Trow

Geotechnical Investigation
Proposed Sewage Lagoon
Hamlet of Clyde River, Nunavut

Prepared for:

CGS Projects – GN
P.O. Box 379
Pond Inlet, Nunavut
X0A 0S0

Trow Associates Inc.

154 Colonnade Road South
Ottawa, Ontario K2E 7J5
Telephone: (613) 225-9940
Facsimile: (613) 225-7337
E-mail: ottawa@trow.com
Web Site: www.trow.com

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Executive Summary

A geotechnical investigation was undertaken at the site of the existing sewage lagoon and the proposed sewage lagoon in the Hamlet of Clyde River, Nunavut. This work was requested by the Government of Nunavut on July 18, 2007.

It is proposed to rehabilitate the existing lagoon and to construct a new lagoon south of the existing lagoon in order to increase the storage capacity.

The existing sewage lagoon is located approximately 1 km west of the community of Clyde River, Nunavut. It drains overland an approximate distance of 800 m to Patricia Bay.

The investigation has revealed that the berms of the existing lagoon comprise of sand and gravel which extends to 0.6 m to 1.5 m depth. The sand and gravel stratum is underlain by silty sand till which extends to 2.5 m to 5.1 m depth. The till is underlain by sand and gravel stratum to the entire depth investigation i.e. 3.0 m to 5.6 m. The permeability of the sand and gravel and the silty sand and gravel till was estimated to vary from 4.9 x 10^{-5} to 1 x 10^{-4} cm/sec.

The site of the proposed new lagoon is located south of the existing lagoon. The surficial soil in this area is silty sand which extends to 1.6 to 1.7 m depth (Elevation 57.9 m and 58.4 m). The silty sand is underlain by ice rich soil which extends to 5.2 m depth (Elevation 54.4 m). Ice layers were encountered in this stratum from 1.7 m to 2.8 m depth, 3.8 m to 4.3 m depth and from 4.6 m to 5.2 m depth. The sandy silt is underlain by silty sand which extends to the entire depth investigated i.e. 7.5 m (Elevation 52.1 m). The permeability of the soils at the proposed location of the new lagoon varies from less than 1 10^{-7} cm/sec to 2.6 x 10^{-4} cm/sec.

It is understood that three different options are being considered for construction of the new lagoon and rehabilitation of the existing lagoon. These include (i) construction of a new lagoon south of the existing lagoon and rehabilitation of the existing lagoon (ii) construction of a new lagoon on the south and west sides of the existing lagoon and rehabilitation of the existing lagoon and (iii) construction of a new lagoon south of the existing lagoon and enlarging the existing lagoon to form a two cell lagoon. It is understood that Option (1) would likely be the preferred option.

It is considered that irrespective of the design option chosen, the recommendations for construction of the new lagoon and for rehabilitation of the existing lagoon that follow would be applicable. The investigation has revealed that the soils on the site are ice rich. Therefore, construction of the conventional berms for the lagoons is not feasible as they will experience large settlements due to thaw of the underlying soils. Also, the on-site soils are permeable and as such the lagoons would have to be lined. Installation of synthetic liners in lagoons constructed on ice rich soils are likely to rupture because of the anticipated large settlements. It is recommended that the proposed berms should be constructed as 'ice dams' i.e. the soil in the core of the berm and the underlying ice rich soils should be maintained in a permanently frozen state. In this case, the frozen soil would act as a liner.

It is recommended that a geothermal analysis should be performed to determine if agradation of the frost into the berm and the underlying natural soils can be achieved naturally or would require installation of thermosyphons. The berms of the existing lagoon would also have to be converted into 'ice dams' to ensure their satisfactory performance.

Stability of the slope analyses was performed to determine the steepest slopes of the berms that would be stable under prevailing conditions. The analyses assumed that the berms would be constructed as 'ice dams'. It is noted that although the central core of the berms and the underlying natural soils would be maintained in a constantly frozen state, the outside and inside slopes of the berms would be subject to seasonal freezing and thawing. The inside slopes of the berms were therefore analysed for completely submerged case whereas the outside slopes of the berms were analysed for steady state seepage conditions. Static as well as seismic loading was considered for each case. The analysis revealed that the slopes would have an adequate factor of safety if the inside and outside berm slopes are constructed at an inclination of 3.5H:1V and 2.75H:1V respectively. It is noted that the computed slopes would be stable provided that the berms are not overtopped, are not subjected to 'rapid drawdown' condition and that the underlying ice rich soils are permanently maintained in a frozen state.

The alternative to construction of the berms as 'ice dams' is to use a liner to prevent seepage out of the lagoons. This option would also require that the underlying ice rich soils are maintained in a constantly frozen state to prevent excessive settlements. There are two options available when lining the lagoons. The first option is to line the entire lagoon. The second option is to line the berms only and to seal the liner into the impervious stratum i.e. permafrost. Theoretically, lined berms will not be subjected to any of the buoyancy or seepage forces. However, potential exists for these conditions to develop if the liner gets damaged or the joints leak. It is therefore considered that the slopes of the berms for this option should also be designed on the assumption that they would be subjected to hydrostatic and seepage forces.

The investigation has revealed that the problems currently being experienced with the existing lagoon relate to its construction on ice rich soils. Construction of the lagoon has resulted in degradation of the permafrost and thawing of the underlying ice rich soils thereby resulting in large settlements of the berms. The geotechnical investigation has also indicated that the berms have been constructed with permeable soils and as a result are prone to seepage. The slopes of the existing lagoons are too steep and slough in an attempt to stabilize themselves.

The remedial measures would essentially consist of arresting the settlements of the berms, preventing seepage out of the berms and flattening the slopes to a stable inclination. In order to prevent additional settlements of the berms, it is essential to restore the permafrost under the existing berms. The permeability of the berms may also be reduced by maintaining the berms in a constantly frozen state or by lining the berms. These objectives may be achieved either by natural processes or by installing thermosyphons in the berms. It has been established that the inside slopes of 3.5H:1V and outside slopes of 2.75H:1V would be stable with adequate factor of safety. These slope inclinations may also be used to rehabilitate the existing lagoon.

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

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Figures

1.0 Introduction

A geotechnical investigation was undertaken at the site of an existing sewage lagoon and at the location of a proposed sewage lagoon in the Hamlet of Clyde River, Nunavut. This work was authorized by Government of Nunavut on July 18, 2007.

The Clyde River sewage lagoon is located approximately 1 km west of the community. The bulky metals dump bounds the existing lagoon on the north side. The community landfill, part of which is occupied by a soil remediation site, is located on the east side of the lagoon. Undeveloped tundra lies to the south and to the west of the existing lagoon. Effluent from the lagoon drains overland an approximate distance of 800 m to Patricia Bay.

A sewage management and planning study for Clyde River was prepared by Dillon Consulting Limited in 2003. This report entitled "Government of Nunavut, Community Government and Transportation, Clyde River Sewage Management-Planning Study, Project 03-2194, Draft report dated November 2003 was made available as reference material. In addition, a report titled "Clyde River Sewage Lagoon Geotechnical Investigation" prepared by Thurber Engineering Ltd. under File #15-23-47 dated October 18, 2007 was also provided as background material.

The existing sewage lagoon measures approximately 59 m x 119 m. The top width of the berms is 4 m. The outside slopes are approximately 1.5H:1V. The capacity of the existing lagoon was estimated by Dillion to be 11600 m^3. Dillion expressed a number of concerns with the existing lagoon. The geotechnically related concerns include:

(1) Settlements of the lagoon berms;

(2) Minor seepage of sewage effluent at the outside toe of the berms at the southwest corner of the lagoon; and

(3) Lack of erosion protection on the slopes which is resulting in slumping of the inside slopes.

As the capacity of the existing lagoon is not sufficient, it is proposed to rehabilitate the existing lagoon and construct a new lagoon adjacent to the existing lagoon with sufficient capacity to serve the Hamlet for the next 20 years.

Trow terms of reference for the geotechnical investigation were as follows:

(1) Determine the cause of settlement of the lagoon berms close to the southwest corner of the lagoon;

(2) Assess stability of the slopes of existing berms of the lagoon and suggest remedial measures to stabilize the berms;

(3) Investigate the cause of seepage and implement required works to repair the berms;

(4) Review the erosion protection on the existing berms and provide design details to address any shortcomings; and

(5) Determine geotechnical conditions at the location of the proposed lagoon and recommend geotechnically related design parameters.

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 Review of Available Information

A geotechnical investigation report prepared by Thurber Engineering Ltd. under Project # 15-23-47 dated October 18, 1991 for construction of the existing sewage lagoon was made available to Trow as reference material. This report has been included in Appendix 'A'.

The Thurber investigation comprised of excavating four test pits on the site to 0.7 m to 1.0 m depth. Excavations into the permafrost were only possible for a few centimetres with the available equipment. Samples taken from the upper levels of the frozen soil revealed high excess ice content.

The report recommended that the pond depth should be created by excavating into the permafrost to the maximum extent possible instead of building berms above the existing grade.

The report recommended a minimum berm height of 2 m, a minimum crest width of 10 m with 4H:1V interior slopes and 3H:1V exterior slopes. The 10 m crest width was recommended to ensure that the permafrost will aggrade into the berms and create a permafrost bowl to retain the sewage.

3.0 Procedure

3.1. Drilling and Soil Sampling

The fieldwork for the geotechnical investigation was undertaken between August 19 and 23, 2007 with a Hilti drill rig. The fieldwork was supervised by a representative of Trow Associates Inc. (Trow) on a full time basis.

The fieldwork consisted of drilling nine (9) boreholes (Boreholes 1, 2, 2A, 3 to 8 inclusive) to depths varying between 0.9 m and 7.5 m. The locations of the boreholes are shown on Site Plan, Figure 1.

The boreholes were initially advanced by performing continuous standard penetration tests and retrieving the soil samples by the split spoon sampler. However, the boreholes could only be advanced by this method in unfrozen soil to a depth of 0.59 m to 1.9 m below which frost was encountered. The boreholes were then cased and advanced by core drilling techniques with the Hilti drill rig. Water was used as flushing medium. During core drilling a careful record of colour of wash water, wash water return and any sudden drops of the drill rods was kept. Because of the limitations of the drilling equipment, it was not possible to advance the boreholes deeper than the drilled depth as the progress was extremely slow since the core barrel kept on blocking. However, in our opinion, the depth investigated is sufficient since the ice content in the soil decreases with depth and the depth investigated exceeds the depth to which undesirable soil conditions would be expected.

Thermisters were installed in Boreholes 2 and 6 to monitor the ground temperatures.

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. Similarly, the rock core was placed in the core boxes, identified and logged. On completion of drilling, all the soil samples and rock core 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 representatives of Trow Associates Inc. The elevations of the borehole refer to the Geodetic datum.

All the soil samples and rock core 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 on selected soil samples.

4.0 Ground Temperatures

Thermisters were installed in Boreholes 2 to 6 to monitor the ground temperatures. The observations made have been documented in Table 1. These readings indicate that the ground temperature varies from -17.9°C to -18.5°C at the ground surface to -4.0°C to -4.5°C at 4.0 m depth.

Table 1
Results of Ground Temperature Monitoring

Depth (m)	Date of Reading				
	August 23, 2007	August 24, 2007		November 29, 2007	
	BH6	BH6	BH2	BH6	BH2
0	7°C	11.5°C	7°C	-17.9°C	-18.5°C
0.76	3.3°C	3°C	4°C	-9.3°C	-15.6°C
1.2	1.2°C	1°C	1.4°C	-6.3°C	-
1.7	0°C	0°C	0.3°C	-4.5°C	-6.5°C
2.1	0°C	-1.5°C	0°C	-3.5°C	-4.8°C
2.6	-2.0°C	-3.0°C	-0.2°C	-3.2°C	-9.2°C
3.0	-3.0°C	-4.0°C	-0.1°C	-3.5°C	-4.0°C
3.5	-4.3°C	-5.0°C	0°C	-4.0°C	-4.0°C
4.0	-5.4°C	-5.8°C	0°C	-4.5°C	-4.0°C

5.0 Site and Soil Description

The sewage lagoon is located approximately 1 km west of the community of Clyde River. It drains overland an approximate distance of 800 mm to Patricia Bay.

A detailed description of the subsurface and groundwater conditions encountered in the nine boreholes drilled at the site have been given in Borehole Logs, Figures 2 to 10 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.

5.1. Geotechnical Conditions

5.1.1. Existing Sewage Lagoon Site

Boreholes 1 to 5 inclusive were drilled on the berms of the existing lagoon in order to investigate the causes of settlement of the existing berms and to obtain soil samples for establishing the geotechnical parameters to be used in the slope stability analysis. A review of the borehole logs indicates that the surficial soil in these boreholes is fill which extends to the entire depth investigated in Boreholes 1, 2A and 5 and to a depth of 0.6 m in Borehole 3 (Elevation 65.0 m), 2.8 m in Borehole 2 (Elevation 62.7 m) and 4.1 m depth (Elevation 61.7 m) in Borehole 4. The fill consists of gravelly sand with some silt and trace clay. The unfrozen portion of the fill is very loose to very dense (‘N’ values of 5 to 68). The natural moisture content of the fill is 3 to 25 percent. Two grain size analyses performed on the fill samples from Borehole 4 are given on Figures 11 and 12. The fill consists of 4 to 5 percent clay, 13 to 19 percent silt, 47 to 53 percent sand and 29 to 30 percent gravel.

The fill in Borehole 2 is underlain by sand and gravel which extends to the entire depth investigated i.e. 5.6 m (Elevation 59.9 m).

The fill in Borehole 3 and 4 is underlain by silty sand till which extends to the entire depth investigated in Borehole 3 (1.6 m depth, elevation 64.0 m) and to 5.1 m depth in Borehole 4 (Elevation 60.4 m). The natural moisture content of this stratum is 9 to 15 percent.

The silty sand till in Borehole 4 is underlain by sand and gravel which extends to the entire depth investigated i.e. 5.7 m, Elevation 59.8 m. The natural moisture content of this stratum varies from 3 to 7 percent.

It is noted that some of the soil sample containers leaked during transportation. Consequently, the moisture contents determining are expected to be somewhat lower than the true moisture content of the samples.

5.1.2. Proposed Sewage Lagoon Site

The site of the proposed lagoon is located adjacent to and south of the existing lagoon. Three boreholes (Boreholes 6, 7 and 8) were drilled in this area to a depth of 0.9 m to 7.5 m. (Figures 8 to 10 inclusive). The surficial soil in this area is silty sand which extends to the entire depth investigated in Borehole 7 (Elevation 58.1 m) and to a depth of 1.7 m and 1.6 m respectively in Boreholes 6 and 8 (Elevation 57.9 m and 58.4 m). This stratum contains 10 to 12 percent clay, 20 to 46 percent silt and 44 to 68 percent sand (Figures 13 and 14). The moisture content of this stratum varies from 10 to 29 percent.

The silty sand in Borehole 6 is underlain by ice rich sandy silt which extends to 5.2 m depth (Elevation 54.4 m). It is noted that frequent ice layers were encountered in this stratum from 1.7 m to 2.8 m depth, 3.8 m to 4.3 m depth and from 4.6 m to 5.2 m depth. Its natural moisture content is 8 to 18 percent. The sandy silt in this borehole is underlain by silty sand till which extends to the entire depth investigated i.e. 7.5 m (Elevation 52.1 m). The till comprises of 3 percent clay, 25 percent silt and 60 percent sand and 12 percent gravel (Figure 15).

The sand and gravel in Borehole 8 is underlain by clayey silt which extends to 3.2 m depth (Elevation 56.8 m). This stratum contains 32 percent clay, 48 percent silt and 20 percent sand (Figure 16). Its moisture content varies from 6 to 20 percent.

The permeabilities of the soils used in the construction of the berms of the existing lagoon and that of the natural soils in the vicinity of the proposed location of the new lagoon were estimated from grain size analysis using Hazen's Formula. The estimated permeabilities have been listed on Table 2. A review of this table indicates that the permeability of the material used in construction of the berms of the existing lagoon varies from 4.9 x 10^{-5} cm/sec to 1 x 10^{-4} cm/sec. (Borehole 4). The permeabilities of the on-site natural soils at the proposed location of the new lagoon (Boreholes 6 and 8) varies from less than 1 x 10^{-7} cm/sec to 2.6 x 10^{-4} cm/sec. It is therefore concluded that the existing berms have been constructed with permeable soils.

Table 2
Estimation of Permeabilities of On-site Soils

Borehole #	Depth (m)	Soil Description	Estimated Permeabily (k) cm/sec	Location on Structure
4	2.4 – 2.5	Sand and Gravel	1×10^{-4}	Existing Lagoon
4	3.5 – 4.1	Silty Sand and Gravel	4.9×10^{-5}	
6	1.2 – 1.7	Silty and Sand, Trace Clay	4×10^{-6}	Proposed Lagoon Location
6	5.3 – 5.9	Silty Sand, Trace Gravel	2.56×10^{-4}	
8	1.0 – 1.2	Silty Sand, Trace Clay	1×10^{-6}	
8	2.6 -2.8	Silty Clay, Some Sand	$<1 \times 10^{-7}$	

It is noted that boreholes were not drilled on the west side of the existing lagoon. At the time of the geotechnical investigation, construction of the new lagoon was proposed on the south side of the existing lagoon and the boreholes were drilled accordingly. During the evolution of the design, the new lagoon was also extended west of the existing lagoon. It was considered that the cost of re-mobilization to the site to drill one or two additional boreholes is not justified considering the remoteness of the site. It is recommended that one to two boreholes should be drilled with locally available drill rig to obtain an appreciation of the geotechnical conditions in this area immediately prior to commencement of construction.

6.0 Discussion

6.1. Construction of New Lagoon

It is understood that consideration is being given to three schemes. These are:

- Construction of a new lagoon south of and adjacent to existing lagoon;
- Construction of a new lagoon on the south and west side of the existing lagoon; and
- Construction of a new lagoon south of and adjacent to the existing lagoon and enlarging of the existing lagoon.

6.1.1. Construction of a New Lagoon South of Existing Lagoon

Under this scheme, the new lagoon will be of sufficient size such that the existing lagoon and the new lagoon will fulfill the future requirements of the community for the next 20 years. It would incorporate the south berm of the existing lagoon. Once the new lagoon has been constructed and is operational, the existing lagoon would be emptied and rehabilitated.

6.1.2. New Lagoon on the South and West Side of Existing Lagoon

A second option being considered is construction of a new lagoon located on the south and west side of the existing lagoon such that the lagoon will end up with two asymmetrical cells. In this case also, the existing lagoon will be emptied and rehabilitated once the new lagoon is operational.

6.1.3. Construction of New Lagoon South of Existing Lagoon and Enlargement of Existing Lagoon

This option would entail construction of a new lagoon south of the existing lagoon and enlarging the existing lagoon to obtain two identical cells. In this case, once the new lagoon is operational, the existing lagoon will be emptied. The west berm of the existing lagoon will be demolished. The north berm of the existing lagoon will be extended in a westerly and southerly direction to meet the west berm of the new lagoon. This would result in a lagoon with two cells.

6.2. Design Options

The investigation has revealed that the existing lagoon has been constructed with permeable soils and is founded on ice rich soils. The proposed lagoon will also be constructed with permeable materials and set on ice rich soils. Conventional berms constructed on ice rich soils are bound to experience large settlements due to degradation of the permafrost and thawing of the underlying ice rich soils. In addition, they are also prone to leakage since the only materials available for construction of the berms are granular. Installation of liners in the lagoons is not considered to be an option since the liners may rupture due to large settlements that the berms may experience.

It is considered that a feasible option is to construct the berms as 'ice dams' i.e. the central core of the berms and the underlying ice rich soils are maintained in a constantly frozen state. The frozen core of the berms would act as a liner and minimize seepage out of the lagoons. The agradation of the permafrost into the berms may be achieved by natural freezing process if sufficient time would be available to achieve this. Alternatively it may be necessary to install thermosyphons in the berms. It is recommended that a geothermal analysis of the site should be undertaken to determine the most economical method of achieving these objectives.

An alternative option is to maintain the ice rich soils underlying the lagoon in a constantly frozen state by installation of thermosyphons and to either fully line the lagoon or line the berms only and seal the liner into an impervious stratum i.e. permafrost. Theoretically, a lined lagoon will not be subjected to buoyant or seepage forces. However, these conditions could develop if the liner is damaged or any of the joints fail. It is therefore recommended that the berms of a lined lagoon should also be designed on the assumption that they would be subjected to buoyancy and seepage forces.

The liner for the lagoons may consist of needle-punched Bentofix Geosynthetic Clay Liner. The liner should be placed on a sand cushion at least 300 mm thick. It should be covered with at least 150 mm of sand fill. In addition, 300 mm of cover material consisting of on site gravel should be provided on top of the sand as erosion protection. The liner should be installed in accordance with the manufacturer's recommendations. Installation of the liner should be supervised by experienced personnel to ensure that it has been installed according to the project specifications since satisfactory performance of the liner is dependant on its proper installation.

It is noted that synthetic liners, such as High Density Polyethylene (HDPE), Reinforced and Unreinforced Chlorinated Polyethylene (CPE) and Chlorosulphonated Polyethylene (hypalon) are also available and have been used in the Arctic environment. However, these liners are expected to be more costly compared to the Geosynthetic Clay Liner.

7.0 Slope Stability Analysis

It is noted that with 'ice dam' method of construction of the berms, the central core of the berms and the underlying foundation soils would be permanently maintained in a frozen state. However, the surfaces of the inside and outside slopes of the berms would still be subject to seasonal freezing and thawing. Also, although the permeability of the frozen soil is very low, it is feasible that a steady state seepage conditions may develop in the berms over a long period of time. Therefore, the stability of slope analyses to compute the design side slopes of the berms were based on unfrozen soils. However, the analyses assumed that the underlying founding soils would be maintained in a frozen state.

A review of the proposed three schemes revealed that the most critical berm section would be the south berm of the new lagoon and that this cross-section is common to all the three options being considered. Therefore, the stability of the slopes of the south berm of the proposed lagoon was analysed to determine the steepest slopes that would be stable.

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. One cross-section of the berm (Cross-Section AA) was analysed. The location of the Cross-Section A-A is shown on Figure 1.

The following assumptions were made in the slope stability analyses:

(1) The crest of the berm is at Elevation 65.0 m. The crest width of the berm is 5 m. The inside slope of the berm was analysed for a slope of 4H:1V and 3.5H:1V. The outside slope of the berm was analysed for an inclination of 3H:1V to 2.5H:1V.

(2) The berms will be constructed with silty sand and gravel fill which contains some cobbles and boulders. The berms would be founded on silty sand to sandy silt soils which are ice rich.

(3) The ice rich soils underlying the berm would be maintained in a permanently frozen state.

(4) The engineering property of the various layers were assumed to be as follows:

Soil Type	Unit Weight (kN/m3)	Effective Cohesion c' (kPa)	Effective Angle of Internal Friction ϕ (degrees)
Silty Sand Fill	18	0	30
Silty Sand	18	0	30
Ice	9	100 – 125	0
Sandy Silt	17	0	27 – 29
Silty Sand Till	20	0	32

It is noted that conservative shear strength parameters were selected for design purposes considering limitations of available construction equipment and experience in the Hamlet.

(5) The water level in the pond would be at Elevation 63.0 m approximately or lower and that the berm would not be overstopped at any time. Also, the berm would not be subject to rapid drawdown condition.

The inside slopes were analysed for a fully submerged condition whereas the outside slopes were analysed for steady state seepage condition. The analysis was performed for static as well as seismic loading conditions.

The results of the analyses are given on Figures 17 to 26 inclusive and have been tabulated on Table 3.

Table 3
Computed Factors of Safety for Upstream and Downstream Berm Slopes

Slope Identification	Slope Inclination	Loading Condition	Computed Factor of Safety	Figure #
Upstream Slope (inside)	4H:1V	Completely submerged	2.87	17
	4H:1V	Completely submerged with seismic loading	1.23	18
	3.5:1V	Completely submerged	2.42	19
	3.5:1V	Completely submerged with seismic loading	1.15	20
Downstream Slope (outside)	2.5H:1V	Steady state seepage	1.3	21
	2.5H:1V	Steady state seepage with seismic loading	0.93	22
	2.75H:1V	Steady state seepage	1.59	23
	2.75H:1V	Steady state seepage with seismic loading	1.08	24
	3H:1V	Steady state seepage	1.99	25
	3H:1V	Steady state seepage with seismic loading	1.31	26

Based on current practice in the industry, a minimum factor of safety of 1.5 is required for static loading conditions and a factor of safety of 1.1 for seismic loading conditions. A review of Table 3 indicates that a 3.5H:1V upstream slope and 2.75H:1V downstream slope would satisfy the requisite factors of safety. Therefore, these slopes may be used in the design. However, it is noted that geothermal considerations may require the inside slope of the berms to be constructed at a flatter inclination than the 3.5H:1V recommended.

It is noted that the computed slopes would be stable provided that the berms are not overtopped and they are not subjected to rapid drawdown conditions and that the underlying ice rich soils are permanently maintained in a frozen state.

8.0 Rapid Drawdown Condition

The upstream slope was also analysed for rapid drawdown condition. The results are given on Table 4. The analysis indicates that a 5.5H:1V slope would have a factor of safety of 1.65 under static loading conditions and 1.01 under seismic loading conditions. It is therefore concluded that if the berm would be subjected to a rapid drawdown condition, the stable upstream slope would be 5.5H:1V or flatter.

Table 4
Computed Factors of Safety of Inside Slope of the Berms for Rapid Drawdown Condition

Slope Inclination	Loading Condition	Computed Factor of Safety	Figure #
4H:1V	Static	1.39	27
4H:1V	Seismic	0.94	28
4.5:1V	Static	1.41	29
4.5:1V	Seismic	0.93	30
5H:1V	Static	1.56	31
5H:1V	Seismic	0.99	32
5.5H:1V	Static	1.65	33
5.5H:1V	Seismic	1.01	34

The rapid drawdown analysis was undertaken since originally unlined berms were proposed. With the installation of a liner, the berms would not be subjected to rapid drawdown conditions.

9.0 Causes of Failure of Existing Lagoon

The investigation has revealed that the problems being experienced with the existing lagoon primarily relate to its construction on ice rich soils. Construction of the lagoon has resulted in degradation of the permafrost and thawing of the underlying ice rich soils resulting in large settlements of the berms. The present investigation has also revealed that the on-site soils are ice rich with ice layers present random depths.

The problems related to the seepage of effluent from the lagoon stem from the fact that permeable soils were used for construction of the berm and a liner was not provided. The permeability of the soil is a function of its gradation, and degree of compaction. Isolated coarse granular pockets which are poorly compacted would be more permeable compared to the parent berm. The permeability of the material used for construction of the berms was estimated to vary from 4.9 x 10^{-5} cm/sec to 1 x 10^{-4} cm/sec. It is noted that the conventional practice in the industry for construction of impervious berms is to use soil with permeability of less than 1 x 10^{-6} cm/sec. Increased solar radiant heating over the south facing downstream berm slope may also have contributed to spatial variations in permafrost distribution within the berm and underlying foundations.

The problems related to the stability of the slopes stem from the fact that the existing slopes are too steep. A visual examination of the berm slopes revealed that the upper 1.0 m to 1.5 m of the inside slope is at an inclination of 1.5H:1V whereas below this depth, the slope flattens. Because of the presence of effluent in the lagoon, it was not possible to establish this slope inclination. However, it is considered that this slope is likely at an inclination of 2.5H:1V to 3H:1V. The outside slope has been estimated to be 1.5H:1V. The geotechnical investigation report for the project prepared by Thurber Engineering Ltd. recommended an inside slope of 4H:1V and outside slope of 3H:1V.

It is noted that the geotechnical investigation report prepared by Thurber Engineering Ltd. (Project 15-23-47 dated October 18, 2001) for the construction of the lagoon indicated a high excess ice content of the soil in the upper levels. Therefore, the report expressed concern regarding thaw settlement of the lagoon. It also indicated that it is not feasible to construct a conventional earth berm lagoon without suffering significant seepage (or leakage) through the berms. The report therefore recommended that the lagoon berms be constructed with sufficient width so that the permafrost table will aggrade (rise) into the berms and create a permafrost bound to retain the sewage. The report also recommended that a number of thermisters should be installed in the berms at various depths to monitor freeze back. The report also recommended a minimum crest width of 10 m with 4:1 horizontal to vertical interior slopes and 3:1 horizontal to vertical exterior slopes. Placement of rip rap to prevent erosion of the slopes was also recommended. However, it appears that these recommendations were not followed and a conventional lagoon with a top berm width of 4 m was constructed.

10.0 Remedial Measures

The remedial measures for rehabilitation of the lagoon would essentially consist of re-instating the degraded permafrost at the site since the lagoon has been built on the rich soils and flattening the slopes to a stable inclination. Failure in re-instatement of the permafrost may result in continued settlements of the berms and/or their sloughing due to lateral spreading.

It is recommended that a geothermal analysis should be undertaken to determine:

(1) Minimum width of the berm required in order to achieve aggregation of the permafrost into the berms and the underlying founding soils.

(2) Time required to achieve agradation of the permafrost by natural processes.

If the thermal analysis indicates that the required width of the berm or the time required to achieve agradation will be excessive or that agradation cannot be achieved by this method, consideration may be given to installation of thermosyphons to freeze the berms and the underlying founding soils.

Alternatively, the soils beneath the berms should be frozen and maintained in a permanently frozen state by installation of thermosyphons and the lagoons lined. The lagoons may either be fully lined or only the berms may be lined and the liner sealed into the permafrost.

It is recommended that the inside slope of the berms should be flattened to 3.5H:1V and the outside slope to 2.75H:1V.

Installation of the liner and erosion protection should be undertaken as discussed previously for the new lagoon.

11.0 Erosion Protection

It is noted that the computed upstream slopes of 3.5H:1V and downstream slope of 2.75H:1V will be stable provided that the berms are not overtopped and are not subjected to a rapid drawdown condition. Potential exists for considerable erosion and possibly failure of the berms if overtopped. Overtopping of the berms may be prevented by construction of a proper spillway structure which is capable of holding the overflow.

It has also been recommended that 300 mm of cover material consisting of on-site gravel should be provided on top of the sand fill as erosion protection.

12.0 Monitoring Requirements

Considering that the berms would be constructed on ice rich soils, it is recommended that settlements of the berms should be monitored for 2 to 3 years subsequent to completion of construction. The settlement readings should be undertaken at the beginning of spring and prior to on set of winter. For this purpose, concrete monuments should be planted in the crest of the berm at regular intervals. The settlements should be referenced to a bench mark installed in the bedrock.

13.0 General Comments

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

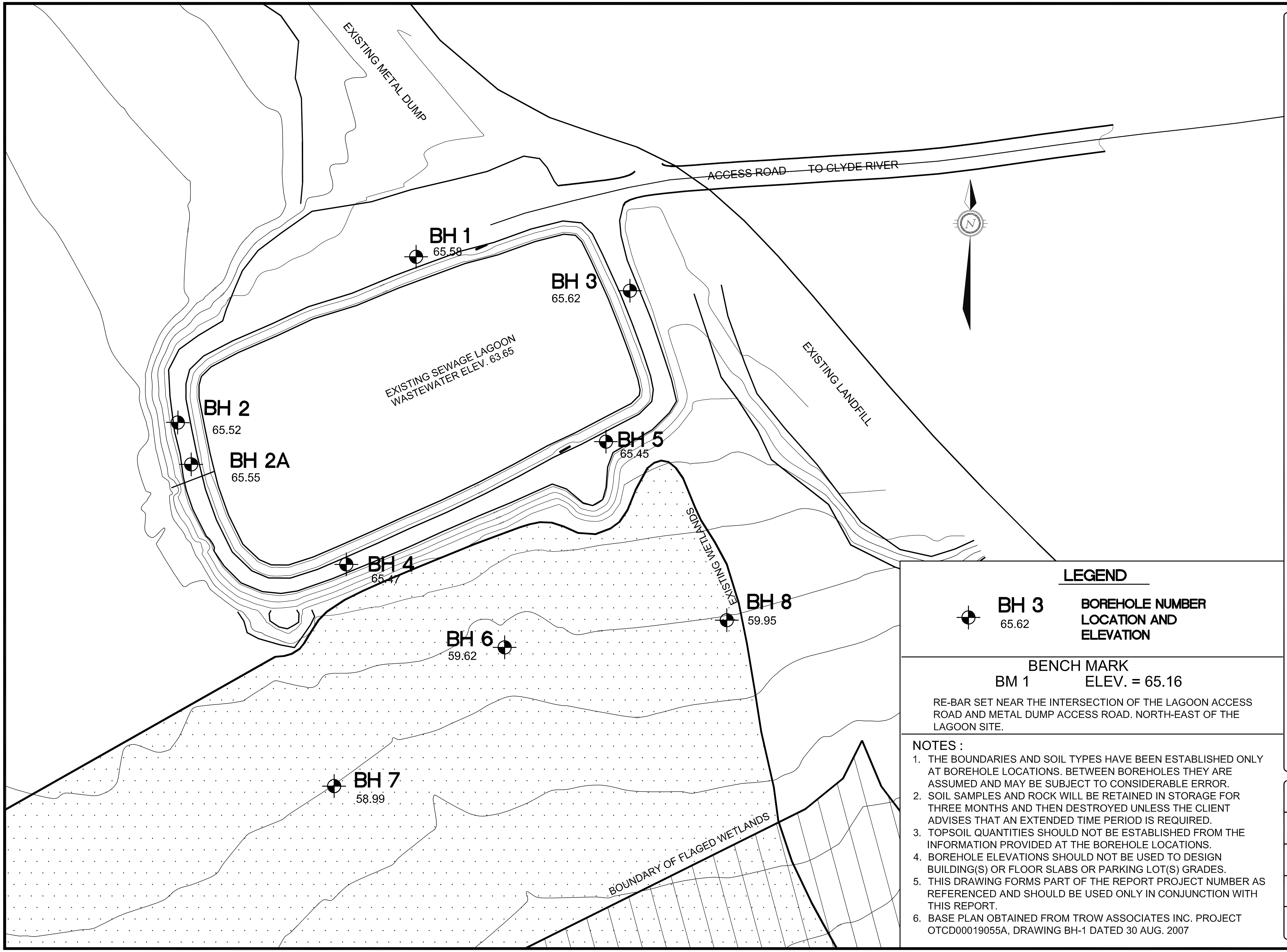
The information contained in this report is not intended to reflect on environmental aspects of the soils. Should specific information be required, including for example, the presence of pollutants, contaminants or other hazards in the soil, additional testing may be required.

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

Trow Associates Inc.

Surinder K. Aggarwal, M.Sc., P.Eng.	Ismail M. Taki, M.Eng, P. Eng.
Senior Project Manager	Manager/Assistant Branch Manager
Geotechnical & Materials Engineering Services	Geotechnical & Material Engineering Services

Figures



LEGEND

● BH 3 65.62 — **BOREHOLE NUMBER LOCATION AND ELEVATION**

BENCH MARK

BM 1 ELEV. = 65.16

RE-BAR SET NEAR THE INTERSECTION OF THE LAGOON ACCESS ROAD AND METAL DUMP ACCESS ROAD. NORTH-EAST OF THE LAGOON SITE.

NOTES :

1. THE BOUNDARIES AND SOIL TYPES HAVE BEEN ESTABLISHED ONLY AT BOREHOLE LOCATIONS. BETWEEN BOREHOLES THEY ARE ASSUMED AND MAY BE SUBJECT TO CONSIDERABLE ERROR.
2. SOIL SAMPLES AND ROCK WILL BE RETAINED IN STORAGE FOR THREE MONTHS AND THEN DESTROYED UNLESS THE CLIENT ADVISES THAT AN EXTENDED TIME PERIOD IS REQUIRED.
3. TOPSOIL QUANTITIES SHOULD NOT BE ESTABLISHED FROM THE INFORMATION PROVIDED AT THE BOREHOLE LOCATIONS.
4. BOREHOLE ELEVATIONS SHOULD NOT BE USED TO DESIGN BUILDING(S) OR FLOOR SLABS OR PARKING LOT(S) GRADES.
5. THIS DRAWING FORMS PART OF THE REPORT PROJECT NUMBER AS REFERENCED AND SHOULD BE USED ONLY IN CONJUNCTION WITH THIS REPORT.
6. BASE PLAN OBTAINED FROM TROW ASSOCIATES INC. PROJECT OTCD00019055A, DRAWING BH-1 DATED 30 AUG. 2007

Trow Associates Inc.
154 COLONNADE ROAD SOUTH PHONE (613) 225-9940
OTTAWA, ONTARIO K2E 7J5 FAX (613) 225-7337

CLIENT: GOVERNMENT OF NUNAVUT

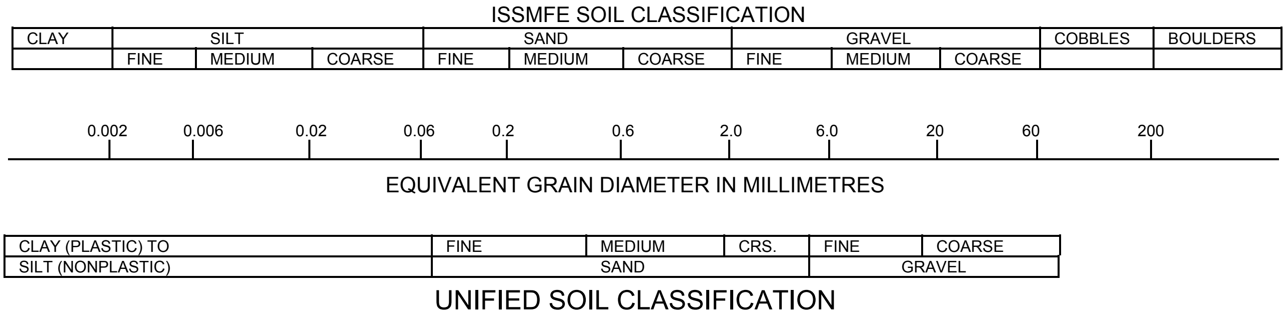
TITLE: BOREHOLE LOCATION PLAN, CLYDE RIVER WASTEWATER LAGOON

scale 1:1000
date 27/11/2007
drawn by M. NUGENT
project no. OTGE00019055B

1

Notes On Sample Descriptions

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



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

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

Log of Borehole 1

Trow

Project No: OTGE00019055B
Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion
Location: Clyde River, Nunavut
Date Drilled: 'August 19, 2007
Drill Type:
Datum: Geodetic
Logged by: Checked by:

Figure No. 2
Feuille. 1 of 1

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

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20 40 60 80) Shear Strength kPa (50 100 150 200)	Combustible Vapour Reading (ppm) (250 500 750) Natural Moisture Content % Atterberg Limits (% Dry Weight) (20 40 60)	SAMPLES	Natural Unit Wt. kN/m³
	▨	**FILL** Fine to coarse sand with fine to medium gravel, brown, moist	65.6	0	27 ○	×	☒	
	▨	**FILL** Gravelly sand, some silt, trace clay, brown to grey brown, moist	65.0		103/250 mm ○	×	☒	
		Refusal to split spoon sampler @ 1.2 m Depth	64.4	1				

NOTES:
1. Borehole/Test Pit data requires interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 2

Trow

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 3

Feuille. 1 of 1

Date Drilled: 'August 23, 2007

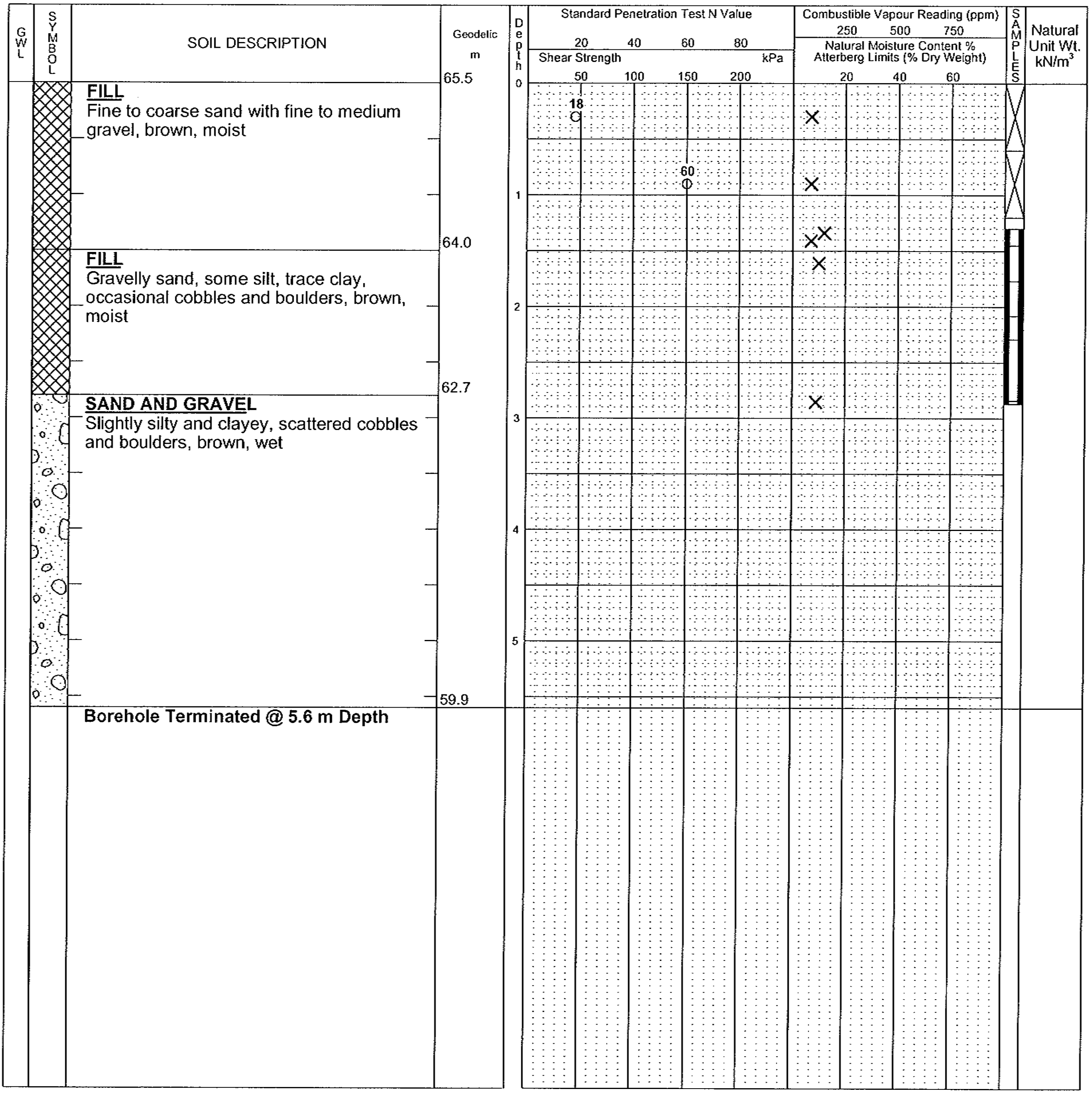
Drill Type:

Datum: Geodetic

Logged by:

Checked by:

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



GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth
			65.5	0
		FILL Fine to coarse sand with fine to medium gravel, brown, moist		
				1
		FILL Gravelly sand, some silt, trace clay, occasional cobbles and boulders, brown, moist	64.0	
				2
		SAND AND GRAVEL Slightly silty and clayey, scattered cobbles and boulders, brown, wet	62.7	
				3
				4
				5
		Borehole Terminated @ 5.6 m Depth	59.9	

NOTES:
1. Borehole/Test Pit data requires interpretation by Trow before use by others
2. Thermostat installed and borehole backfilled upon completion of drilling
3. Field work supervised by a Trow representative
4. See Notes on Sample Descriptions
5. This Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 2 (A)

Trow

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 4

Feuille. 1 of 1

Date Drilled: 'August 19, 2007

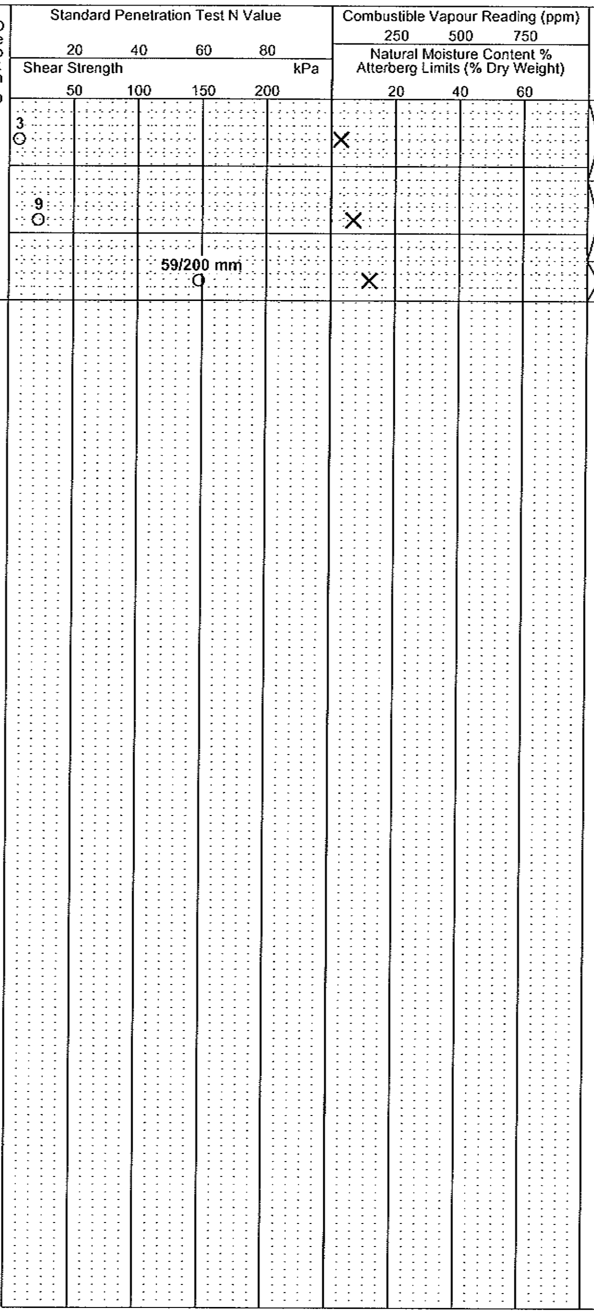
Drill Type:

Datum: Geodetic

Logged by: Checked by:

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

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth	Standard Penetration Test N Value (20 40 60 80) / Shear Strength kPa (50 100 150 200)	Combustible Vapour Reading (ppm) (250 500 750) / Natural Moisture Content % Atterberg Limits (% Dry Weight) (20 40 60)	SAMPLES	Natural Unit Wt. kN/m³
	▩	**FILL** Gravelly sand, trace to some silt, brown to grey, moist to wet	65.6	0	3	×	☒	
	▩				9	×	☒	
	▩		64.1	1	59/200 mm	×	☒	
		Refusal to split spoon sampler @ 1.5 m Depth						



NOTES:
1. Borehole/Test Pit data requires interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 3

Trow

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 5

Feuille. 1 of 1

Date Drilled: 'August 19, 2007

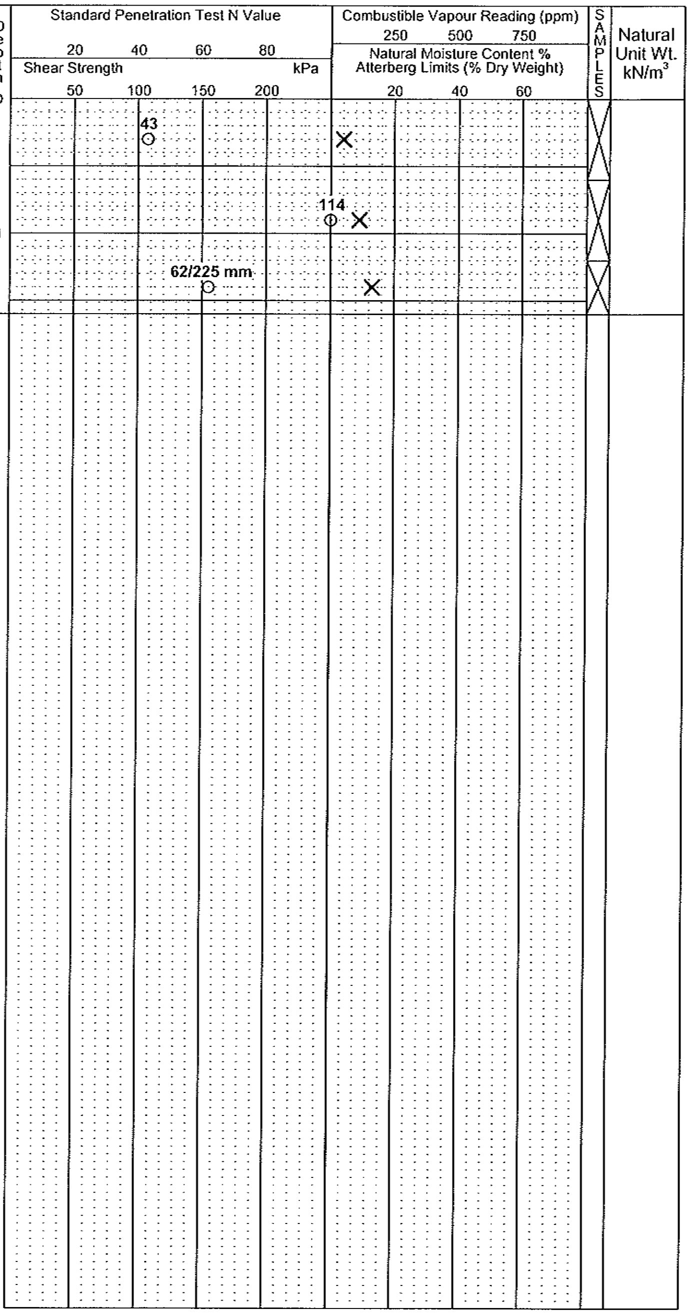
Drill Type:

Datum: Geodetic

Logged by: Checked by:

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

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m	Depth
			65.6	0
	▨	**FILL** Fine to coarse sand with fine to medium gravel, brown, moist	65.0	
	▨	**SILTY SAND TILL** Slightly cohesive and silty, scattered gravel, cobbles and boulders, brown		1
			64.0	
		Refusal to split spoon sampler @ 1.6 m Depth		



NOTES:
1. Borehole/Test Pit data requires Interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

LOG OF BOREHOLE BH1TO1~1.GPJ TROW OTTAWA.GDT 28/7/08

Log of Borehole 4

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 6

Feuille. 1 of 1

Date Drilled: 'August 19, 2007

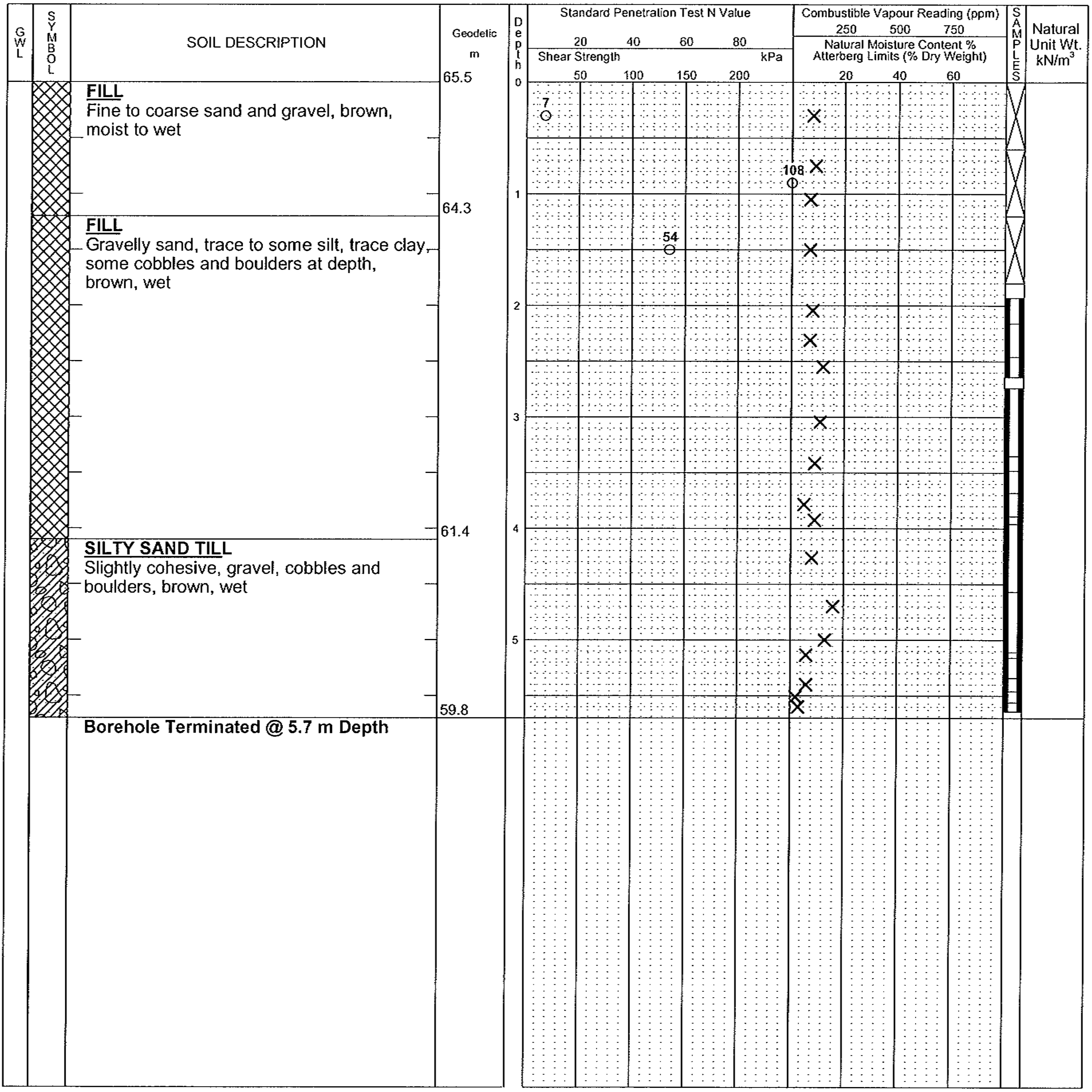
Drill Type:

Datum: Geodetic

Logged by:

Checked by:

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



FILL
Fine to coarse sand and gravel, brown, moist to wet

FILL
Gravelly sand, trace to some silt, trace clay, some cobbles and boulders at depth, brown, wet

SILTY SAND TILL
Slightly cohesive, gravel, cobbles and boulders, brown, wet

Borehole Terminated @ 5.7 m Depth

NOTES:
1. Borehole/Test Pit data requires Interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 5

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 7

Feuille. 1 of 1

Date Drilled: 'August 24, 2007

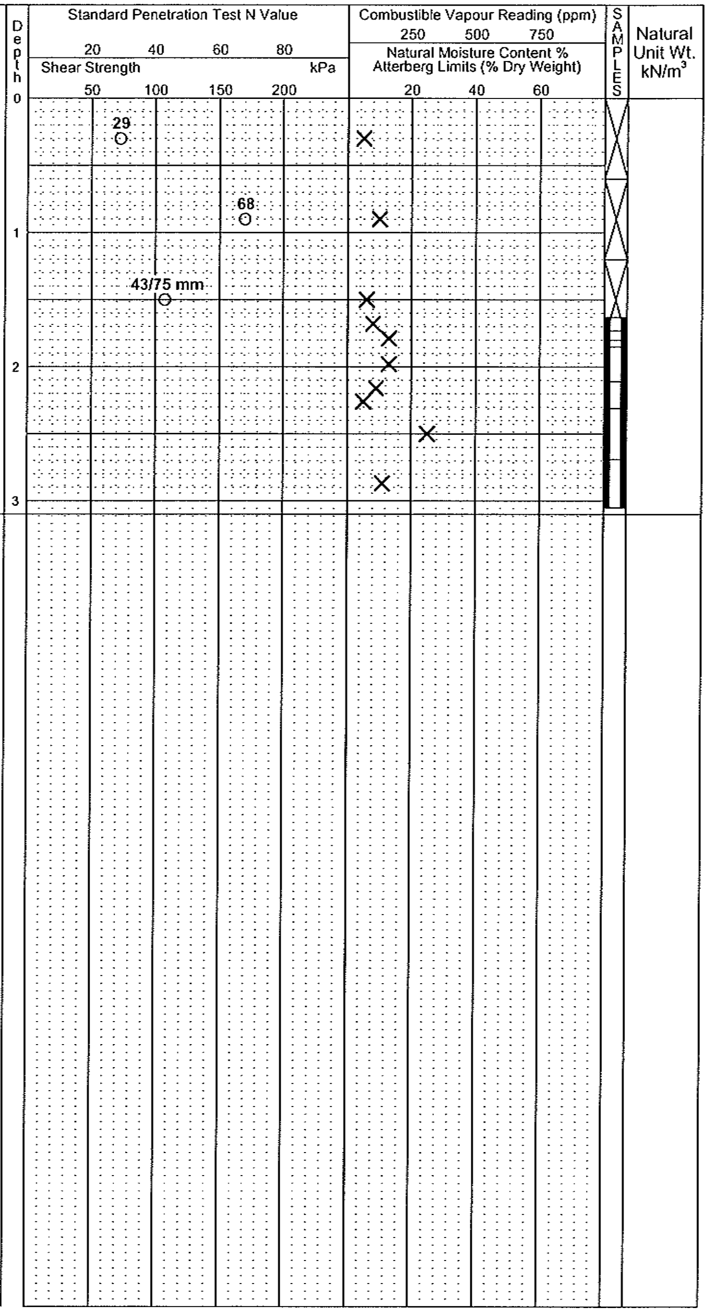
Drill Type:

Datum: Geodetic

Logged by: Checked by:

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

GWL	SYMBOL	SOIL DESCRIPTION	Geodetic m
			65.5
	▨	**FILL** Gravelly sand with some silt, trace clay, organic inclusions below 2.5 m depth brown, moist	
			64.3
	▨	**FILL** Trace clay, fine to medium gravel, grey to grey brown, moist	
			63.0
	▨	**FILL** Slightly cohesive, some organics, brown	
			62.4
		Borehole Terminated @ 3.1 m Depth	



LOG OF BOREHOLE BH1TO1~1.GPJ TROW OTTAWA.GDT 28/7/08

NOTES:
1. Borehole/Test Pit data requires Interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 6

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Date Drilled: 'August 19, 2007

Drill Type:

Datum: Geodetic

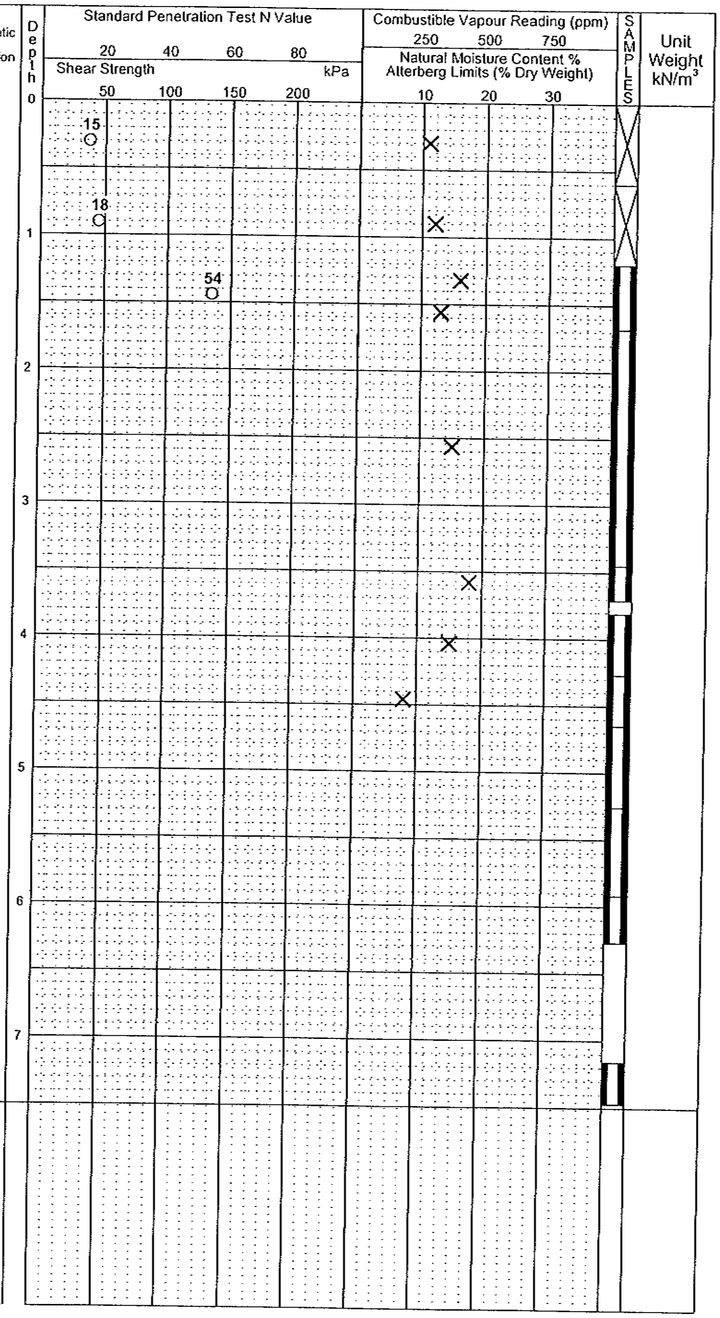
Logged by: Checked by:

Figure No. 8

Sheet No. 1 of 1

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

GWL	SYMBOLE	SOIL/ROCK DESCRIPTION	Geodetic Elevation m
		SILTY SAND Slightly cohesive, scattered gravel, cobbles and boulders, brown	59.6
		ICE	57.9
		SANDY SILT Grey, wet	56.8
		ICE	55.8
		SANDY SILT Organic, black, wet	55.3
		ICE	55.0
		SILTY SAND TILL Scattered gravel, cobbles and boulders, reddish brown to brown	54.4
		Borehole Terminated @ 7.5 m Depth	52.1



NOTES:
1. Borehole/Test Pit data requires interpretation by Trow before use by others
2. Thermostat installed and borehole backfilled upon completion of drilling
3. Field work supervised by a Trow representative
4. See Notes on Sample Descriptions
5. This Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 7

Trow

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 9

Sheet No. 1 of 1

Date Drilled: 'August 19, 2007

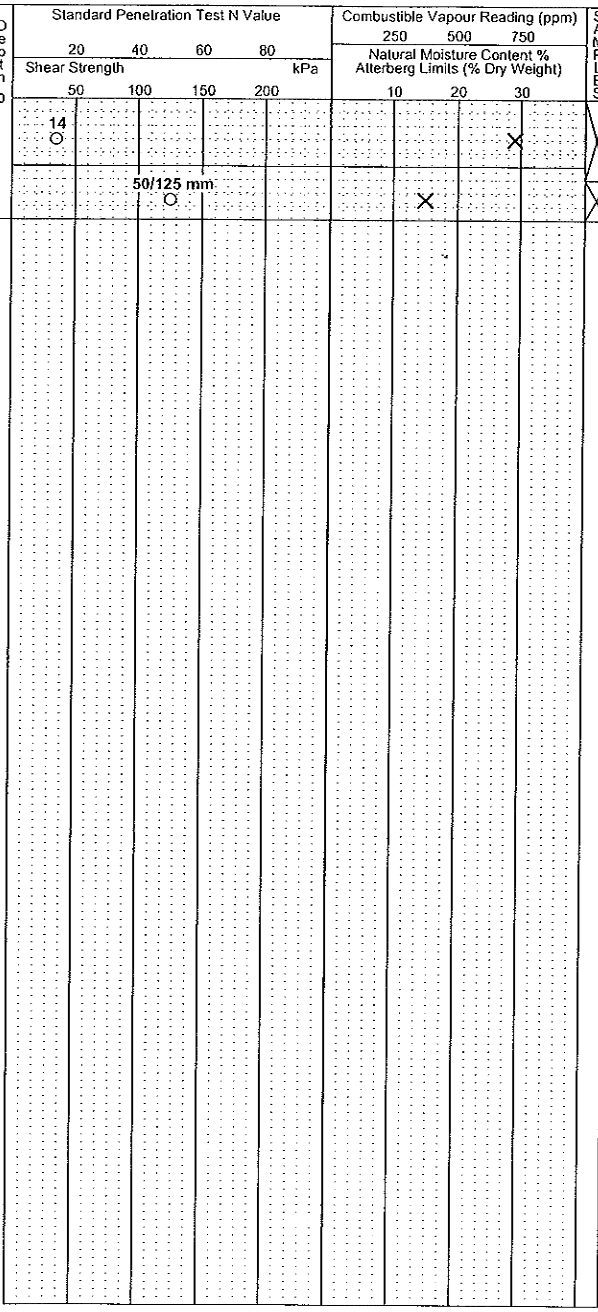
Drill Type:

Datum: Geodetic

Logged by: Checked by:

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

GWL	SYMBOLE	SOIL/ROCK DESCRIPTION	Geodetic Elevation m	Depth	SAMPLES	Unit Weight kN/m³
			59	0		
		TOPSOIL	58.7		☒	
		SILTY SAND Slightly cohesive, some organics, some gravel, dark brown, wet	58.1		☒	
		Refusal to split spoon sampler @ 0.9 m Depth				



NOTES:
1. Borehole/Test Pit data requires interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

CORE DRILLING RECORD

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

Log of Borehole 8

Trow

Project No: OTGE00019055B

Project: Geotechnical Investigation - Proposed Sewage Lagoon Expansion

Location: Clyde River, Nunavut

Figure No. 10

Sheet No. 1 of 1

Date Drilled: 'August 19, 2007

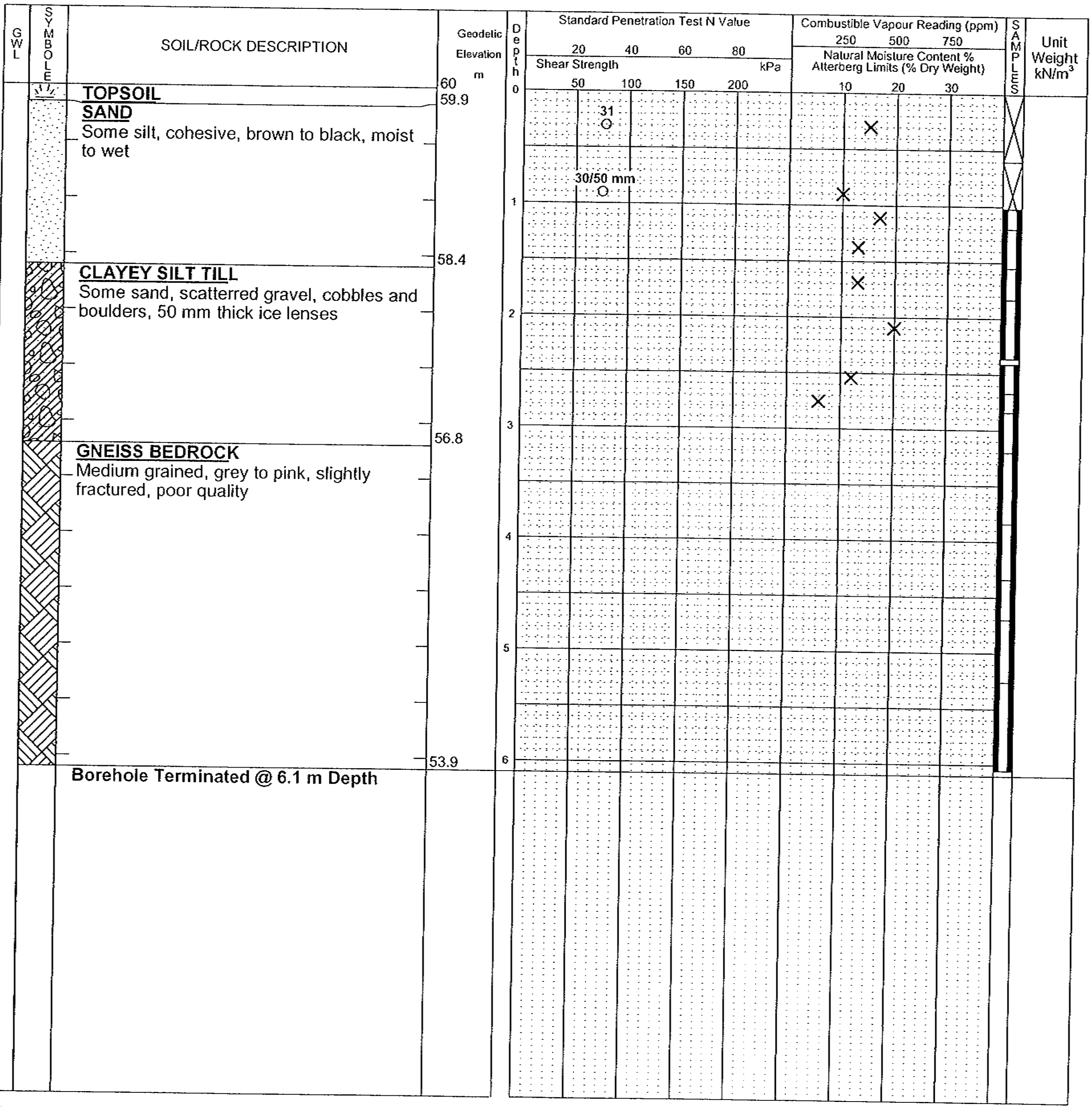
Drill Type:

Datum: Geodetic

Logged by: Checked by:

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 ▲



TOPSOIL

SAND
Some silt, cohesive, brown to black, moist to wet

CLAYEY SILT TILL
Some sand, scatterred gravel, cobbles and boulders, 50 mm thick ice lenses

GNEISS BEDROCK
Medium grained, grey to pink, slightly fractured, poor quality

Borehole Terminated @ 6.1 m Depth

NOTES:
1. Borehole/Test Pit data requires interpretation by 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 Figure is to read with Trow Associates Inc. report OTGE00019055B

WATER LEVEL RECORDS

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

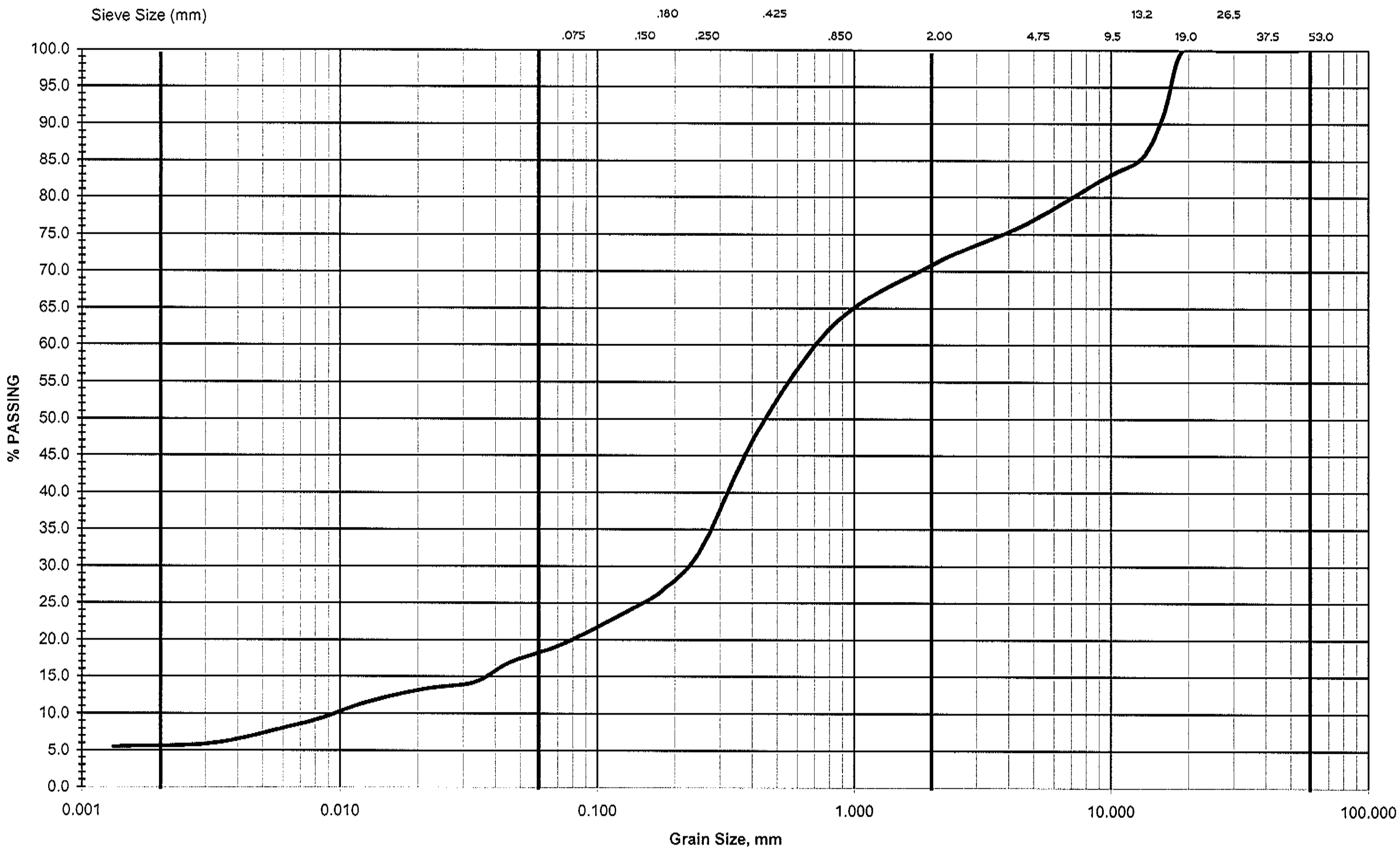
CORE DRILLING RECORD

Run No.	Depth (m)	% Rec.	RQD %
1	3.2 - 3.84	76	66
2	3.84 - 4.34	45	0
3	4.34 - 4.7	43	0
4	4.7 - 5.26	23	0
5	5.26 - 6.05	19	0

Trow

FIGURE: 11

GRAIN SIZE DISTRIBUTION CURVE

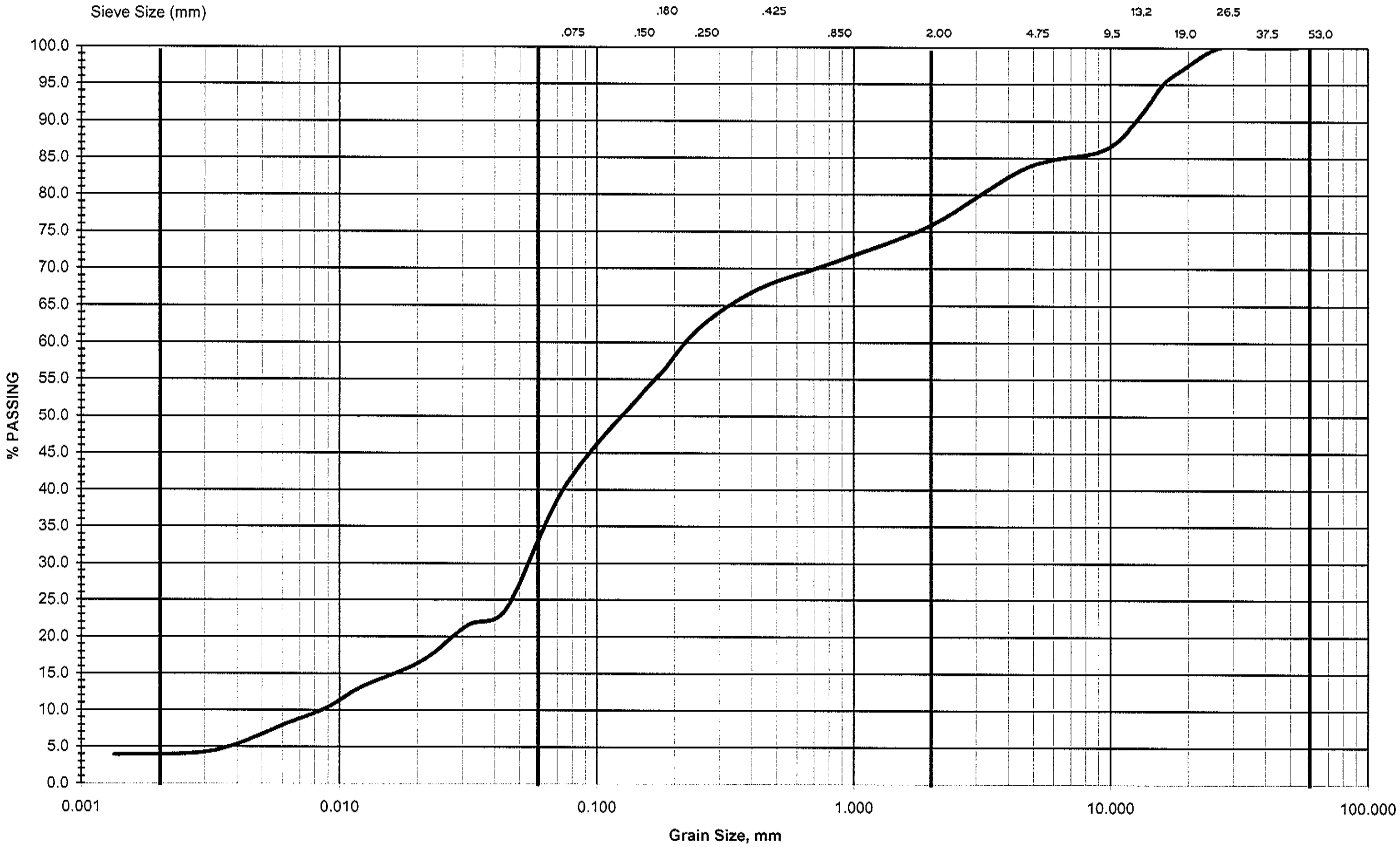


CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
	SILT			SAND			GRAVEL		
Modified M.I.T. Classification									

PROJECT :	OTGE00019055B	NAME & LOCATION:	Proposed Sewage Lagoon - Clyde River, Nunavut				
DATE SAMPLED:	September 17, 2007	BOREHOLE No.:	4	SAMPLE No.:	SS5	DEPTH (m):	2.4 to 2.5
SAMPLE DESCRIPTION:	Sand and gravel, some silt, trace clay						

FIGURE: 12

GRAIN SIZE DISTRIBUTION CURVE



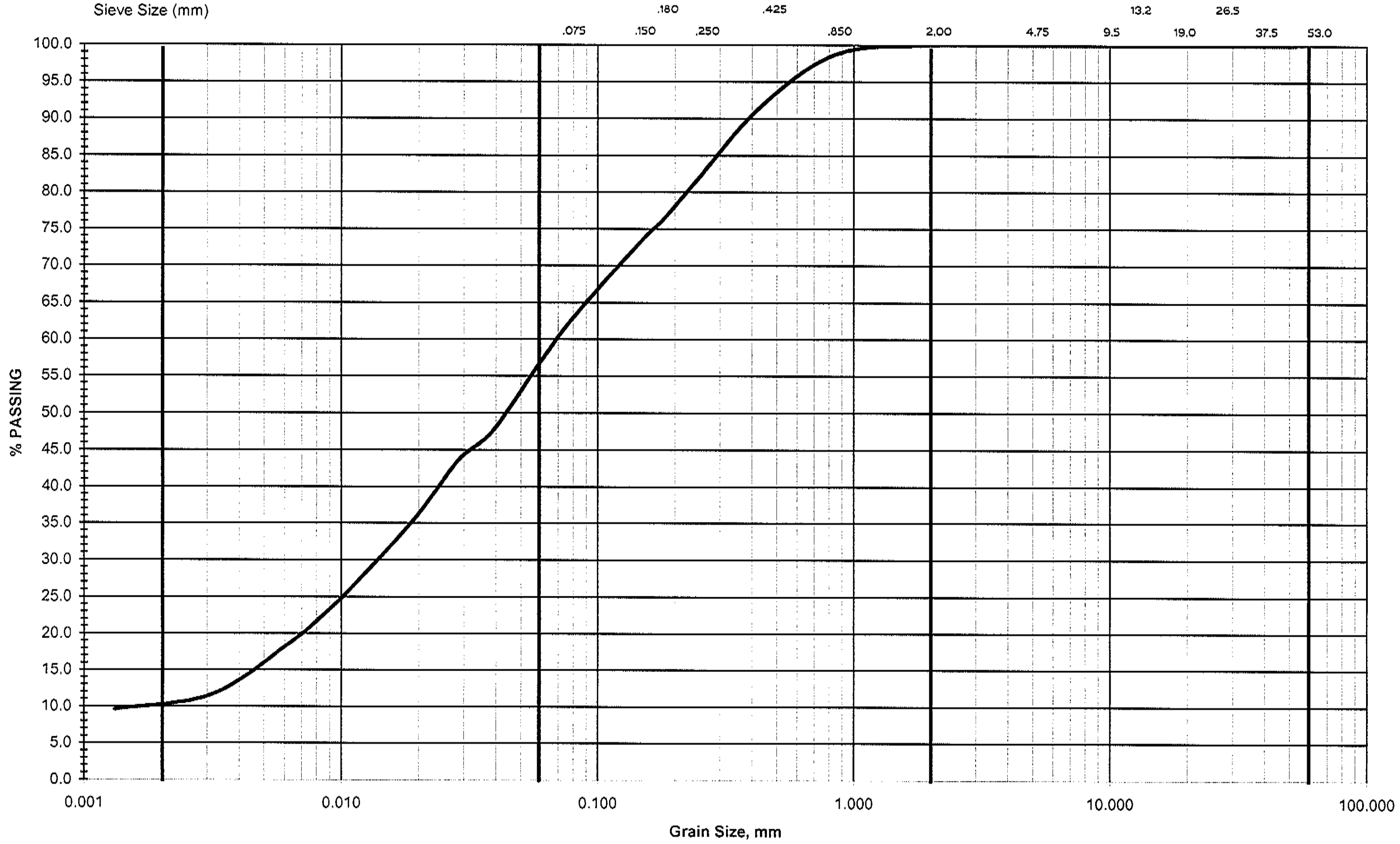
CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
	SILT			SAND			GRAVEL		
Modified M.I.T. Classification									

PROJECT :	OTGE00019055B	NAME & LOCATION:	Proposed Sewage Lagoon - Clyde River, Nunavut		
DATE SAMPLED:	September 17, 2007	BOREHOLE No.:	4	SAMPLE No.: SS9	DEPTH (m): 3.5 to 4.1
SAMPLE DESCRIPTION:	Silty sand, some gravel, trace clay				

Trow

FIGURE: 13

GRAIN SIZE DISTRIBUTION CURVE



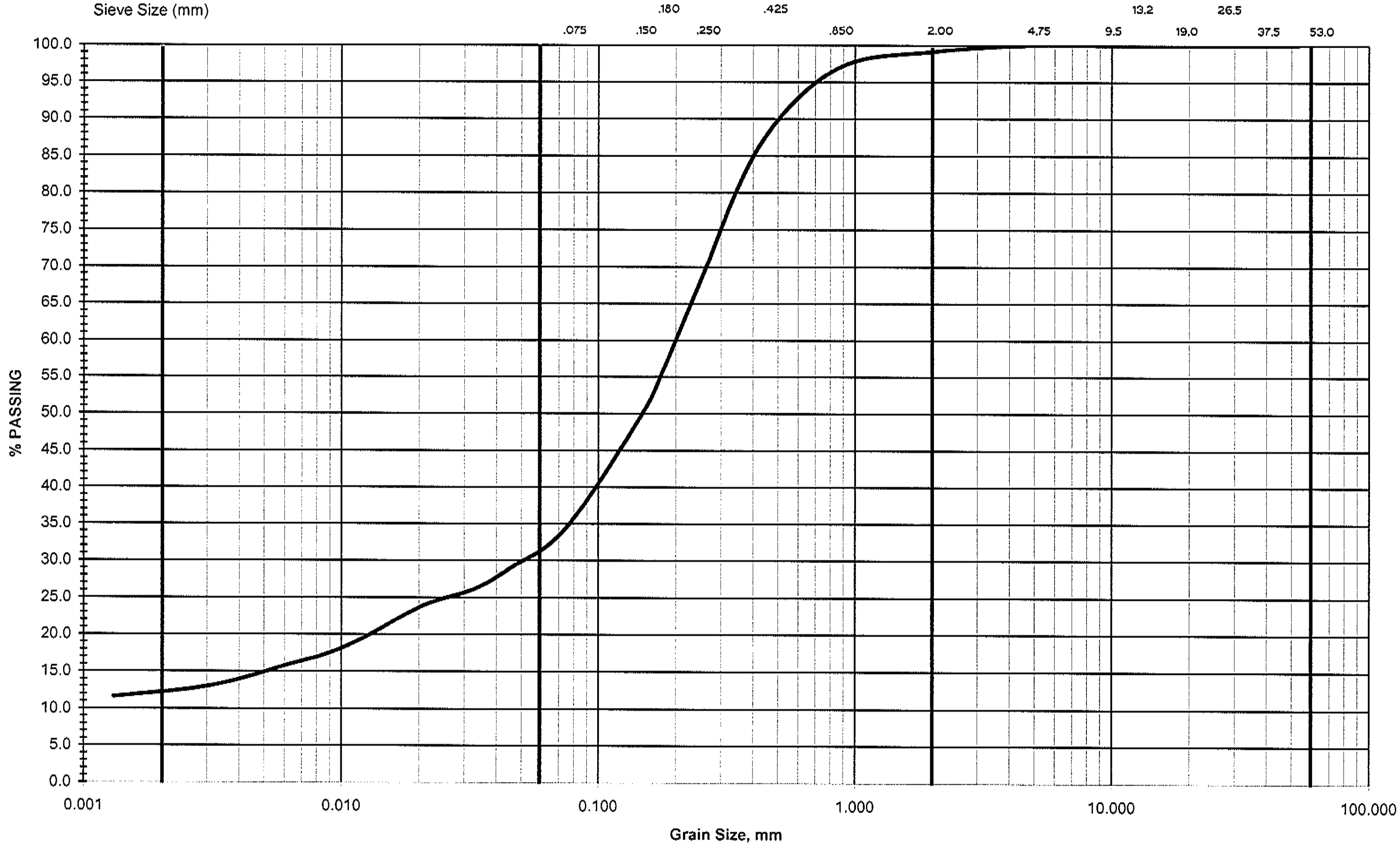
CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
	SILT			SAND			GRAVEL		
Modified M.I.T. Classification									

PROJECT :	OTGE00019055B	NAME & LOCATION:	**Proposed Sewage Lagoon - Clyde River, Nunavut**				
DATE SAMPLED:	September 17, 2007	BOREHOLE No.:	6	SAMPLE No.:	SS3	DEPTH (m):	1.2 - 1.7
SAMPLE DESCRIPTION:	**Silty sand, trace clay**						

Trow

FIGURE: 14

GRAIN SIZE DISTRIBUTION CURVE



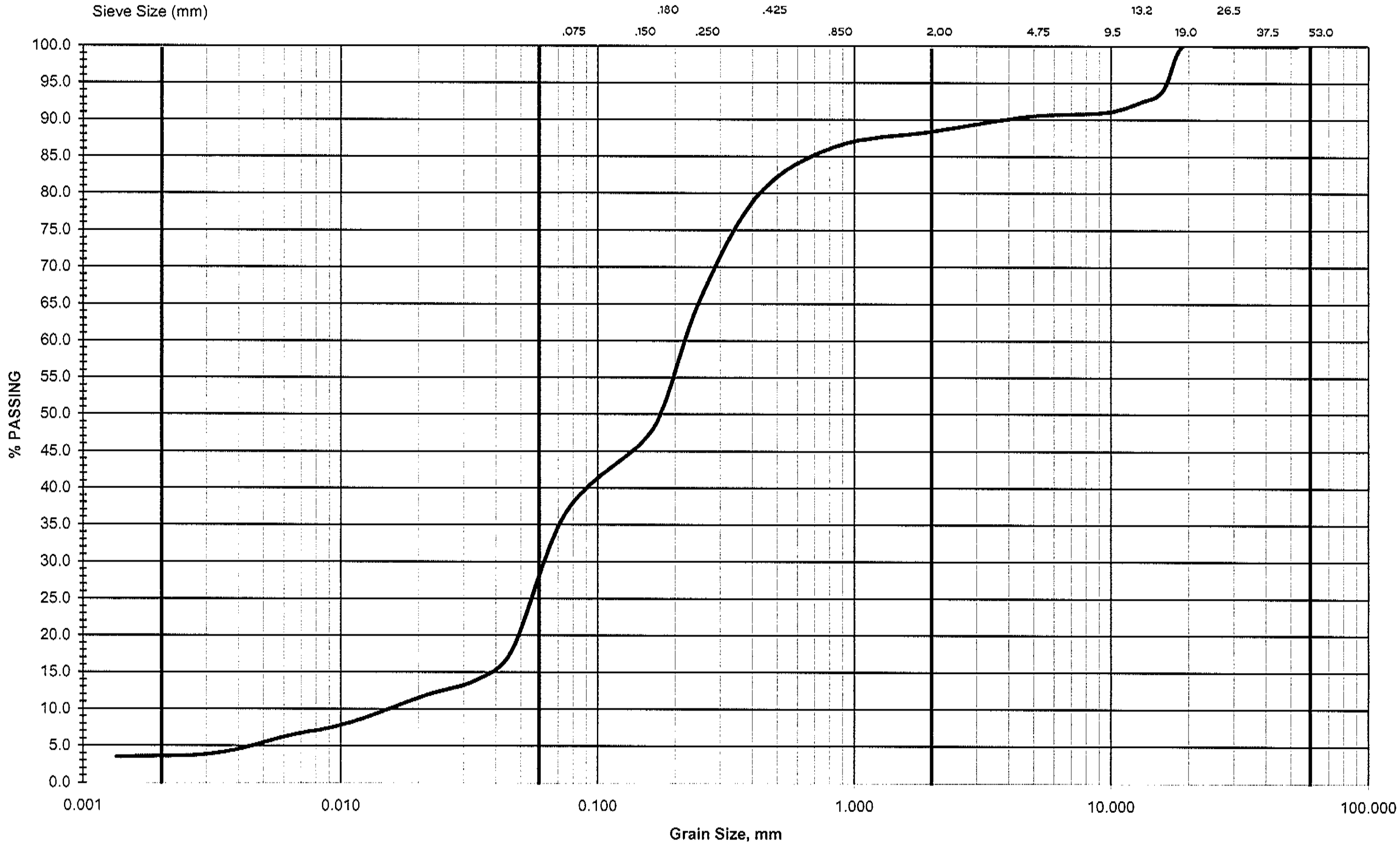
<table>
<tr><td rowspan="2">CLAY</td><td>FINE</td><td>MEDIUM</td><td>COARSE</td><td>FINE</td><td>MEDIUM</td><td>COARSE</td><td>FINE</td><td>MEDIUM</td><td>COARSE</td></tr>
<tr><td colspan="3">SILT</td><td colspan="3">SAND</td><td colspan="3">GRAVEL</td></tr>
<tr><td colspan="10">Modified M.I.T. Classification</td></tr>
</table>

PROJECT :	OTGE00019055B	NAME & LOCATION:	**Proposed Sewage Lagoon - Clyde River. Nunavut**		
DATE SAMPLED:	September 17, 2007	BOREHOLE No.: 8	SAMPLE No.: SS3	DEPTH (m):	1.0 - 1.2
SAMPLE DESCRIPTION:	**Sand, some clay and silt**				

Trow

FIGURE: 15

GRAIN SIZE DISTRIBUTION CURVE



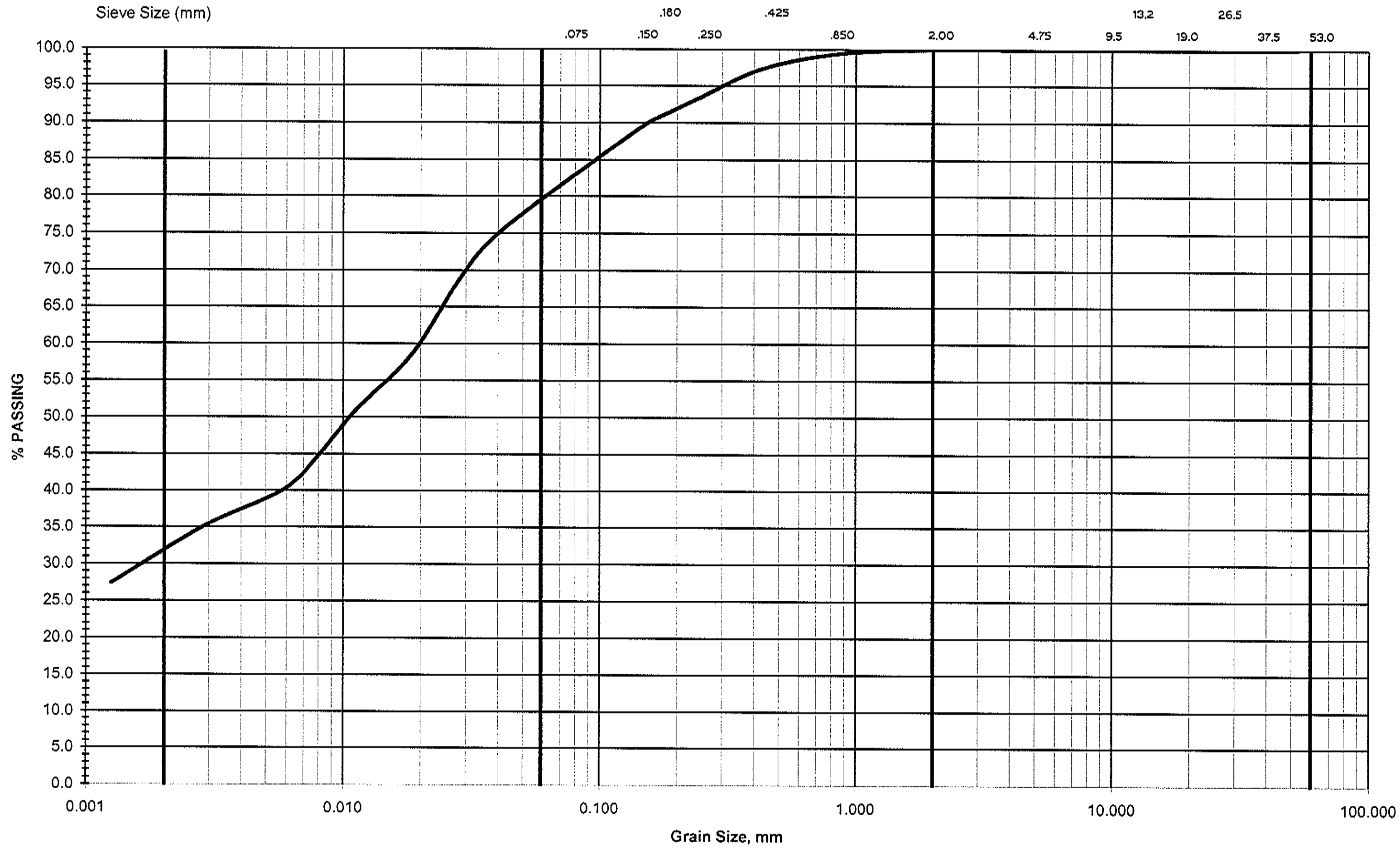
CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
	SILT			SAND			GRAVEL		
Modified M.I.T. Classification									

PROJECT :	OTGE00019055B	NAME & LOCATION:	**Proposed Sewage Lagoon - Clyde River. Nunavut**		
DATE SAMPLED:	September 17, 2007	BOREHOLE No.: 6	SAMPLE No.: SS6	DEPTH (m):	5.3 to 5.9
SAMPLE DESCRIPTION:	**Silty sand, some gravel**				

Trow

FIGURE: 16

GRAIN SIZE DISTRIBUTION CURVE



CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
	SILT			SAND			GRAVEL		
Modified M.I.T. Classification									

PROJECT :	OTGE00019055B	NAME & LOCATION:	**Proposed Sewage Lagoon - Clyde River. Nunavut**			
DATE SAMPLED:	September 17, 2007	BOREHOLE No.:	8	SAMPLE No.: SS8	DEPTH (m):	2.6 - 2.8
SAMPLE DESCRIPTION:	**Clayey silt, some sand**					

Figure 17

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 4H to 1V
Completely Submerged Analysis

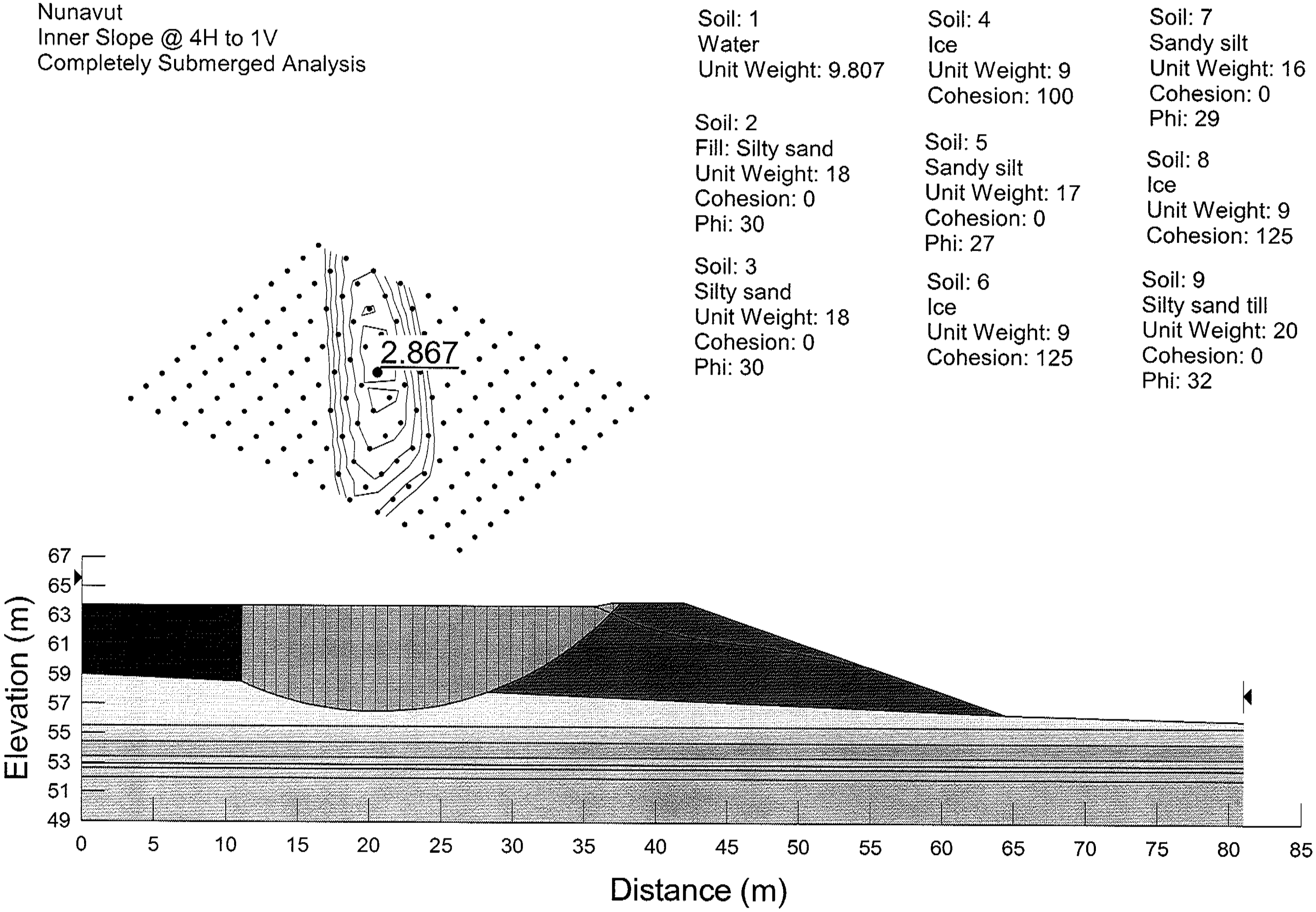
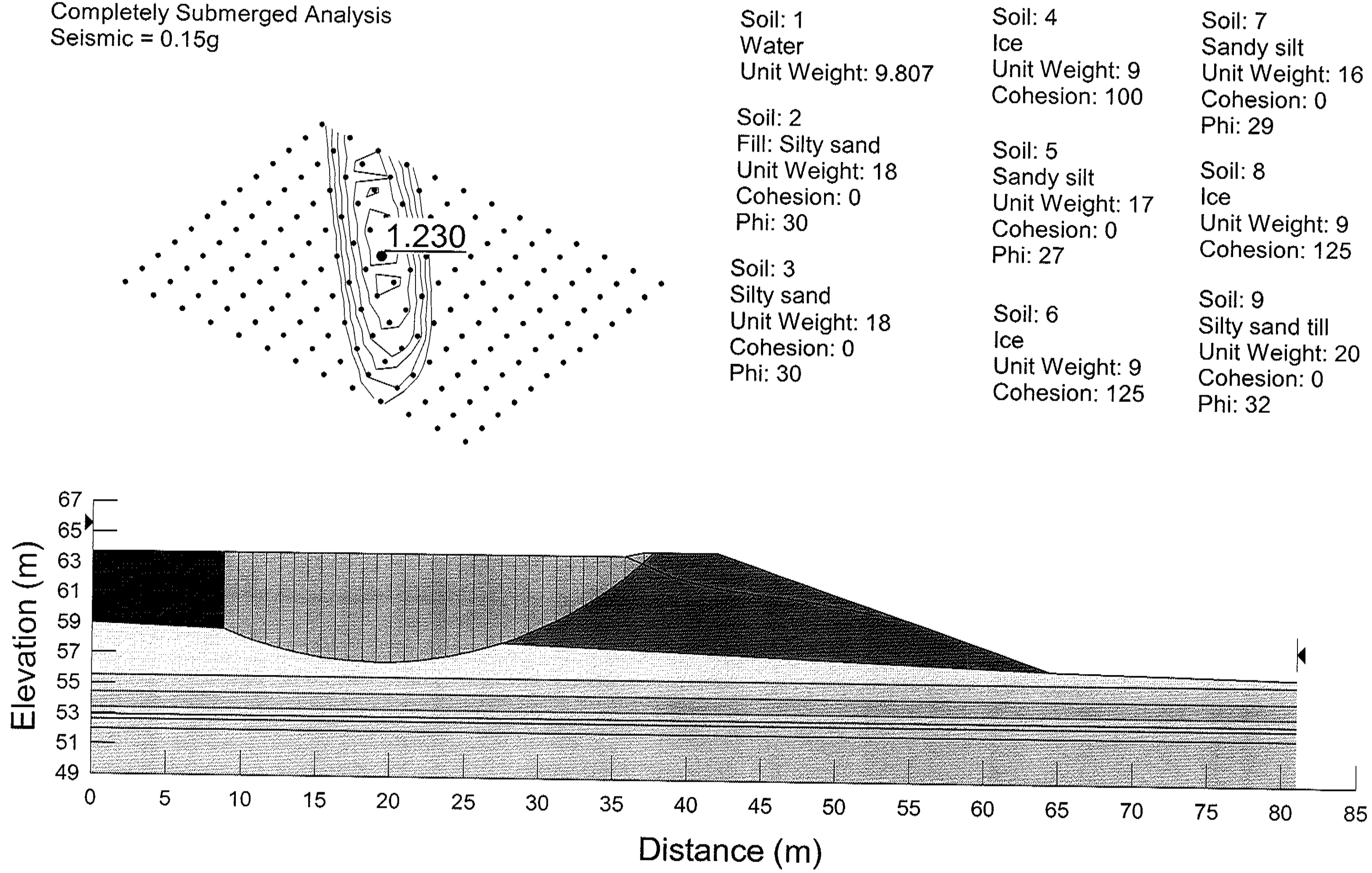


Figure 18

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 4H to 1V
Completely Submerged Analysis
Seismic = 0.15g



OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 3.5H to 1V
Completely Submerged Analysis

Figure 19

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 4
Ice
Unit Weight: 9
Cohesion: 100

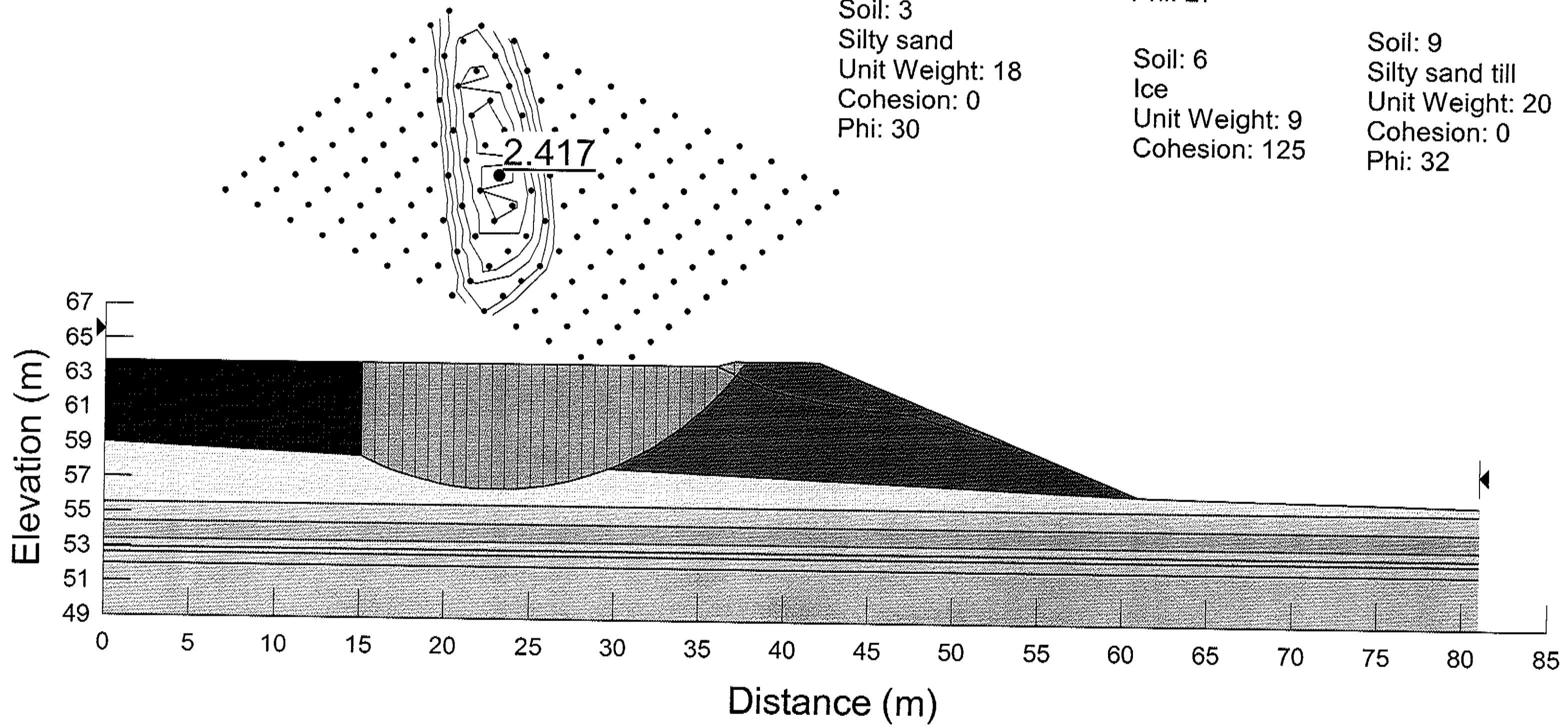
Soil: 5
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 6
Ice
Unit Weight: 9
Cohesion: 125

Soil: 7
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 8
Ice
Unit Weight: 9
Cohesion: 125

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32



OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 3.5H to 1V
Completely Submerged Analysis
Seismic = 0.15g

Figure 20

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 4
Ice
Unit Weight: 9
Cohesion: 100

Soil: 5
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 6
Ice
Unit Weight: 9
Cohesion: 125

Soil: 7
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 8
Ice
Unit Weight: 9
Cohesion: 125

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

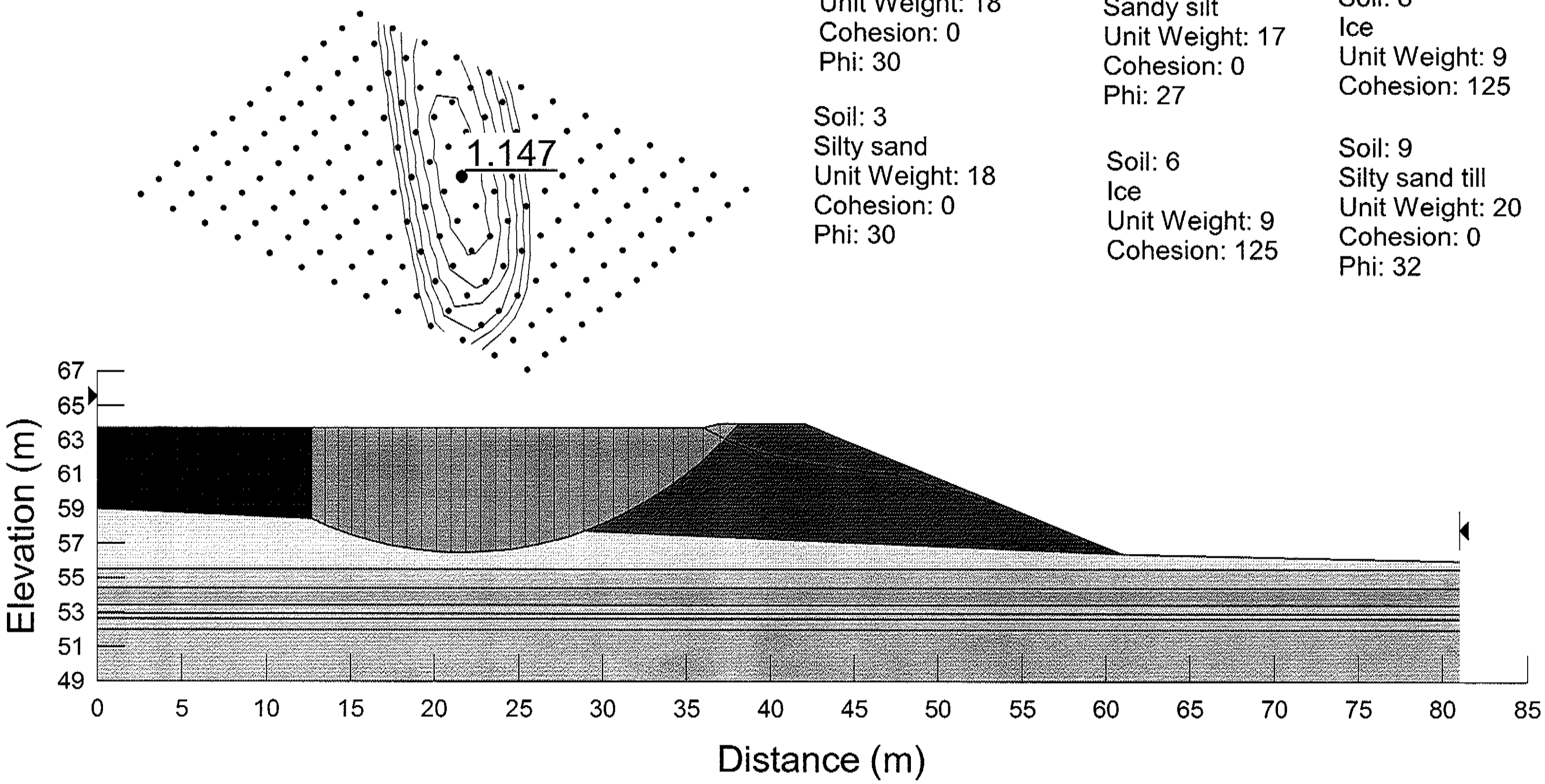


Figure 21

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Outside Slope @ 2.5H to 1V
Steady State Seepage Analysis

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 4
Ice
Unit Weight: 9
Cohesion: 100

Soil: 5
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 6
Ice
Unit Weight: 9
Cohesion: 125

Soil: 7
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 8
Ice
Unit Weight: 9
Cohesion: 125

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

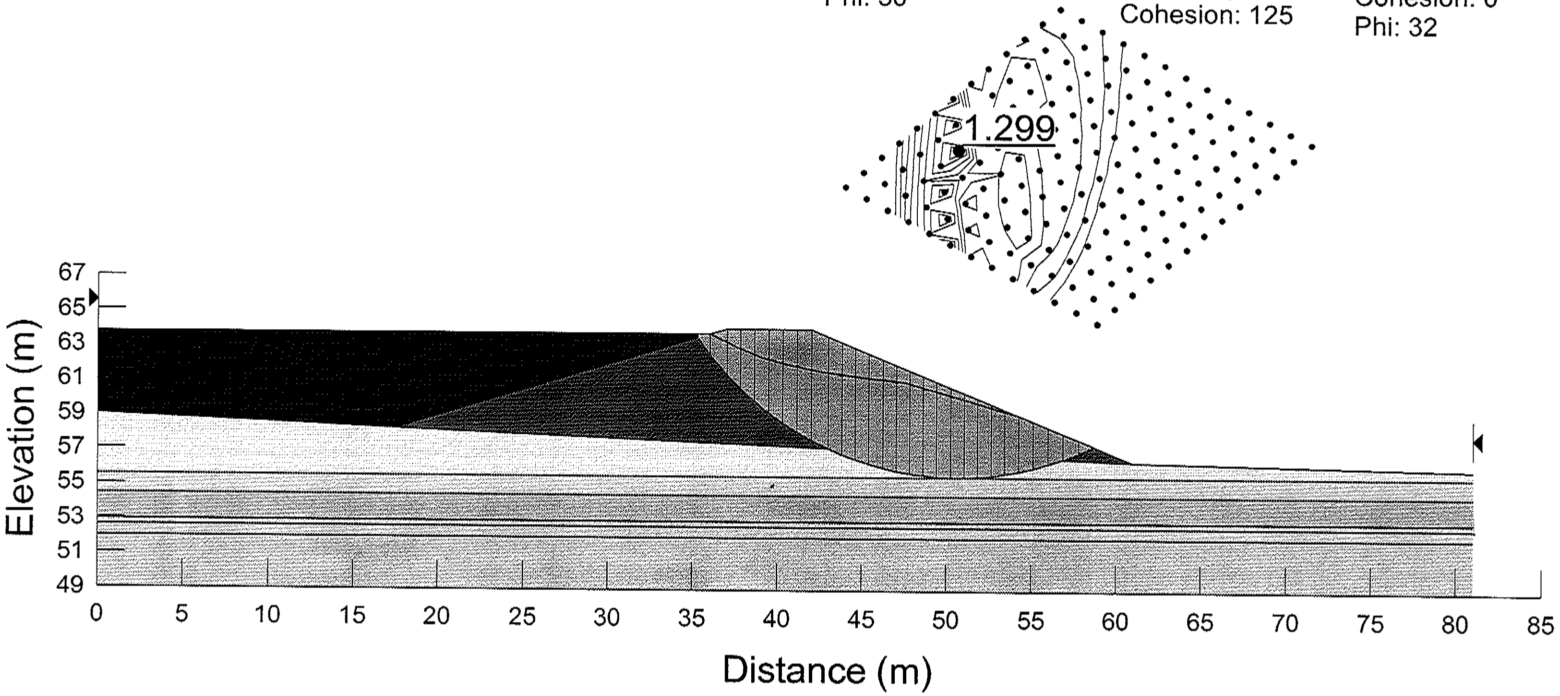


Figure 22

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Outside Slope @ 2.5H to 1V
Steady State Seepage Analysis
Seismic = 0.15g

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 4
Ice
Unit Weight: 9
Cohesion: 100

Soil: 5
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 6
Ice
Unit Weight: 9
Cohesion: 125

Soil: 7
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 8
Ice
Unit Weight: 9
Cohesion: 125

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

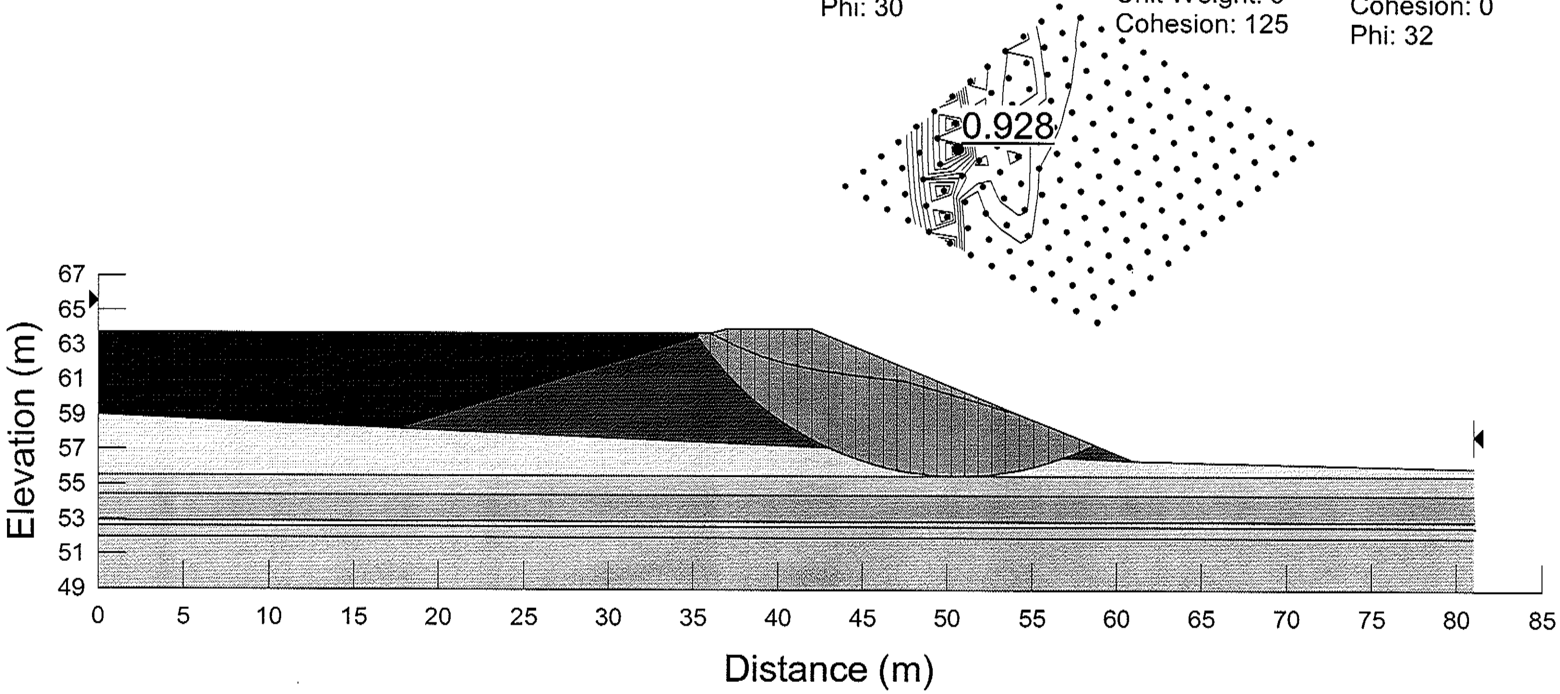
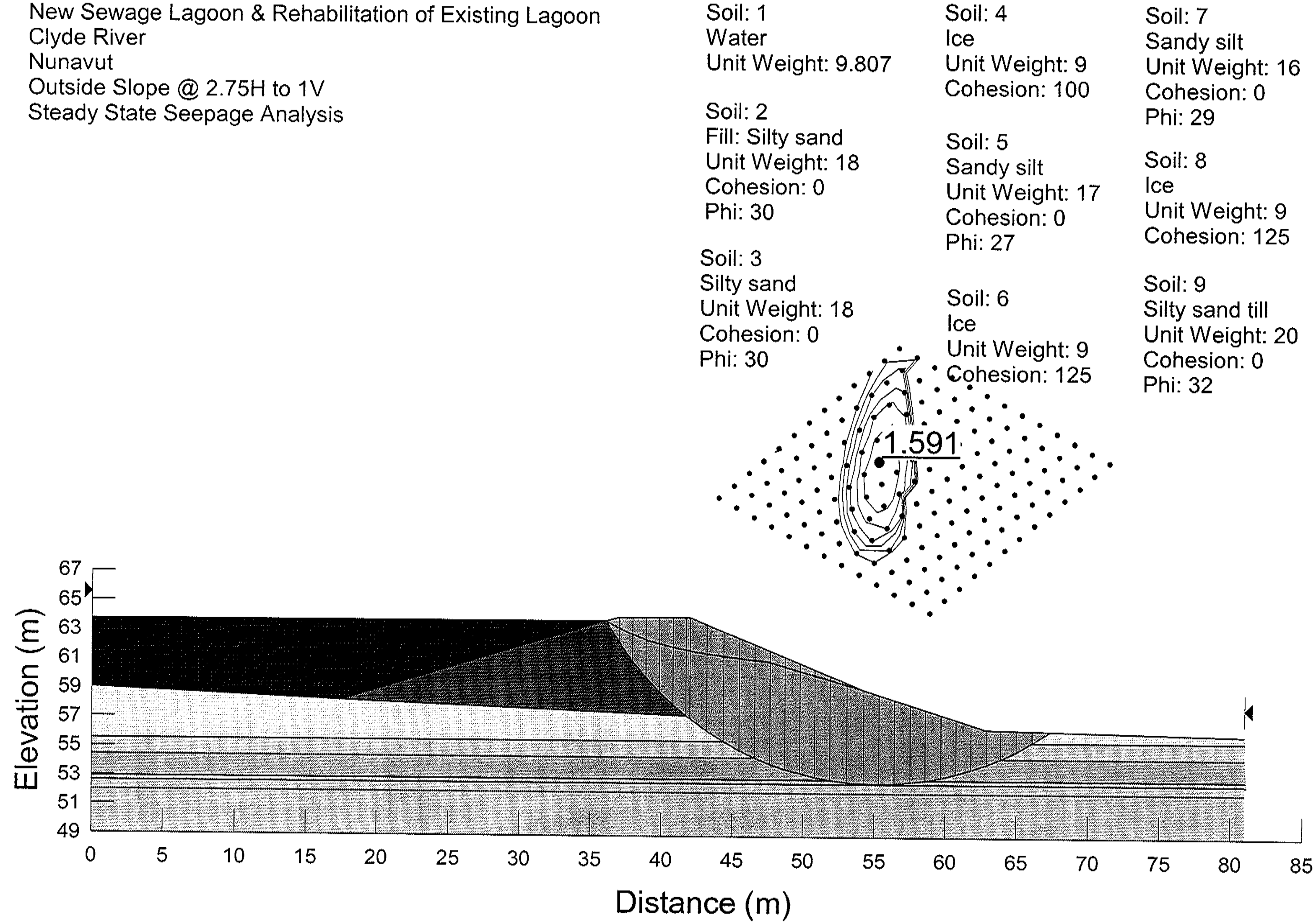


Figure 23

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Outside Slope @ 2.75H to 1V
Steady State Seepage Analysis



Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 4
Ice
Unit Weight: 9
Cohesion: 100

Soil: 5
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 6
Ice
Unit Weight: 9
Cohesion: 125

Soil: 7
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 8
Ice
Unit Weight: 9
Cohesion: 125

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

Figure 24

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Outside Slope @ 2.75H to 1V
Steady State Seepage Analysis
Seismic = 0.15g

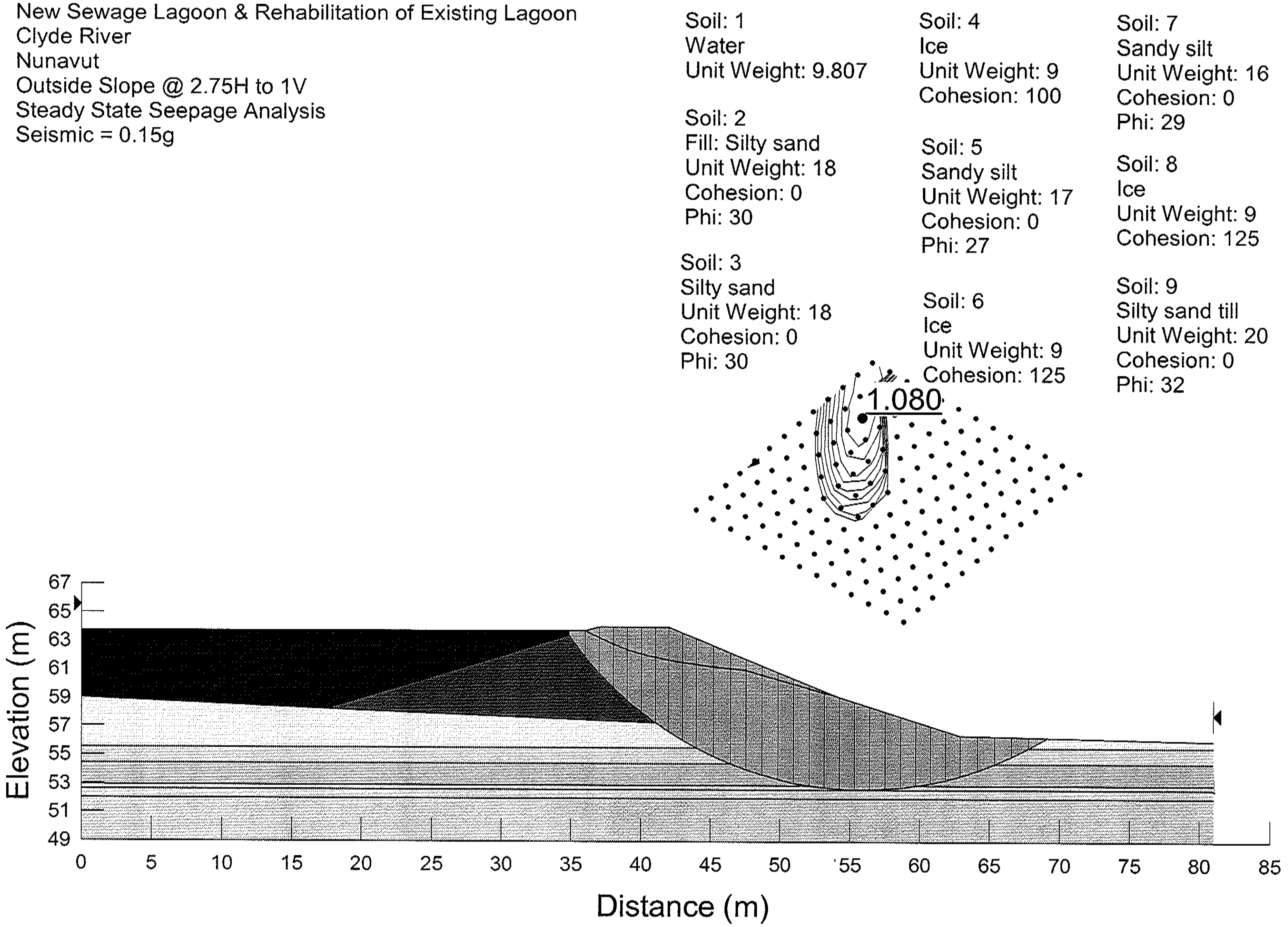


Figure 25

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Outside Slope @ 3.0H to 1V
Steady State Seepage Analysis

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 4
Ice
Unit Weight: 9
Cohesion: 100

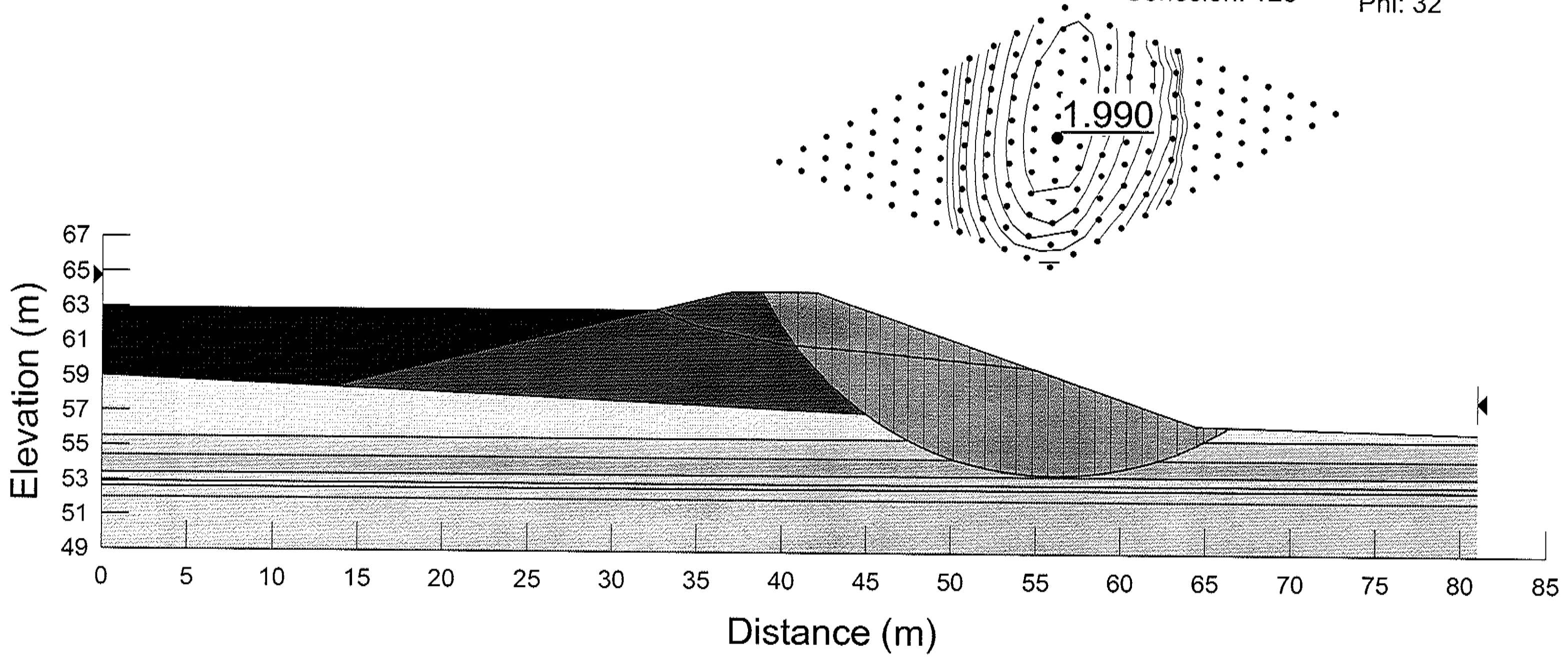
Soil: 5
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 6
Ice
Unit Weight: 9
Cohesion: 125

Soil: 7
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

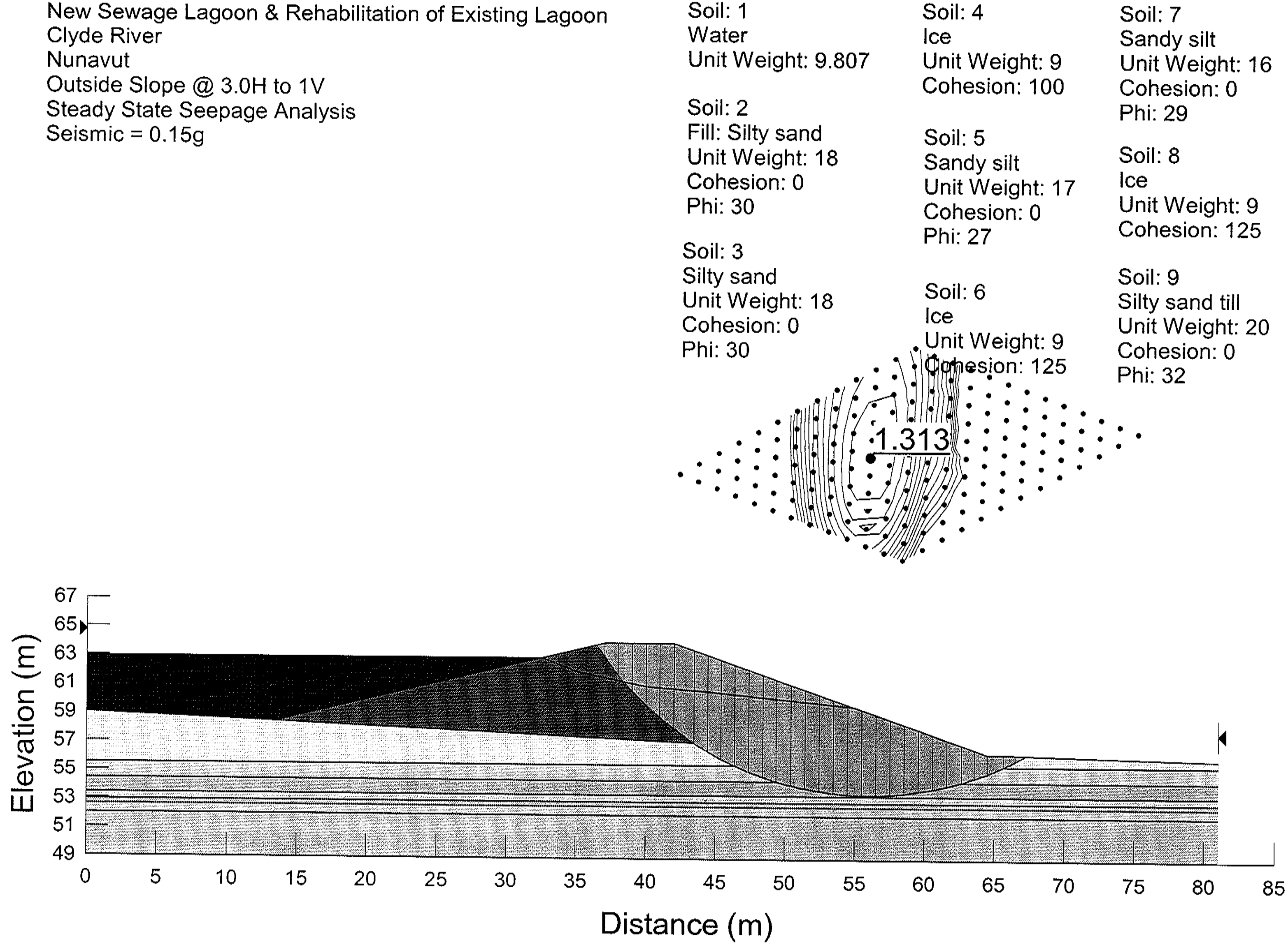
Soil: 8
Ice
Unit Weight: 9
Cohesion: 125

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32



OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Outside Slope @ 3.0H to 1V
Steady State Seepage Analysis
Seismic = 0.15g

Figure 26



OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 4H to 1V
Rapid Drawdown Analysis

Figure 27

Soil: 1
Fill: Silty Sand
Unit Weight: 18

Soil: 2
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Ice
Unit Weight: 9
Cohesion: 100

Soil: 4
Sandy silt
Unit Weight: 17
Cohesion: 0

Soil: 5
Ice
Unit Weight: 9
Cohesion: 125

Soil: 6
Sandy silt
Unit Weight: 16
Cohesion: 0

Soil: 7
Ice
Unit Weight: 9
Cohesion: 125

Soil: 8
Silty sand till
Unit Weight: 20
Cohesion: 0

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

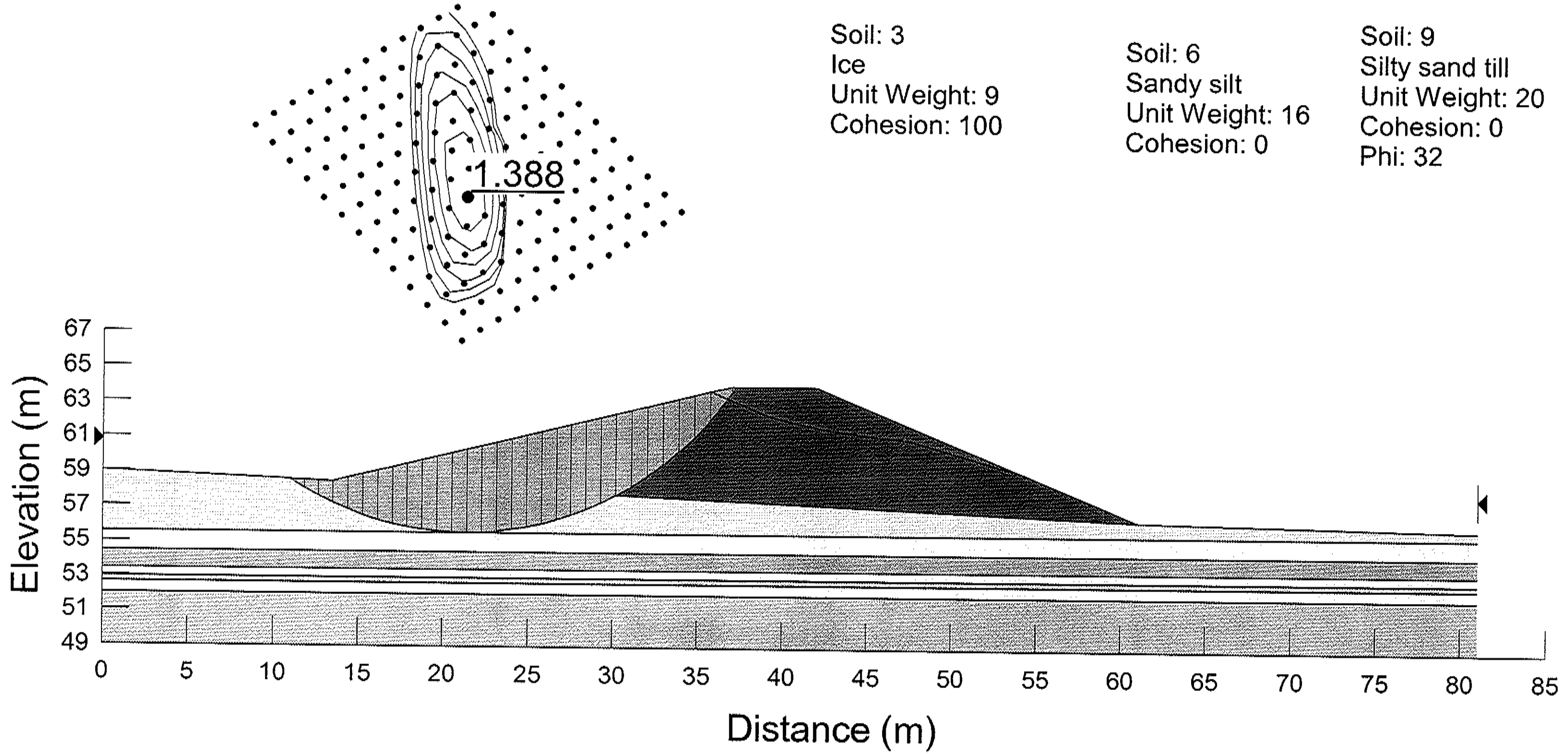


Figure 28

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 4H to 1V
Rapid Drawdown Analysis
Seismic = 0.15g

Soil: 1
Fill: Silty Sand
Unit Weight: 18

Soil: 2
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Ice
Unit Weight: 9
Cohesion: 100

Soil: 4
Sandy silt
Unit Weight: 17
Cohesion: 0

Soil: 5
Ice
Unit Weight: 9
Cohesion: 125

Soil: 6
Sandy silt
Unit Weight: 16
Cohesion: 0

Soil: 7
Ice
Unit Weight: 9
Cohesion: 125

Soil: 8
Silty sand till
Unit Weight: 20
Cohesion: 0

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

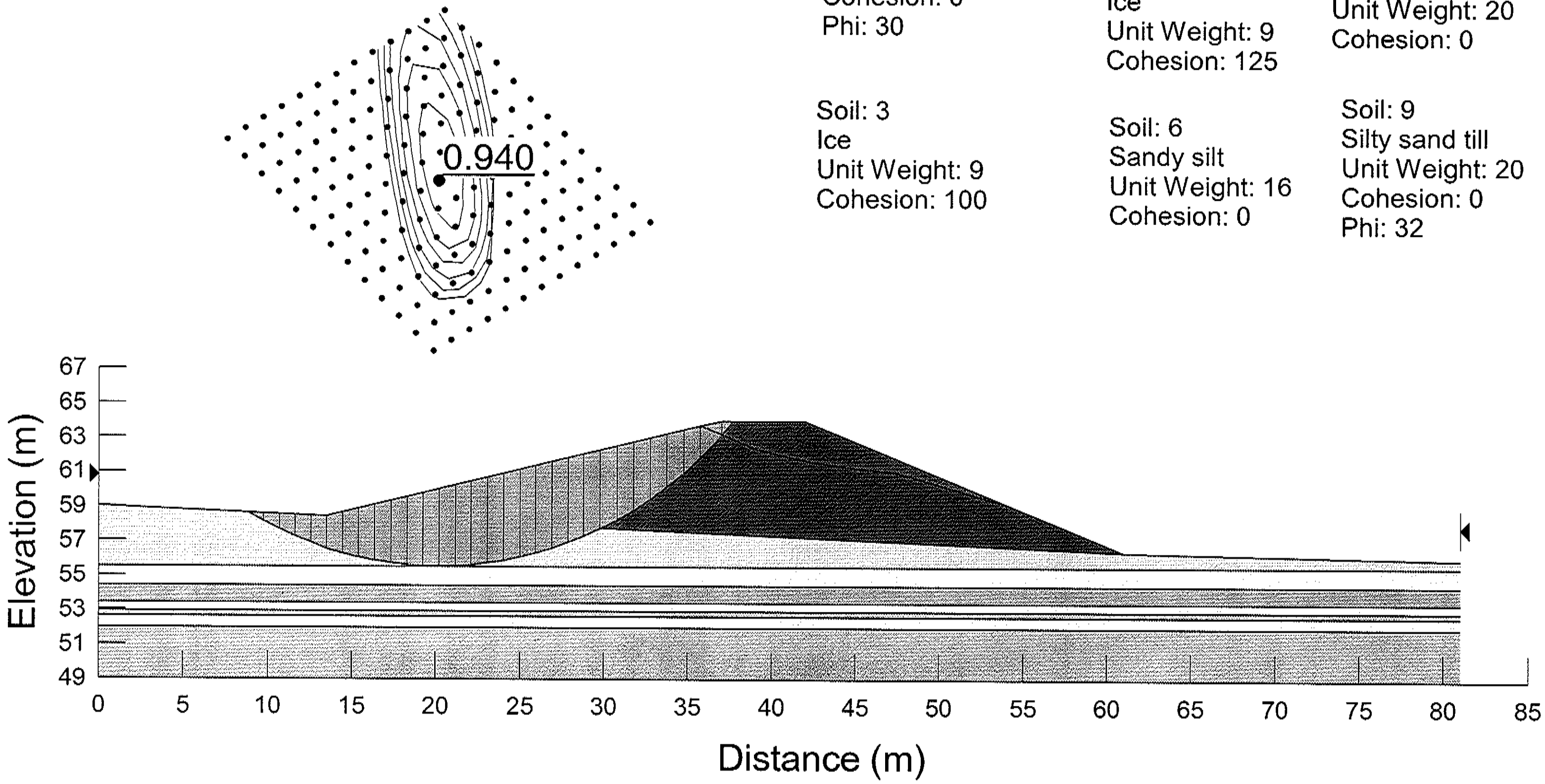
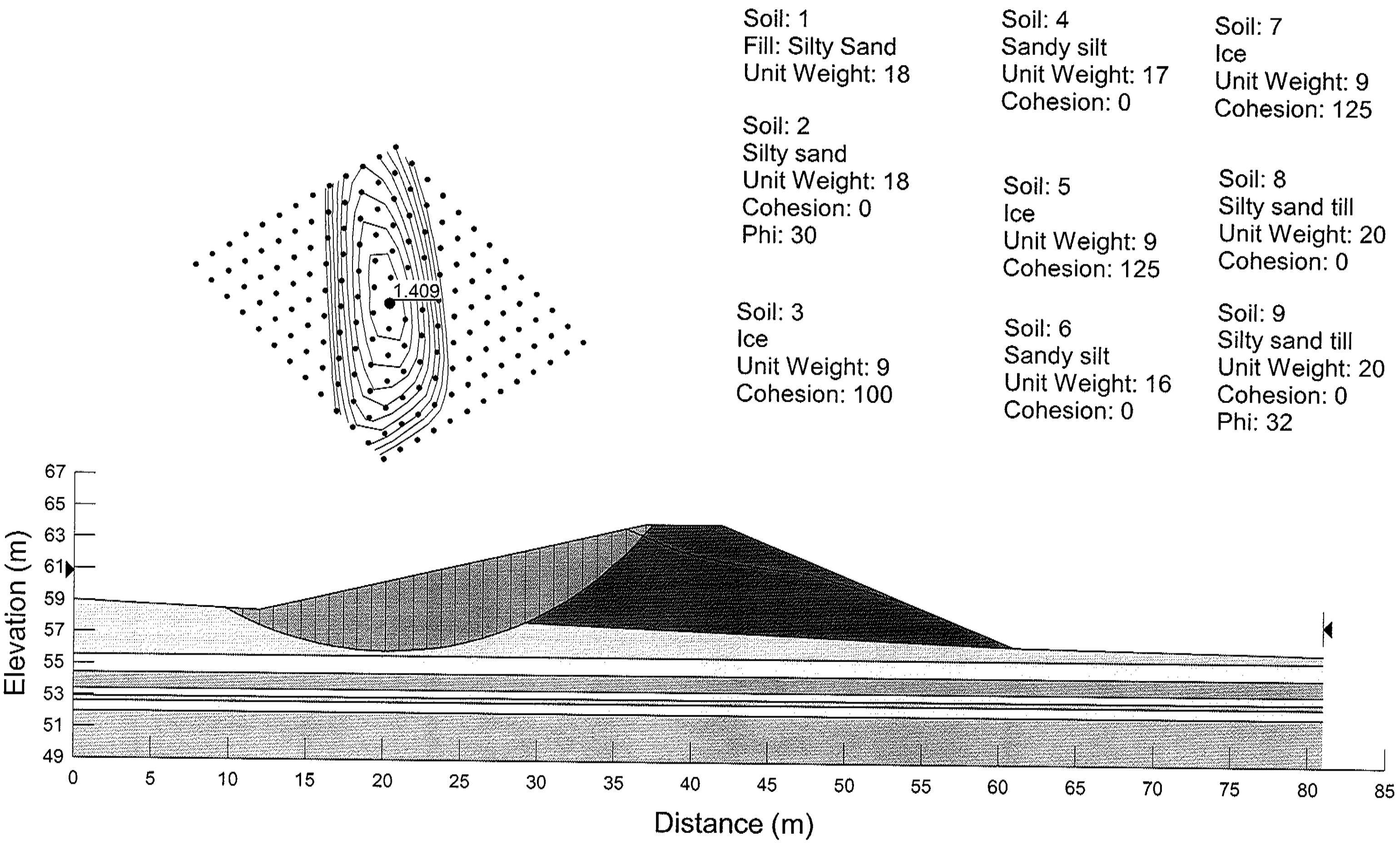


Figure 29

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 4.5H to 1V
Rapid Drawdown Analysis



Soil: 1
Fill: Silty Sand
Unit Weight: 18

Soil: 2
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Ice
Unit Weight: 9
Cohesion: 100

Soil: 4
Sandy silt
Unit Weight: 17
Cohesion: 0

Soil: 5
Ice
Unit Weight: 9
Cohesion: 125

Soil: 6
Sandy silt
Unit Weight: 16
Cohesion: 0

Soil: 7
Ice
Unit Weight: 9
Cohesion: 125

Soil: 8
Silty sand till
Unit Weight: 20
Cohesion: 0

Soil: 9
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 4.5H to 1V
Rapid Drawdown Analysis
Seismic = 0.15g

Figure 30

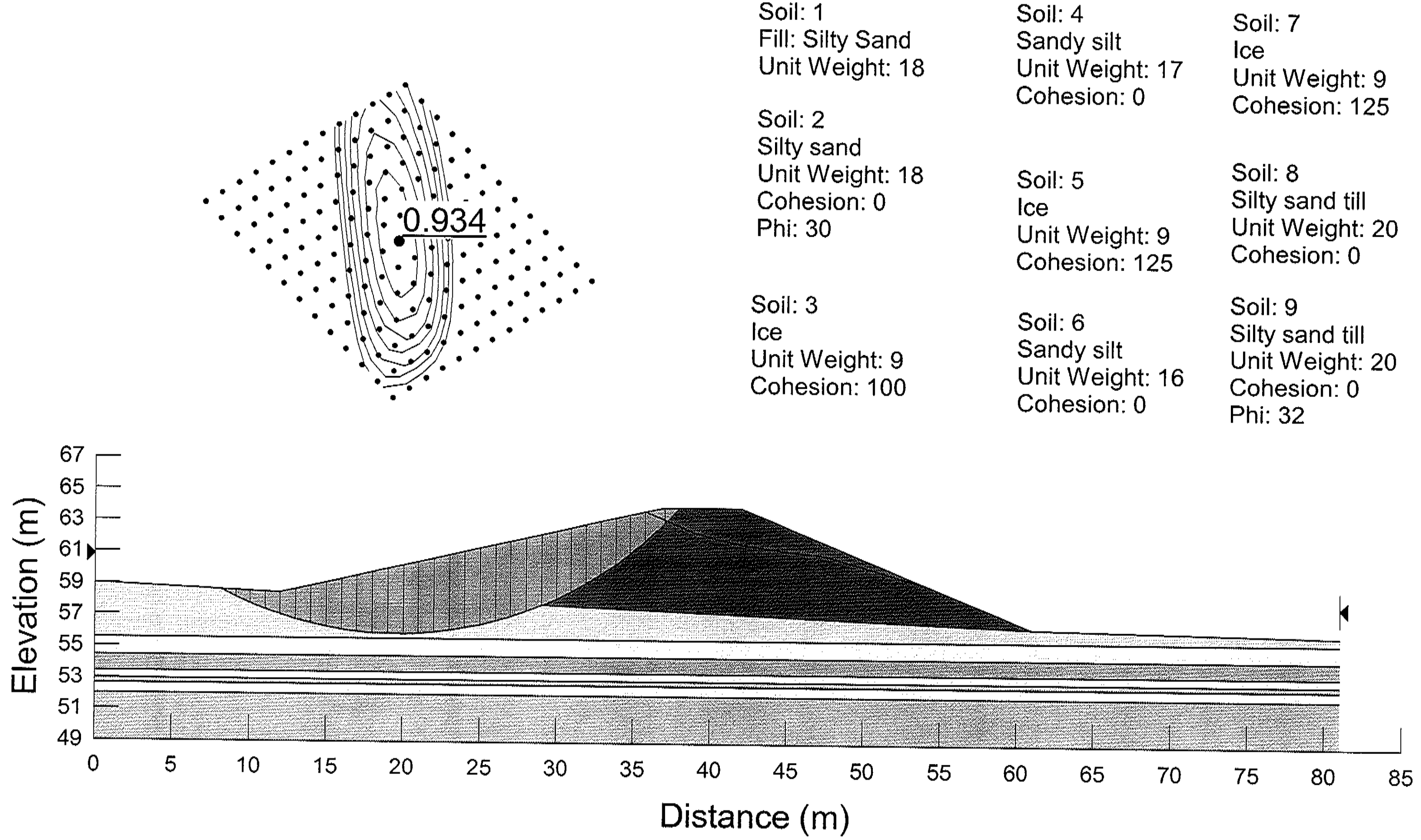


Figure 31

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 5H to 1V
Rapid Drawdown Analysis

Soil: 1
Fill: Silty Sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 2
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Ice
Unit Weight: 9
Cohesion: 100

Soil: 4
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 5
Ice
Unit Weight: 9
Cohesion: 125

Soil: 6
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 7
Ice
Unit Weight: 9
Cohesion: 125

Soil: 8
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

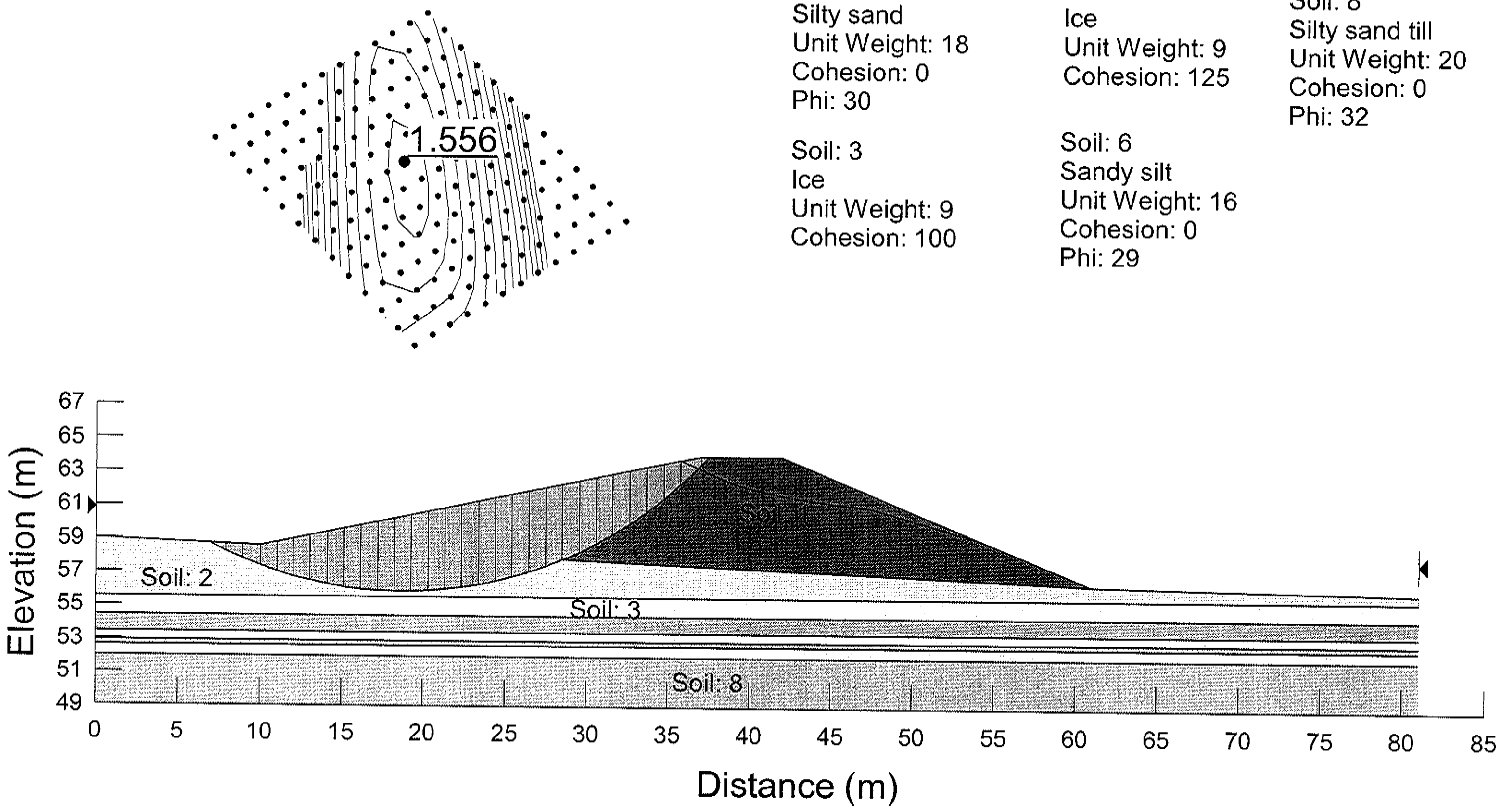


Figure 32

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 5H to 1V
Rapid Drawdown Analysis
Seismic = 0.15g

Soil: 1
Fill: Silty Sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 2
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Ice
Unit Weight: 9
Cohesion: 100

Soil: 4
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 5
Ice
Unit Weight: 9
Cohesion: 125

Soil: 6
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 7
Ice
Unit Weight: 9
Cohesion: 125

Soil: 8
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32

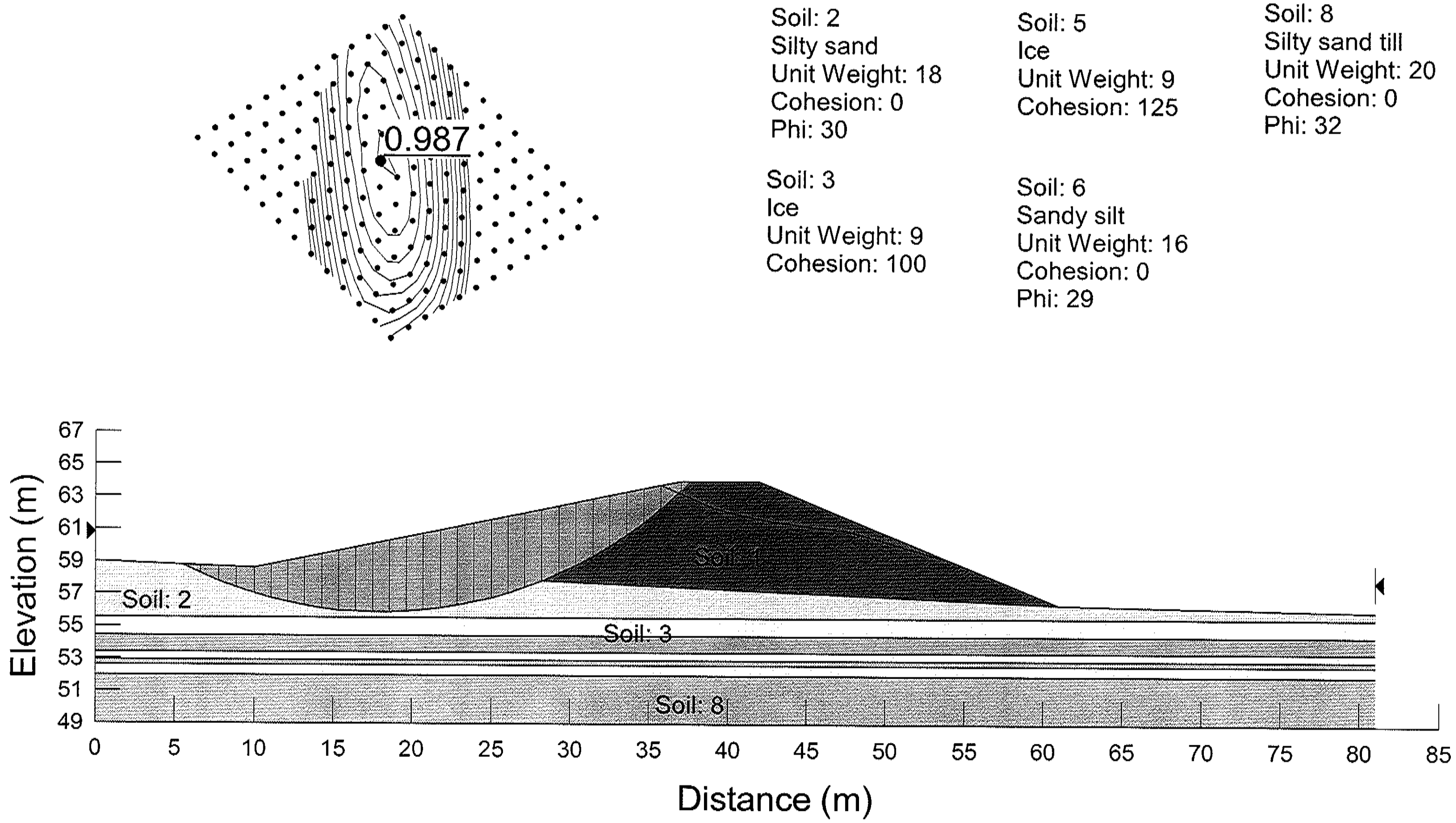


Figure 33

OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 5.5H to 1V
Rapid Drawdown Analysis

Soil: 1
Fill: Silty Sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 2
Silty sand
Unit Weight: 18
Cohesion: 0
Phi: 30

Soil: 3
Ice
Unit Weight: 9
Cohesion: 100

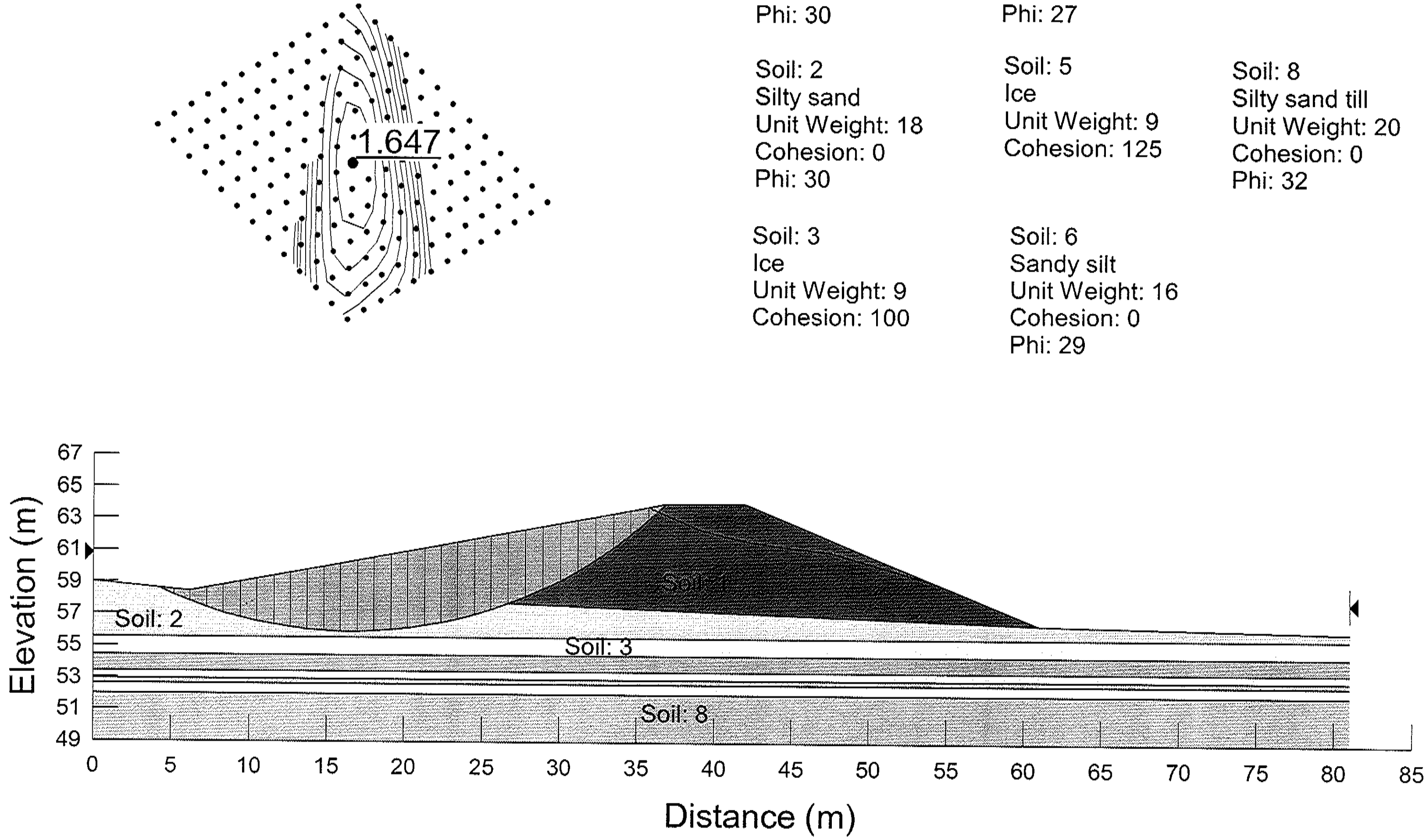
Soil: 4
Sandy silt
Unit Weight: 17
Cohesion: 0
Phi: 27

Soil: 5
Ice
Unit Weight: 9
Cohesion: 125

Soil: 6
Sandy silt
Unit Weight: 16
Cohesion: 0
Phi: 29

Soil: 7
Ice
Unit Weight: 9
Cohesion: 125

Soil: 8
Silty sand till
Unit Weight: 20
Cohesion: 0
Phi: 32



OTGE00019055B
Slope Stability Analysis
New Sewage Lagoon & Rehabilitation of Existing Lagoon
Clyde River
Nunavut
Inner Slope @ 5.5H to 1V
Rapid Drawdown Analysis
Seismic = 0.15g

Figure 34