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Geotechnical Investigation
Sewage Lagoon
City of Iqaluit, Nunavut

Prepared for:

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Executive Summary

A geotechnical investigation was undertaken at the site of the sewage lagoon located in the west part of the City of Iqaluit south of the airport runway. This work was authorized by the City of Iqaluit via letter dated July 10, 2003. The purpose of the investigation was to undertake a topographic survey of the lagoon and slope stability analysis of the slopes of the berms. A detailed hydrologic analysis of the structure was also required and has been discussed in a separate report.

The investigation comprised the drilling of eight borehole to 2.2 m to 5.4 m depth from the crest of the east, southeast and west dykes of the lagoon. The investigation revealed that the berms comprise of sand and gravel fill which extends to a depth of 1.4 m to 2.9 m (Elevation 4.2 m to 5.9 m). The fill was frozen below 1.1 m to 1.4 m depth. The unfrozen portion of the fill was loose to compact ('N' values of 4 to 13). Its effective angle of internal friction was determined to be 44 degrees.

The fill in Boreholes 1 and 2 was underlain by silty sand to sand to a depth of 2.7 m to 5.7 m. A direct shear strength test performed on this stratum gave an effective angle of internal friction of 42 degrees. The fill in Boreholes 3, 5 and 7 was underlain by a layer of silt which extends to a depth of 2 m to 2.8 m (Elevation 4.4 m to 5.2 m). The fill in Boreholes 5 and 8 and the silt in Borehole 6 and 7 are underlain by sand and gravel stratum which extends to the entire depth investigated in Boreholes 5 to 7 (i.e. 2.8 m to 3.5 m) and to a depth of 3.3 m (Elevation 4.1 m) in Borehole 8. The sand and gravel stratum has an effective angle of internal friction of 44 degrees. This stratum in Borehole 8 is underlain by silty sand to 4 m depth (Elevation 3.4 m). The silty sand in Boreholes 2 and 8 is underlain by silty sand till.

Water level was established at a depth of 0.9 m to 1.5 m below the crest of the berms in Borehole 1, 3, 5 and 8.

The upstream slopes of the east, southeast and west berms were analysed for steady state seepage and for rapid drawdown conditions. The downstream slopes of the berms were analysed for steady state seepage conditions. In addition, the downstream slope of the west dyke was also analyzed for weakened soil due to spring thaw with high phreatic surface due to icing at the toe of the berm.

The Canadian Dam Safety Guidelines require a minimum factor of safety of 1.5 for the downstream slopes under steady seepage conditions. The computed factor of safety for the three berms varied from 1.9 to 2.4. Similarly, the Dam Safety Guidelines require a minimum factor of safety of 1.2 to 1.3 for the upstream slopes under rapid drawdown conditions. The computed factors of safety were 1.3 to 1.4. Based on the results of the analysis, it is concluded that adequate factors of safety are available to satisfy the Dam Safety Guidelines for the steady state seepage and rapid drawdown conditions.

It is noted that the west berm has breached in the past on a number of occasions. The breach of the berm was likely due to overtopping due to spring runoff, undermining the toe of the downstream slope by tidal fluctuations and blockage of the drainage path due to formation of ice lenses in the bottom part of the berm resulting in higher than normal phreatic line in the berm. Stability of slope analysis was undertaken for the latter condition assuming that the phreatic line in the west berm would be at the same level as the water level in the lagoon. A factor of safety of 1.1 was computed for this condition. The United States Federal Register 1977 indicates that a factor of safety of 1.0 is acceptable for these conditions.

It is concluded that the slopes of the berms of the lagoon are expected to be stable as long as the berms are protected against overtopping and adequate erosion protection is provided to the downstream slope of the west berm. Therefore a catastrophic failure of the berm is unlikely. However, localized failures or seep are expected to continue unless the lagoon is lined with an impervious liner.

Remedial measures should consist of preventing overtopping of the structure by construction of a spillway of adequate capacity to accommodate peak run off during spring thaw. In addition, adequate toe protection should be provided to the downstream slope of the west dyke to prevent erosion.

The above and other related considerations are discussed in a greater detail in the body of the report.

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1.0 Introduction

Trow Associates was retained by the City of Iqaluit to undertake a geotechnical investigation at the site of the sewage lagoon located south of the Iqaluit Airport Runway in the City of Iqaluit, Nunavut. This work was authorized by the City via letter dated July 10, 2003.

The purpose of the investigation was to obtain additional information to assess the condition of the sewage lagoon dykes in order to meet the requirements of the Canadian Dam Safety Guidelines. This information includes:

(a)   A detailed topographic survey of the lagoon and the dyke structures,

(b)   A detailed geotechnical program involving boreholes to assess the integrity and material properties of the dyke structures and their foundations, and installation of piezometers to monitor phreatic levels within the dyke structures at various locations.

(c)   Development of as-built drawings with a detailed site plan and dyke cross sections at various locations indicating the geometry and material properties of the structures.

(d)   Detailed hydrologic analyses to more accurately assess the impact of flooding on lagoon levels in order to prevent potential overtopping conditions. Diversion schemes to prevent outside surface water from entering the lagoon need to be developed.

This report deals with the stability of the slopes of the berms of the lagoon. The results of the hydrologic study would be compiled in a separate report.

The comments and recommendations given in this report are based on the assumption that the above-described design concept will proceed into construction. If changes are made either in the design phase or during construction, this office must be retained to review these modifications. The result of this review may be a modification of our recommendations or it may require additional field or laboratory work to check whether the changes are acceptable from a geotechnical viewpoint.

2.0 History and Background

2.1. Sewage Lagoon

The existing sewage lagoon is located to the west of the City, and immediately south of the Iqaluit Airport runway, on the tidal plain at the head of Koojesse Inlet. The sewage lagoon was reportedly constructed at this location in 1978, with the design by Reinders Northern Engineering Ltd.

The sewage lagoon was formed by the construction of two main dykes that connect the northwestern shoreline to a natural island formation in the Inlet. The man-made structures form the east and west boundaries of the lagoon, while the north and south boundaries utilize the natural topography. A shorter dyke is located in the southeast corner of the lagoon and blocks a narrow gap between a small island and the main island acting as the southern barrier for the lagoon. The layout of the sewage lagoon as surveyed is shown on Drawing No. 1.

The original area and capacity of the lagoon are reported in the literature to be approximately 17,000 square meters and 32,000 cubic meters, respectively.

The dykes were designed as "leaky" dams, constructed of relatively pervious local sand and gravel materials designed to allow seepage and partial treatment of the effluent to occur. Typical cross sections through the west, east and southeast dykes as developed from the survey and geotechnical work under taken at the site are shown on Drawing No. 2.

2.2. History

It is reported that in 1981, a partial wash out of the north end of the west dyke occurred during high tide, which was subsequently repaired. The repair reportedly washed out again one month later.

According to the literature, the lagoon was the subject of investigative studies in 1983 and 1984, which proposed various upgrades, including the following:

- Lining of exterior slopes with filter cloth and rip-rap.

- Construction of an overflow (spillway) in the west dyke.

- Construction of a positive outlet control.

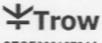- Installation of an impermeable liner on the interior slopes.

The berm were upgraded in 1983 which increased the capacity of the lagoon to approximately 56,000 cubic metres.

In 1987, the lagoon reportedly overflowed during the spring runoff and a portion of the west dyke was washed out. In June 1991, an 18 m wide breach of the west dyke occurred in the vicinity of the lagoon level control structure, resulting in a major effluent spill into Koojesse Inlet. The cause was again attributed to excessive surface runoff discharge into the lagoon during the spring runoff. Following repairs to the breach, a minor washout occurred in December 1991 at the lagoon overflow channel.

A preliminary engineering report by UMA Engineering Ltd. Dated July 1991, indicates that the previously recommended spillway and impermeable liner upgrades were not implemented and that as-built drawings for the previous upgrades could not be located. The 1991 report recommended specific repairs and improvement for the west dyke reconstruction area. These included erosion protection (filter cloth and rip-rap) on the upstream and downstream sides, section conformity (2H:1V and 3H:1V) slopes on the upstream and downstream sides respectively), and construction of a spillway section. The repaired section was intended to match the existing construction, maintaining the "leaky dam" concept.

In December 1991, a supplementary report by UMA which included a report by their sub-consultant Hardy BBT Limited, expressed concern over material suitability for the west dyke repairs (i.e. the silty sand and gravel placed was not sufficiently free-draining). These concerns prompted the recommendation to further flatten the slopes to 3H:1V and 4H:1V on the upstream and downstream sides, respectively, with rip-rap protection. If was recognized that the substitute material would be more susceptible to erosion and frost action, and the downstream slope of the dyke would be subjected to periodic wetting by tide level fluctuations. Slope stability analyses were carried out by Hardy to confirm the suitability of the above slope angles, assuming a variety of conditions, such as rapid drawdown, and rapid drawdown with thaw consolidation on the downstream ocean side, and low lagoon levels and thaw consolidation for the upstream side. Minimum factors of safety ranging from 1.4 to 1.9 for the upstream slopes and 1.8 to 2.7 for the downstream slopes were obtained, by Hardy BBT Limited depending on the pore pressure conditions assumed. Based on the results, Hardy considered the repaired dyke to have an appropriately conservative slope design and cross section. Recommendations were also provided for the design of the overflow spillway section, to be located further to the south along the crest of the west dyke.

In December 1997, significant high level seepage developed on the downstream face of the west dyke, 7 m to 17 m to the south of the outflow pipe and control vault, and beyond the section repaired previously by UMA. The seepage was investigated by Ferguson Simek Clark Engineers & Architects (FSC). The ice associated with the seepage was clear with a green colour. There was concern that the significant accumulation of ice and snow along the downstream face was blocking the internal drainage system of the dyke. Although the dyke was considered stable, recommendations were made in FSC's February 5, 1998 engineering report to increase monitoring, to develop a spill preparedness plan, and to maintain the lagoon at its lowest possible level. Without the ability to manage the accumulated ice cover along the downstream face at the toe drains and French drains, seeps could be expected to reoccur, depending on weather, snow

and ice conditions, and tide conditions. FSC report also recommended that surface runoff from outside the immediate watershed (i.e. airport and road side ditches) should be diverted away from the lagoon.

As a result of lowering the level of the sewage lagoon, the current retention volume was estimated to range from between 12,000 m^3 and 25,000 m^3, at operating water levels of 0.7 m and 1.5 m, respectively. The sewage production rate in 1998 was estimated at 1,800 m^3 per day, providing a retention time varying between 6.7 and 13.8 days. Sewage is transferred to the lagoon by gravity sewers, forcemains, and trucking.

In June 1998, a Spill Contingency Plan (ref 7) was prepared for the City of Iqaluit by Dillon Consulting Limited, which included a Sewage Lagoon Preparedness Plan. In that document, it is stated that City staff checks the sewage lagoon 5 days per week for lagoon level and leaks. If problems are suspected, the monitoring frequency increases to 7 days per week. It is recognized that the potential exists for further uncontrolled sewage releases due to dyke failure.

3.0 Methodology

3.1. Topographic Survey of Ponds

The topographic survey was undertaken by NorthTech Land Surveying and Engineering of Iqaluit, Nunavut. The survey was carried out using a combination of GPS and total station survey methods to define the location and geometry of the existing dykes. Cross sections of the berms were established at approximately 20 m intervals. In addition, an approximately 15 m to 20 m wide area around the detention lagoon was also surveyed except for the north east side of the lagoon. In this area, a more detailed topographic survey of the drains channels was geometry and material properties of the structures are given on Drawing Nos. 1 and 2 respectively.

4.0 Procedure

4.1. Drilling and Soil Sampling

The fieldwork for the geotechnical investigation was undertaken between July 21 and 26, 2003 with Hilti drill rig, winch and hammer. The fieldwork was supervised by a representative of Trow Associates Inc. (Trow) on a full time basis.

The fieldwork consisted of drilling 8 boreholes to depths varying between 2.2 m and 5.4 m. The locations of the boreholes are shown on Site Plan, Drawing 1.

The borehole were initially advanced by performing continuous standard penetration tests and retrieving the soil samples. However, the boreholes could only be advanced by this method in unfrozen soil to a depth of 1.1 m to 1.4 m below which frost was encountered. The boreholes were then cased and advanced by core drilling techniques with the Hilti drill rig. Dry coring was used to advance the boreholes and to retrieve the soil samples since wet coring would have resulted in washing out of the soil. As a result, the core barrel got blocked after short runs and had to be pulled out to retrieve the soil sample. The drilling progress was therefore very slow.

Water level observations were made in the boreholes during the course of the fieldwork. Standpipes were installed in selected boreholes to establish the groundwater table at the site. All the soil samples were visually examined in the field for textural classification, preserved in plastic bags and identified. The boreholes were logged. On completion of drilling, all the soil samples were transported to the Trow laboratory in the City of Ottawa (previously City of Nepean).

The locations and elevations of the boreholes were established by NorthTech Land Surveying and Engineering Limited. The elevations of the borehole refer to the Geodetic datum.

All the soil samples were visually examined in the laboratory by a geotechnical engineer and borehole logs prepared. The engineer also assigned the laboratory testing. The laboratory testing consisted of performing natural moisture content on all the samples and grain size analysis and direct triaxial shear tests on selected soil samples.

5.0 Site and Soil Description

The sewage lagoon is located close to the west end of the City of Iqaluit south of the Iqaluit Airport, on the tidal plain at the head of Koojesse Inlet. As indicated previously, the sewage lagoon was constructed by connecting the northwestern shoreline to a natural island formation in the Inlet by three dyke i.e. east, southeast and wet dykes. Survey work undertaken for this project indicates that the dykes are up to 3.5 m high with side slopes varying from 2.25H:1V to 4.8H:1V upstream and 2.9H:1V to 5.3H:1V on the downstream side. The exception to this is the downstream slope of the west dyke which is at an indication of 6.5H:1V to 9.4H to 1V. It is likely that this slope was flattened at the time of placement of rip-rap protection. The elevation of the crest of the dykes varies from Elevation 7.1 m to elevation 7.7 m. The crest width varies from 3.8 to 10 metres.

A detailed description of the subsurface and groundwater conditions encountered in the eight boreholes drilled at the site have been given in Borehole Logs, Drawings 4 to 12 inclusive. The boreholes logs and related information depict subsurface conditions only at the specific locations and time indicated. Subsurface conditions and water levels at other locations may differ from conditions at the locations where sampling was conducted. The passage of time also may result in changes in the conditions interpreted to exist at the locations where sampling was conducted. Boreholes were drilled to provide representation of subsurface conditions as part of a geotechnical exploration program and are not intended to provide evidence of potential environmental conditions.

A review of Drawings 3 to 10 indicates that the berms comprise of sand and gravel fill which extends to the entire depth investigated in Borehole 4 (2.6 m) and to a depth of 1.4 m to 2.9 m (Elevation 4.2 m to 5.9 m) in the other boreholes. The fill was frozen below 1.1 m to 1.4 m depth. Standard penetrate tests performed in the unfrozen portion of the fill indicated that the fill is loose to compact with 'N' values of 4 to 13. The results of a grain size analysis performed on a sample of the fill are given on Drawing 11. This drawing indicates that the fill contains 17 percent silt, 76 percent sand and 7 percent gravel. A direct shear box test was performed on a sample of the fill sample obtained from Borehole 4 from 1.5 m depth. The test result indicate that the silty sand and gravel fill has an effective angle of internal friction of 45 degrees with zero effective cohesion (Drawing 12).

The fill in Boreholes 1 and 2 is underlain by a layer of silty sand to sand which extend to the entire depth investigated in Borehole 1 (i.e. 5.7 m depth, Elevation 1.4 m) and to a depth of 2.7 m (Elevation 4.6 m) in Borehole 2. This stratum was frozen in both the boreholes. Its natural moisture content varied from 7 to 19 percent. However, the moisture content values determined are likely to be lower than the true moisture content since the boreholes were advanced by dry core drilling and are of the moisture from the soil likely evaporated due to the heat generated during coring. A grain size analysis performed on a sample of this stratum from Borehole 8 from 3.4 m to 4.2 m depth indicated a soil composition of 40 percent silt, 46 percent sand and 14

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percent gravel (Drawing 13). The effective angle of internal friction for this material was established to be 45 degrees (Drawing 14).

The fill in Borehole 3, 6 and 7 is underlain by a layer of silt which extends to a depth of 2.0 m to 2.8 m (Elevation 4.4 m to 5.2 m).

The fill in Borehole 5 and 8 and the silt in Boreholes 6 and 7 are underlain by sand and gravel stratum which extends to the entire depth investigated in Borehole 5, 6 and 7 (i.e. 2.8 m to 3.5 m, Elevation 3.9 m to 4.7 m) and to a depth of 3.3 m (Elevation 4.1 m) in Borehole 8. The natural moisture content of this stratum varies from 4 to 13 percent. This stratum comprises of 17 percent silt, 72 percent sand and 11 percent gravel (Drawing 15). It has an effective angle of internal friction of 45 degrees with no effective cohesion (Drawing 16).

The sand and gravel stratum in Borehole 8 is underlain by a layer of layer of silty sand to 4 m depth (Elevation 3.4 m).

The silty sand in Borehole 2 and 8 is underlain by silty sand till. This stratum contains fine to coarse sand and fine to medium gravel. Its effective angle of internal friction was assumed to be 36 degrees with no effective cohesion based on literature search.

The silt in Borehole 3 was underlain by limestone which extended to the maximum depth investigated i.e. 2.2 m (Elevation 5.0 m). Because of the limited amount of drilling undertaken, it was not possible to establish whether the limestone encountered was part of a boulder or bedrock.

Water level observations were made in the boreholes during drilling and in standpipes installed in the boreholes subsequent to drilling. Water level was recorded at a depth of 0.9 m to 1.5 m below the crest of the berm in Boreholes 1, 3, 5 and 8 approximately 10 to 15 days after completion of the fieldwork.

6.0 Slope Stability Analysis

The stability of the slopes was analyzed by using Bishop's Modified Method. Slope/W, Geoslope office, Version 4.23 computerized system was used to assess stability of the slopes. Three cross-sections of the east, southeast and west berms were analysed to provide a complete coverage of the slopes of the berms at the site. The locations of the Cross-Sections A-A, B-B and C-C are shown on Drawing 1. The cross-sections have been plotted on Drawing 2. These sections were surveyed by NorthTech Surveying and Engineering Ltd. were used for the slope stability analyses.

The upstream slopes of all the berms were analysed for the following conditions:

(1)   Steady state seepage conditions with high water level in the lagoon and low tide conditions.

(2)   Steady state seepage conditions with high water level in the lagoon and low tide conditions with seismic loads.

(3)   Rapid drawdown conditions.

(4)   Rapid drawdown conditions with seismic loads.

The downstream slopes of all the berms were analysed for:

(1)   Steady state seepage conditions with high water level in the lagoon.

(2)   Steady state seepage conditions with high water level in the lagoon and seismic loads.

(3)   In addition to the above analyses, the downstream slope of the west berm was also analysed for low tide conditions with the soil weakened due to low tide and due to spring thaw. This slope was also analysed for steady state seepage with the phreatic line at the same level as the water level in the lagoon without and with seismic loading. The case was meant to simulate conditions during spring thaw.

The following assumptions were made in the analysis:

(1)   Surveyed cross-sections AA, BB and CC represent the existing berm slopes at locations shown on Drawing 1. The elevation of the crest of the berms varies from Elevation 7.1 m to 7.7 m. The berms have a crest width of 3.8 m to 10 m and upstream slopes of 2.3H:1V to 4.8H:1V. The downstream slopes vary from 2.9H:1V to 9H:1V. The maximum height of the berm is in the order of 3.5 m.

(2)   The soil stratigraphy generally comprises of silty sand and gravel berm fill underlain by silty sand and/or sand and gravel and/or silty sand and gravel till. The soil stratigraphy for each cross section analysed is given on Drawings 17 to 38 inclusive.

(3)   The soil properties used in the slope stability analysis have been listed on Table I. It is noted that although somewhat higher values of effective angle of internal friction were measured for the sand and gravel fill, natural sand and gravel and silty sand stratum, a somewhat conservative approach was used and lower values were selected for use in the analysis.

Table I
Engineering Progress of Various Soil Strata used in Stability Analysis

Soil Stratum	Effective Cohesion (kPa)	Effective Angle of Internal Friction Value Use in Analysis	Unit Weight (kN/m^3)
Sand and Gravel Fill	0	36	21
Sand and Gravel	0	36	21
Silty Sand	0	28	21
Sand and Gravel Till	0	36	22
Rip-rap	0	40	20

(4)   The analysis was undertaken assuming that the high water level in the lagoon was at Elevation 7.3 m in the case of the east and southeast dykes and at Elevation 6.9 m in the case of the west dyke. It is noted that the crest elevation of the east and southeast dykes is at Elevation 74.5 m and 74.4 m. respectively whereas the crest elevation of the west berm is at Elevation 7.1 m with the invert of the spillway structure at Elevation 6.9 m.

The results of the analyses are given on Table II.

Table II
Results of Slope Stability Analysis of the Lagoon Slopes

Structure	Slope	Type of Analysis	F of S	Remarks
East Dyke	Upstream	Steady State Seepage	3.46	
	Upstream	Steady State Seepage with Seismic Loading	2.75	
	Upstream	Rapid Drawdown	2.72	
	Upstream	Rapid Drawdown with Seismic Loading	2.28	
	Downstream	Steady State Seepage	2.53	

Table II (cont.)
Results of Slope Stability Analysis of the Lagoon Slopes

Structure	Slope	Type of Analysis	F of S	Remarks
	Downstream	Steady State Seepage with Seismic Loading	2.19	
Southeast Dyke	Upstream	Steady State Seepage	3.61	
	Upstream	Steady State Seepage with Seismic Loading	2.82	
	Upstream	Rapid Drawdown Condition	2.41	
	Upstream	Rapid Drawdown Condition with Seismic Loading	2.0	
	Downstream	Steady State Seepage	2.93	
	Downstream	Steady State Seepage with Seismic Loading	2.43	
West Dyke	Upstream	Steady State Seepage	2.10	
	Upstream	Steady State Seepage with Seismic Loading	1.73	
	Upstream	Rapid Drawdown Condition	1.24	
	Upstream	Rapid Drawdown Condition with Seismic Loading	1.13	
	Downstream	Steady State Seepage	2.24	
	Downstream	Steady State Seepage with Seismic Loading	1.85	
	Downstream	Steady State Seepage. Soil weakened by Low Tide	2.1	
	Downstream	Steady State Seepage. Soil weakened by Thaw	1.53	
	Downstream	Steady State Seepage. Soil weakened by Thaw. High Phreatic Line	1.42	
	Downstream	Steady State Seepage. Soil weakened by Thaw. High Phreatic Line with Seismic Loading	1.16	

The Dam Safety Guidelines require a minimum factor of safety of 1.5 m for the downstream slope under steady state seepage conditions. The minimum factor of safety required for the upstream slopes is 1.2 to 1.3 under rapid drawdown conditions.

A review of Table II indicates that the factor of safety of the downstream slopes of the east, southeast and west berms of the lagoon under steady state seepage conditions is 2.19, 2.43 and 1.85 respectively. The computed factors of safety are higher than the minimum 1.5 factor of safety required by the Dam Safety Guidelines for this condition.

The factor of safety of the upstream slopes of the east, southeast and west berms of the lagoons under rapid drawdown conditions was computed to be 2.4, 2.32 and 1.28 respectively. The factors of safety computed are well above the minimum factor of safety required by the Dam Safety Guidelines. The exception to this is the west dyke where the computed factor of safety marginally satisfies the Dam Safety Guidelines.

The slopes of the berms would be weakened during the spring thaw. The downstream slope of the west dyke is also subject to tidal fluctuations. A factor of safety of 2.1 and 1.5 respectively was obtained for the weakened slope due to low tide and due to thaw during spring season. The downstream slope was also analysed for the steady state seepage conditions assuming the phreatic line to be at the same level as water level in the lagoon. This was to simulate the condition that may be achieved during the spring season due to ice build up during the winter.

A factor of safety of 1.42 was obtained for this condition. The factor of safety decreases to 1.16 when seismic loading is also taken into consideration. It is noted that according to the United States (Federal Register 1977) a factor of safety of 1.0 is acceptable for this condition.

Based on the results of the slope stability analysis, it is considered that a catastrophic failure of the berms is unlikely.

Discussion

It is reported that the western dyke has breached on several occasions in the past. The failure has occurred as a result of one or combination of the following factors: (i) overtopping due to high water level in the lagoon during spring run off, (ii) undermining of the toe of the downstream slope of the berm by tidal fluctuations and (iii) blockage of the drainage path due to formation of ice lenses in the bottom part of the berm resulting in higher than normal phreatic line.

It is considered that the stability problems experienced in the past are inherent to the 'leaky' dam design concept as indicated previously in the Dam Safety Review Report (Trow Project MU15152B/S08768G, Oct 4, 2002), given the extremely cold climate of Iqaluit and the exposure of the west dyke to severe tidal fluctuation in the Koojesse Inlet. Based on a review of the previous report, it is clear that problems are being experienced with the west dyke due to seepage through the sand and gravel fill structures. Water seeping out of the lagoon close to the toe of the dykes freezes in the fall months and accumulates as ice along the toe of the dyke forming an increasingly thick impervious barrier. The ice barrier blocks the drainage at the toe of the berm and gradually moves higher into the embankment as the ice builds up resulting in high phreatic levels within the interior of the dyke. In addition, ice lenses likely form in the sand and gravel fill. The ice cap provides additional stability to the downstream toe of the berm during the winter months. However, during the spring season, the exposed ice melts and the frozen soil thaws, resulting in a reduced strength of the soil. The reduced strength of the soil coupled with the high phreatic levels in the berms results in a much lower factor of safety.

In addition, the materials used for construction of the berms (sand and gravel) are extremely erodible due to wave action or overtopping. During the high tide, potential exists for undermining of the toe of the west dyke by wave action.

Remedial Measures

If it is desirable to ensure that the berms do not leak or do not develop any seeps, localized areas of failure etc., the only solution would be that the bottom and sides of the lagoon are lined with an impervious liner, such as a High Density Polyethylene Liner. However, if some localized seeps or failures can be tolerated, the remedial measures may consist of the following:

(1) Prevention of erosion of the downstream toe of the west dyke. This may be achieved by providing rip-rap which is capable of withstanding the tidal fluctuations and is properly designed to prevent loss of berm material.

(2) Prevention of overtopping of the berms. This may be achieved by providing a proper spillway structure capable of handling the over flow such that the berms are not overtopped. Alternatively, the discharge outlet should be of sufficient size such that the flow can be adjusted to prevent overtopping of the berms.

It is understood that the sewage lagoon would be operational for only 3 to 4 years until construction of the sewage treatment plant is complete at which stage the lagoon would be decommissioned. For these reasons, the authorities may not feel that the additional expenses to line the lagoon are justified at this stage.

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

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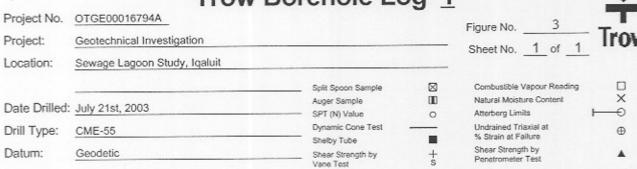# Drawings

NOTES ON SAMPLE DESCRIPTIONS

1. All descriptions included in this report follow the 'modified' Massachusetts Institute of Technology soil classification system. The laboratory grain-size analysis also follows this classification system. Others may designate the unified classification system as their source; a comparison of the two is shown for your information. Please note that, with the exception of those samples where the grain-size analysis has been carried out, all samples are classified visually and the accuracy of visual examination is not sufficient to differentiate between the classification systems or exact grain sizing. The MIT system has been modified and the Trow classification includes a designation for cobbles above the 75mm size and boulders above the 200mm size.
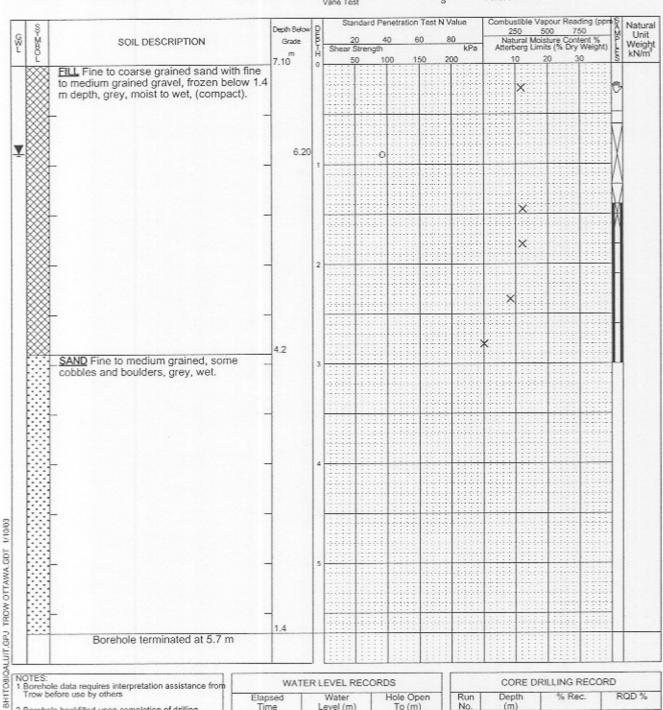
			Sand			Gravel		
Unified Soil Classification	Fines (silt or clay)		Fine	Medium	Coarse	Fine	Coarse	Cobbles
Massachusetts Institute of Technology Soil Classificaiton	Clay	Silt	Sand			Gravel		
			Fine	Med	Coarse			
Sieve Sizes			200	40	10	4	1/2 in 3/4 in	3 in
Particle Size (mm)	0.001 0.002 0.003 0.004 0.006 0.008 0.01	0.02 0.03 0.04 0.06 0.08 0.1	0.2 0.3 0.4 0.6 0.8 1.0	2.0 3.0 4.0	6.0 8.0 10	20	30 40 60 80	

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

3. **Till**: The term till on the borehole logs indicates that the material originates from a geological process associated with glaciation. Because of this geological process the till must be considered heterogeneous in composition and as such may contain pockets and/or seams of material such as sand, gravel silt or clay. Till often contains cobbles (75 to 200mm) or boulders (over 200mm) and therefore contractors may encounter them during excavation, even if they are not indicated by the borings. It should be appreciated that normal sampling equipment can not differentiate the size or type of any obstruction. Because of the horizontal and vertical variability of till, the sample description may be applicable to a very limited area; caution is therefore essential when dealing with sensitive excavations or dewatering programs in till material.

Trow Borehole Log 1

Project No. OTGE00016794A

Project: Geotechnical Investigation

Location: Sewage Lagoon Study, Iqaluit

Figure No. 3

Sheet No. 1 of 1

Trow

Date Drilled: July 21st, 2003

Drill Type: CME-55

Datum: Geodetic

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

SOIL DESCRIPTION

FILL Fine to coarse grained sand with fine to medium grained gravel, frozen below 1.4 m depth, grey, moist to wet, (compact).

SAND Fine to medium grained, some cobbles and boulders, grey, wet.

Borehole terminated at 5.7 m

Depth Below Grade (m): 7.10, 6.20, 4.2, 1.4

Standard Penetration Test N Value: 20 40 60 80

Shear Strength (kPa): 50 100 150 200

Combustible Vapour Reading (ppm): 250 500 750

Natural Moisture Content % / Atterberg Limits (% Dry Weight): 10 20 30

Natural Unit Weight kN/m³

NOTES:
1. Borehole data requires interpretation assistance from Trow before use by others
2. Borehole backfilled upon completion of drilling
3. Field work supervised by a Trow representative
4. See Notes on Sample Descriptions
5. This Drawing to be read with Trow Consulting Engineers Ltd. report OTGE00016794A

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	0.8	N/A
3 days	0.9	

CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %
1	1.2 - 1.4		
2	1.4 - 1.5		
3	1.5 - 2.1		
4	2.1 - 2.6		
5	2.6 - 2.9		

LOG OF BOREHOLE BH1TOBIQALUIT.GPJ TROW OTTAWA.GDT 1/10/03

Trow Borehole Log 2

Project No. OTGE00016794A

Project: Geotechnical Investigation

Location: Sewage Lagoon Study, Iqaluit

Date Drilled: July 23rd, 2003

Drill Type: CME-55

Datum: Geodetic

Figure No. 4

Sheet No. 1 of 1

Trow

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

SOIL DESCRIPTION

FILL Sandy silt to silty sand, some gravel, some organics, grey-brown, moist, (loose).

Depth Below Grade 7.30 m

SILTY SAND Fine to medium grained, dark grey, moist.

5.9 / 5.8

SILTY SAND Fine to medium grained, some fine to medium grained gravel, occasional cobbles and boulders, grey brown to grey, wet.

Ice layer found 2.3 m to 2.5 m depth

4.6

TILL Silty sand, some fine to medium grained gravel, wet.

4.2

Borehole terminated at 3.1 m

Standard Penetration Test N Value: 20, 40, 60, 80

Shear Strength kPa: 50, 100, 150, 200

Combustible Vapour Reading (ppm): 250, 500, 750

Natural Moisture Content % / Atterberg Limits (% Dry Weight): 10, 20, 30

Natural Unit Weight kN/m³

NOTES:
1. Borehole data requires interpretation assistance from Trow before use by others

2. Borehole backfilled upon completion of drilling

3. Field work supervised by a Trow representative

4. See Notes on Sample Descriptions

5. This Drawing to be read with Trow Consulting Engineers Ltd. report OTGE00016794A

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	N/D	N/A

CORE DRILLING RECORD

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

Trow Borehole Log 3

Trow

Legend:

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

Borehole log columns: GWL | SYMBOL | SOIL DESCRIPTION | Depth Below Grade (m) | DEPTH | Standard Penetration Test N Value / Shear Strength (kPa) | Combustible Vapour Reading (ppm) / Natural Moisture Content % / Atterberg Limits (% Dry Weight) | SAMPLES | Natural Unit Weight kN/m³

Soil Description:

FILL Silty sand, some fine to medium grained gravel, brown to grey, moist to wet.

SILT Grey, wet.

LIMESTONE Possible bedrock or boulder, grey.

Borehole terminated at 2.2 m

Depth Below Grade: 7.20 (top), 5.3, 5.2, 5.0

WATER LEVEL RECORDS		
Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	N/D	N/A

CORE DRILLING RECORD			
Run No.	Depth (m)	% Rec.	RQD %

Trow Borehole Log 4

Project No. OTGE00016794A

Project: Geotechnical Investigation

Location: Sewage Lagoon Study, Iqaluit

Figure No. 6

Sheet No. 1 of 1

Date Drilled: July 23rd, 2003

Drill Type: CME-55

Datum: Geodetic

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

GWL	SYMBOL	SOIL DESCRIPTION	Depth Below Grade m	DEPTH	Standard Penetration Test N Value / Shear Strength kPa	Combustible Vapour Reading (ppm) / Natural Moisture Content % / Atterberg Limits (% Dry Weight)	SAMPLES	Natural Unit Weight kN/m³
		FILL Silty sand, fine to coarse grained, some fine to coarse grained gravel, brown to grey, moist to wet.	7.70			×		
				1		×		
						×		
				2		× ×		
						× ×		
		Borehole terminated at 2.6 m	5.1			× ×		

NOTES:
1. Borehole data requires interpretation assistance from Trow before use by others
2. Borehole backfilled upon completion of drilling
3. Field work supervised by a Trow representative
4. See Notes on Sample Descriptions
5. This Drawing to be read with Trow Consulting Engineers Ltd. report OTGE00016794A

LOG OF BOREHOLE BH1TOBIQALUIT.GPJ TROW OTTAWA.GDT 1/10/03

WATER LEVEL RECORDS		
Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	N/D	N/A

CORE DRILLING RECORD			
Run No.	Depth (m)	% Rec.	RQD %

Trow Borehole Log 5

Project No.	OTGE00016794A
Project:	Geotechnical Investigation
Location:	Sewage Lagoon Study, Iqaluit
Date Drilled:	July 23rd, 2003
Drill Type:	CME-55
Datum:	Geodetic

Figure No. 7
Sheet No. 1 of 1

Trow

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

SOIL DESCRIPTION

FILL Silty sand, fine to medium grained, some fine to coarse grained gravel, frozen below 1.3 m depth, brown to grey, moist to wet.

Some roots in lower levels

SAND AND GRAVEL Fine to coarse grained, grey brown, wet.

Borehole terminated at 3.5 m

Depth Below Grade m: 7.60 / 4.9 / 4.1

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	N/D	N/A

CORE DRILLING RECORD

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

LOG OF BOREHOLE BH1T08IQALUIT.GPJ TROW OTTAWA.GDT 1/10/03

Trow Borehole Log 6

Project No. OTGE00016794A

Project: Geotechnical Investigation

Location: Sewage Lagoon Study, Iqaluit

Figure No. 8

Sheet No. 1 of 1

Date Drilled: July 23rd, 2003

Drill Type: CME-55

Datum: Geodetic

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

Soil Description

FILL silty sand, fine to coarse grained, some fine to coarse grained gravel, frozen below 1.1 m depth, brown, moist to wet.

Depth Below Grade (m): 7.20

SANDY SILT Some roots, black, wet. — 4.5 / 4.4

SILTY SAND AND GRAVEL grey, wet. — 3.9

Borehole terminated at 3.3 m

Test Columns

Standard Penetration Test N Value: 20, 40, 60, 80

Shear Strength: 50, 100, 150, 200 (kPa)

Combustible Vapour Reading (ppm): 250, 500, 750

Natural Moisture Content % / Atterberg Limits (% Dry Weight): 10, 20, 30

Natural Unit Weight kN/m³

NOTES:

1. Borehole data requires interpretation assistance from Trow before use by others
2. Borehole backfilled upon completion of drilling
3. Field work supervised by a Trow representative
4. See Notes on Sample Descriptions
5. This Drawing to be read with Trow Consulting Engineers Ltd. report OTGE00016794A

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	N/D	N/A

CORE DRILLING RECORD

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

LOG OF BOREHOLE BH1TOIQALUIT.GPJ TROW OTTAWA.GDT 1/10/03

Trow Borehole Log 7

Legend:

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

GWL	SYMBOL	SOIL DESCRIPTION	Depth Below Grade m	DEPTH m	Standard Penetration Test N Value / Shear Strength / Combustible Vapour Reading / Natural Moisture Content / Atterberg Limits	SAMPLES	Natural Unit Weight kN/m³
		FILL Sand, fine to medium grained, some fine to medium grained gravel, frozen below 1.2 m depth, brown to grey brown, moist to wet.	7.50	0			
		SANDY SILT Organic staining, some roots, dark grey, wet.	5.6	2			
		SAND AND GRAVEL Fine to coarse grained sand, fine to medium grained gravel, occasional cobbles and boulders, grey brown, wet..	5.2				
		Borehole terminated at 2.8 m	4.7				

NOTES:

1. Borehole data requires interpretation assistance from Trow before use by others
2. Borehole backfilled upon completion of drilling
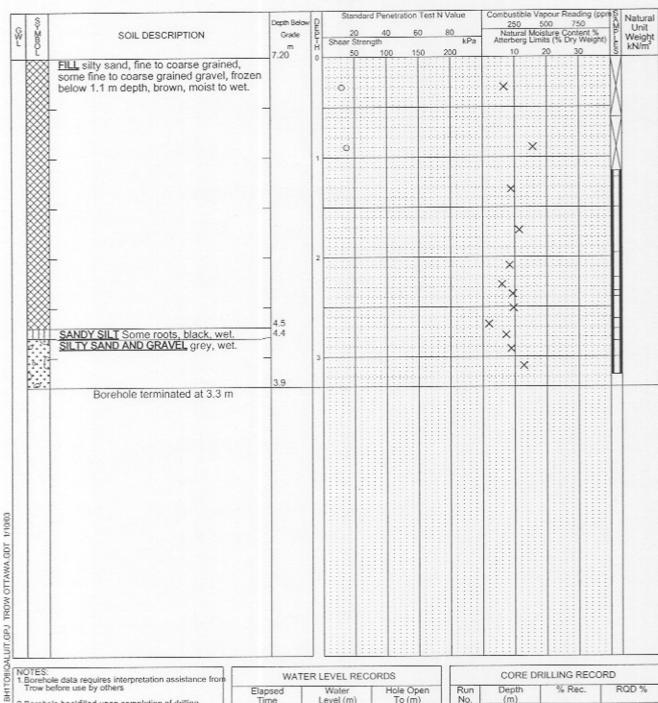3. Field work supervised by a Trow representative
4. See Notes on Sample Descriptions
5. This Drawing to be read with Trow Consulting Engineers Ltd. report OTGE00016794A

WATER LEVEL RECORDS		
Elapsed Time	Water Level (m)	Hole Open To (m)
Completion	N/D	N/A

CORE DRILLING RECORD			
Run No.	Depth (m)	% Rec.	RQD %

LOG OF BOREHOLE BH1TOBIDAIAUIT.GPJ TROW OTTAWA.GDT 1/15/03

Trow Borehole Log 8

Project No. OTGE00016794A

Project: Geotechnical Investigation

Location: Sewage Lagoon Study, Iqaluit

Figure No. 10

Sheet No. 1 of 1

Trow

Date Drilled: July 24th, 2003

Drill Type: CME-55

Datum: Geodetic

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

SOIL DESCRIPTION

FILL Sand, fine to medium grained, some fine to coarse grained gravel, frozen below 1.3 m depth, brown, moist to wet.

SAND AND GRAVEL Fine to coarse grained, grey brown, moist.

SILTY SAND Fine to medium grained, some gravel and organic staining, dark grey, wet.

SILTY SAND Some fine to coarse gravel, grey, moist.

Borehole terminated at 5.4 m

Depth Below Grade (m): 7.40, 5.0, 4.1, 3.4, 2.0

WATER LEVEL RECORDS

Elapsed Time	Water Level (m)	Hole Open To (m)

CORE DRILLING RECORD

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

GRAIN SIZE ANALYSIS — ASTM D 422

⊀ Trow

Fill, sand and gravel

MODIFIED M.I.T. CLASSIFICATION

Borehole No. 4 — Run 2
4'11" — 6'6" depth

Direct Shear Test Friction Angle
BH 4 Run 2 & 3 4'
Sand and Gravel Fill

$y = 0.9891x$

368

257.3

126.7

σ_n, kPa

τ, kPa

Series1
Linear (Series1)

GRAIN SIZE ANALYSIS – ASTM D 422

PERCENTAGE RETAINED

PERCENTAGE PASSING
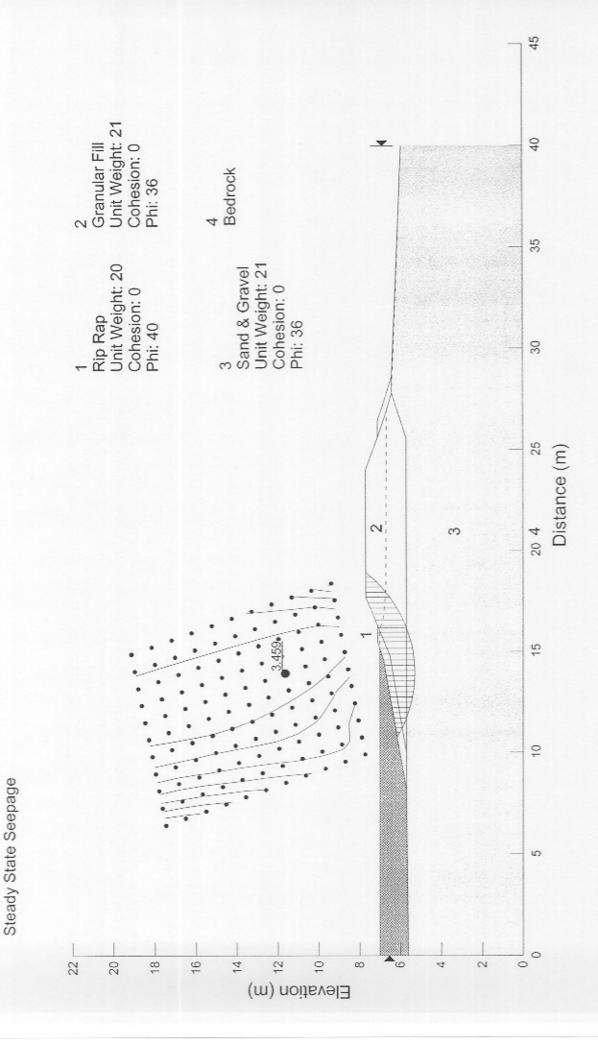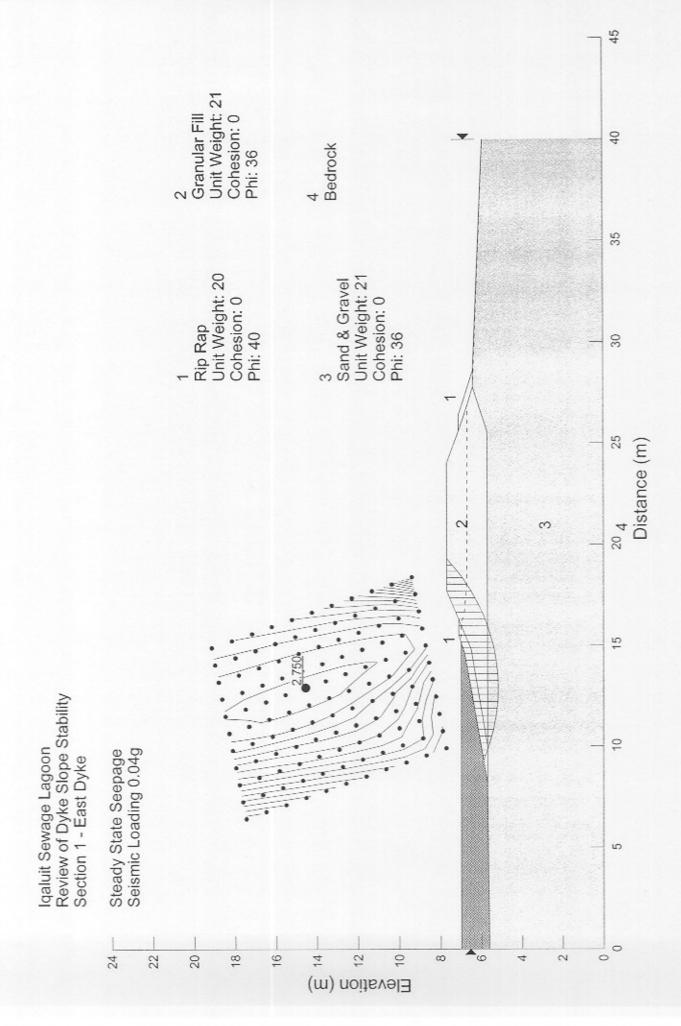
SIEVE SIZES (mm)

EQUIVALENT GRAIN DIAMETER IN MILLIMETERS

Trow

MODIFIED M.I.T. CLASSIFICATION

CLAY	SILT			SAND			GRAVEL		
	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE

Silty sand

Borehole No. 8
11'4" – 13'10" depth

Direct Shear Test Friction Angle
BH8 Run 22 11'-4" - 13'-10"

Silty Sand

$y = 0.893x$

Series1
Linear (Series1)

337.5

215.7

131.7

σ_n, kPa

τ, kPa

GRAIN SIZE ANALYSIS – ASTM D 422

PERCENTAGE RETAINED

SIEVE SIZES (mm)

PERCENTAGE PASSING

EQUIVALENT GRAIN DIAMETER IN MILLIMETERS

	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	
CLAY	SILT			SAND			GRAVEL			

MODIFIED M.I.T. CLASSIFICATION

Sand and gravel

Borehole No. 5
10'11" – 11'4" depth

✳ Trow

Direct Shear Test Friction Angle Samples 4,5,6
BH 5 Run 13 Igaluit Lagoon 10'-11"-11'-4"

Sand and Gravel

$y = 0.9837x$

- Series1
- Linear (Series1)

365

255

130.7

σ_n, kPa

τ, kPa

Drawing No. 17

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 1 - East Dyke

Steady State Seepage

1
Rip Rap
Unit Weight: 20
Cohesion: 0
Phi: 40

2
Granular Fill
Unit Weight: 21
Cohesion: 0
Phi: 36

3
Sand & Gravel
Unit Weight: 21
Cohesion: 0
Phi: 36

4
Bedrock

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 1 - East Dyke

Steady State Seepage
Seismic Loading 0.04g

1
Rip Rap
Unit Weight: 20
Cohesion: 0
Phi: 40

2
Granular Fill
Unit Weight: 21
Cohesion: 0
Phi: 36

3
Sand & Gravel
Unit Weight: 21
Cohesion: 0
Phi: 36

4
Bedrock

2.750

Distance (m)

Elevation (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 1 - East Dyke

Rapid Drawdown Condition

Drawing No. 19

1
Rip Rap
Unit Weight: 20
Cohesion: 0
Phi: 40

2
Granular Fill
Unit Weight: 21
Cohesion: 0
Phi: 36

3
Sand & Gravel
Unit Weight: 21
Cohesion: 0
Phi: 36

4
Bedrock

2.722

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 1 - East Dyke

Rapid Drawdown Condition
Seismic Loading 0.04g

Drawing No. 20

1
Rip Rap
Unit Weight: 20
Cohesion: 0
Phi: 40

2
Granular Fill
Unit Weight: 21
Cohesion: 0
Phi: 36

3
Sand & Gravel
Unit Weight: 21
Cohesion: 0
Phi: 36

4
Bedrock

2.283

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 1 - East Dyke

Steady State Seepage

1
Rip Rap
Unit Weight: 20
Cohesion: 0
Phi: 40

2
Granular Fill
Unit Weight: 21
Cohesion: 0
Phi: 36

3
Sand & Gravel
Unit Weight: 21
Cohesion: 0
Phi: 36

4
Bedrock

2.528

Drawing No. 21

Drawing No. 22

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 1 - East Dyke

Steady State Seepage
Seismic Loading 0.04g

1
Rip Rap
Unit Weight: 20
Cohesion: 0
Phi: 40

2
Granular Fill
Unit Weight: 21
Cohesion: 0
Phi: 36

3
Sand & Gravel
Unit Weight: 21
Cohesion: 0
Phi: 36

4
Bedrock

2.185

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 3 - Southeast Dyke

Steady State Seepage

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand & Gravel
Unit Weight:21
Cohesion:0
Phi:36

4
Silty Sand
Unit Weight:20
Cohesion:0
Phi:28

5
Silty Sand Till
Unit Weight:22
Cohesion:0
Phi:36

6
Bedrock

3.614

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 3 - Southeast Dyke

Steady State Seepage
Seismic Loading 0.04g

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand & Gravel
Unit Weight:21
Cohesion:0
Phi:36

4
Silty Sand Organic
Unit Weight:20
Cohesion:0
Phi:28

5
Silty Sand Till
Unit Weight:22
Cohesion:0
Phi:36

6
Bedrock

2.824

Distance (m)

Elevation (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 3 - Southeast Dyke

Rapid Drawdown Condition

Drawing No. 25

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand & Gravel
Unit Weight:21
Cohesion:0
Phi:36

4
Silty Sand Organic
Unit Weight:20
Cohesion:0
Phi:28

5
Silty Sand Till
Unit Weight:22
Cohesion:0
Phi:36

6
Bedrock

2.412

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 3 - Southeast Dyke

Rapid Drawdown Condition
Seismic Loading of 0.04g

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand & Gravel
Unit Weight:21
Cohesion:0
Phi:36

4
Silty Sand Organic
Unit Weight:20
Cohesion:0
Phi:28

5
Silty Sand Till
Unit Weight:22
Cohesion:0
Phi:36

6
Bedrock

2.048

Elevation (m)

Distance (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 3 - Southeast Dyke

Steady State Seepage

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand & Gravel
Unit Weight:21
Cohesion:0
Phi:36

4
Silty Sand Organic
Unit Weight:20
Cohesion:0
Phi:28

5
Silty Sand Till
Unit Weight:22
Cohesion:0
Phi:36

6
Bedrock

2.934

Distance (m)

Elevation (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 3 - Southeast Dyke

Steady State Seepage
Seismic Loading 0.04g

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand & Gravel
Unit Weight:21
Cohesion:0
Phi:36

4
Silty Sand Organic
Unit Weight:20
Cohesion:0
Phi:28

5
Silty Sand Till
Unit Weight:22
Cohesion:0
Phi:36

6
Bedrock

2.434

Drawing No. 29

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand
Unit Weight:21
Cohesion:0
Phi:32

4
Bedrock

2.099

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage
Seismic Loading of 0.04g

Drawing No. 30

1 Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2 Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3 Sand
Unit Weight:21
Cohesion:0
Phi:32

4 Bedrock

1.730

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A – West Dyke

Rapid Drawdown Condition

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
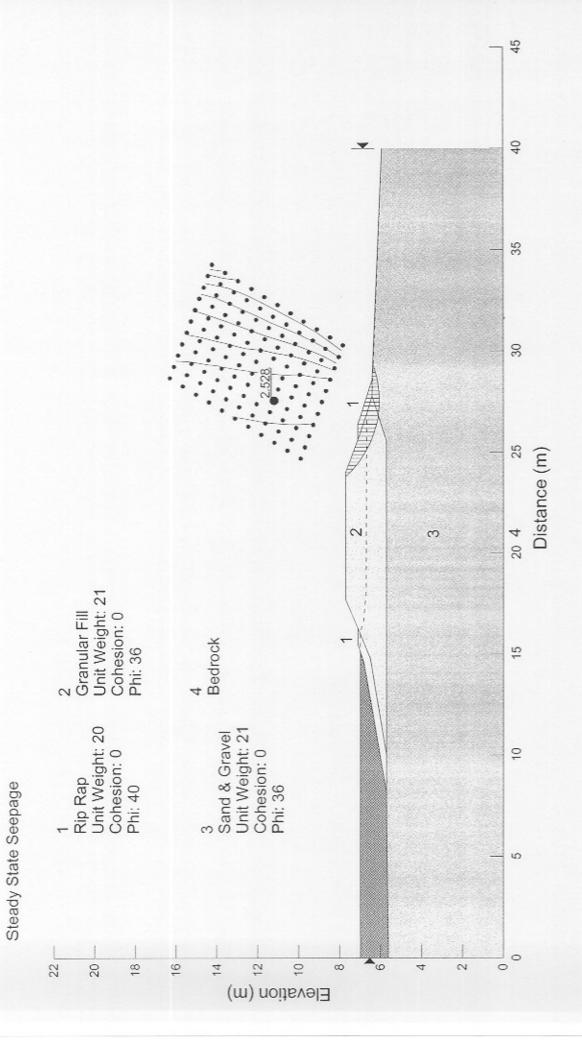Phi:36

3
Sand
Unit Weight:21
Cohesion:0
Phi:32

4
Bedrock

Drawing No. 32

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Rapid Drawdown Condition
Seismic Loading of 0.04

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand
Unit Weight:21
Cohesion:0
Phi:32

4
Bedrock

1.134

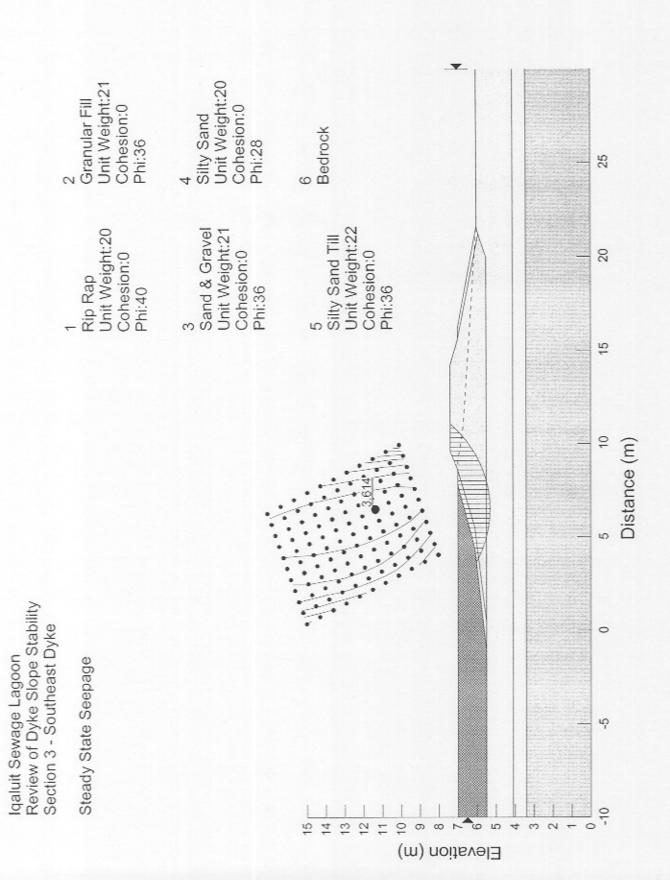Horizontal Distance (m)

Elevation (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage

1 Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2 Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3 Sand
Unit Weight:21
Cohesion:0
Phi:32

4 Bedrock

2.238

Elevation (m) — 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3 -4

Horizontal Distance (m) — -5 0 5 10 15 20 25 30 35 40 45

Drawing No. 34

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage
Seismic Loading of 0.04g

1.846

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:36

3
Sand
Unit Weight:21
Cohesion:0
Phi:32

4
Bedrock

Elevation (m)

Horizontal Distance (m)

Drawing No. 35

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage
Weakened By Low Tide

1
Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2
Granular Fill
Unit Weight:21
Cohesion:0
Phi:30

3
Sand
Unit Weight:21
Cohesion:0
Phi:32

4
Bedrock

2.096

Elevation (m)

Horizontal Distance (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage
Weakened By Thaw

1   Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2   Granular Fill
Unit Weight:21
Cohesion:0
Phi:20

3   Sand
Unit Weight:21
Cohesion:0
Phi:32

4   Bedrock

1.530

Horizontal Distance (m)

Elevation (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage
Weakened By Thaw

1 Rip Rap
Unit Weight:20
Cohesion:0
Phi:40

2 Granular Fill
Unit Weight:21
Cohesion:0
Phi:20

3 Sand
Unit Weight:21
Cohesion:0
Phi:32

4 Bedrock

1.422

Elevation (m)

Horizontal Distance (m)

Iqaluit Sewage Lagoon
Review of Dyke Slope Stability
Section 6A - West Dyke

Steady State Seepage
Weakened By Thaw
Seimic Loading of 0.04

1	Rip Rap	2	Granular Fill
	Unit Weight:20		Unit Weight:21
	Cohesion:0		Cohesion:0
	Phi:40		Phi:20

3	Sand	4	Bedrock
	Unit Weight:21		
	Cohesion:0		
	Phi:32		

1.164