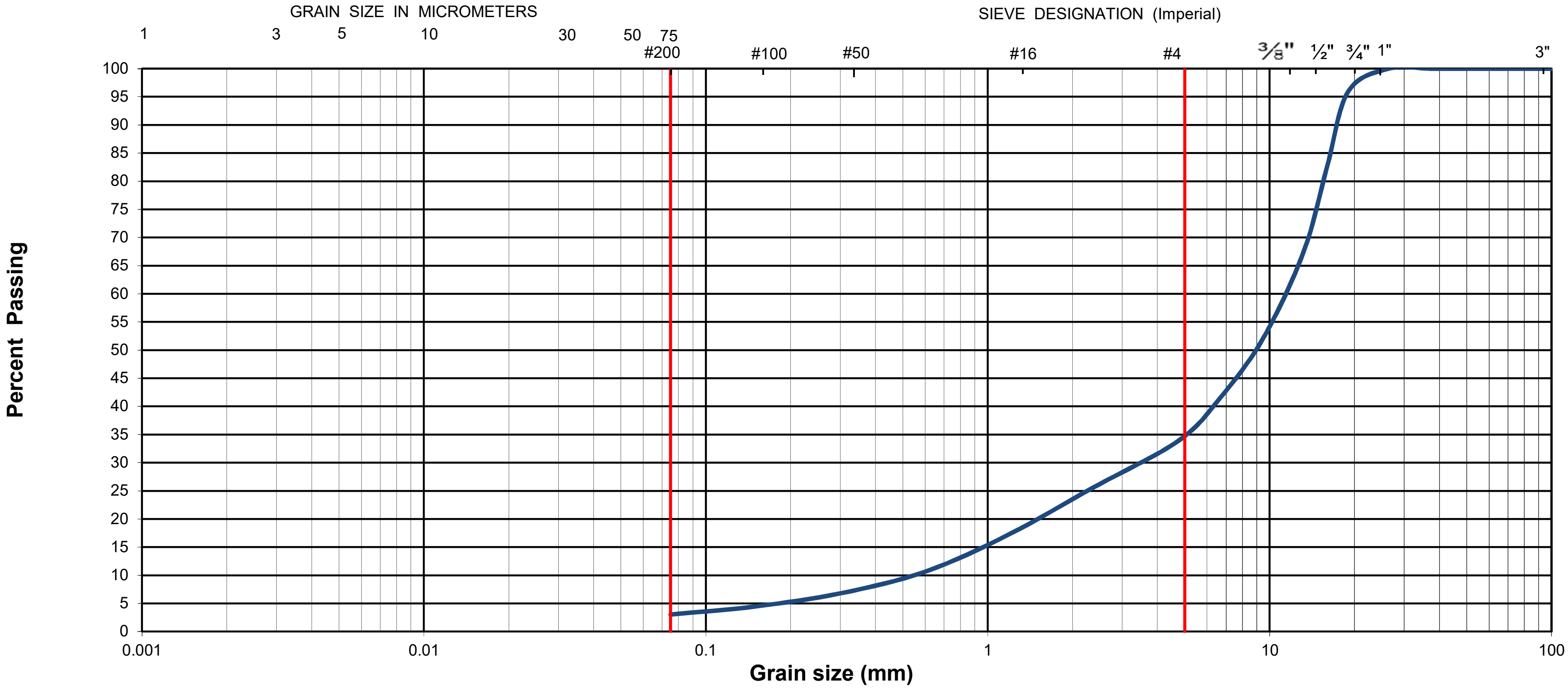
exp.

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

EXP Services Inc.
100-2650 Queensview Drive
Ottawa, ON K2B 8H6

Unified Soil Classification System

CLAY AND SILT	SAND			GRAVEL	
	Fine	Medium	Coarse	Fine	Coarse



EXP Project No.:	**OTT-00255134**	**Project Name :**	**Geotechnical Investigation Sanikiluaq**					
Client :	**N/S**	**Project Location :**	**Sanikiluaq**					
Date Sampled :	**September 19, 2019**	**Borehole No:**	**N/A**	**Sample:**	**N/A**		**Depth (m) :**	**0**
Sample Composition :		**Gravel (%)**	**66**	**Sand (%)**	**31**	**Silt & Clay (%)**	**3**	**Figure :** **xxx**
Sample Description :	**Well Graded Sandy Gravel (GW)**							