GEOTECHNICAL EVALUATION AND PRELIMINARY DESIGN CLEAN UP OF CAM-F DEW LINE SITE SARCPA LAKE, NWT

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CLEAN UP OF CAM-F DEW LINE SITE
SARCPA LAKE, N.W.T.

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TABLE OF CONTENTS

	Page
1.0 INTRODUCTION	1
2.0 SITE DESCRIPTION	1
2.1 SITE LOCATION	1
2.2 GEOLOGICAL SETTING	2
2.3 CLIMATE	2
3.0 EXISTING LANDFILLS	4
3.1 DUMP A	4
3.2 DUMP B	5
4.0 NEW NON-HAZARDOUS WASTE LANDFILLS	6
4.1 DESIGN CONSIDERATIONS	6
4.2 ALTERNATIVE SITES FOR NON HAZARDOUS LANDFILLS	8
4.2.1 Dump A Proposed Landfill	8
4.2.2 Tower Landfill	8
4.3 DESIGN PARAMETERS	9
5.0 TIER II LANDFILLS	10
6.0 BORROW MATERIAL	11
6.1 MATERIAL SOURCES	11
6.2 FILL MATERIAL SPECIFICATIONS	11
6.2.1 Landfill Cover Material and Containment Berms	11
6.2.2 Saturated Containment Berms	12
6.2.3 Landfill Backfill Material	12
7.0 QUALITY ASSURANCE	13
8.0 POST CONSTRUCTION MONITORING	13
8.1 GENERAL	13
8.2 VISUAL MONITORING PROGRAM	14
8.3 THERMAL MONITORING	14
8.4 GROUND WATER OR SURFACE WATER MONITORING	14
9.0 LIMITATIONS AND RISK	15

FIGURES

APPENDIX A - Photos
APPENDIX B - Testpit Logs
APPENDIX C - Laboratory Test Results
APPENDIX D - Geophysical Data
APPENDIX E- Geothermal Analyses

1.0 INTRODUCTION

EBA Engineering Consultants Ltd. (EBA) conducted a geotechnical reconnaissance of the Sarcpa Lake (CAM-F) N.W.T., DEW Line site from Aug 3 to Aug 6, 1996. The purpose of the investigation was to provide geotechnical design data for the proposed construction and clean up works at this site. Specifically, the field included:

- evaluation of two existing dump sites;
- assessment of two alternative locations for the development of new landfills; and
- identification and characterization of potential granular borrow sources.

A total of 18 shallow testpits were excavated at proposed construction and potential borrow source areas to obtain information about the surficial soils. A magnetometer and EM-31 geophysical survey was carried out over the Dump A area to assist in determining the extent of the landfill. Selected soil samples were retained for laboratory determination of water content, and grain size distributions and salinity.

EBA's scope of work was focused on geotechnical issues related to the clean up. Environmental sampling and testing was carried out by Queens University Analytical Group, and the Clean up criteria and protocol were specified by Queens University Analytical Group, and Royal Military College Environment Science Group, (RRMC, 1993). UMA Engineering Ltd. carried out a topographic survey and surveyed the location of testpits, dump perimeters and debris areas.

2.0 SITE DESCRIPTION

2.1 SITE LOCATION

The Sarcpa Lake site is located approximately 85 km west of Hall Beach, Northwest Territories on the Melville Peninsula at longitude of 83° 19' W and a latitude of 68° 33' N. Site is land locked limiting site access to helicopters and small aircraft (i.e. twin otter). The site construction was completed in 1957 as an Intermediate site (I-site) for the DEW Line system. It was used for a short period of time until it was abandoned in 1963. It was converted to a Scientific research station in 1977 under the Science Institute of the Northwest Territories and Canada, Department of Indian and Northern Affairs (DIAND).

The site consists of an airstrip (1100 m x 30 m), a warehouse, garage, an Inuit hut, POL and a small quonset and a main building train. The site contains thousand of barrels and other site debris. The site also had a radar tower which has been knocked down. An "old camp" area exists 0.8 km southeast of the station. The old camp area consists primarily of scattered drums and old construction equipment.

2.2 GEOLOGY

The main station is situated on hill 260 m above sea level. The site was covered with glaciers until 8000 years ago. When the glaciers retreats from the area the site was above sea level.

The terrain is dominated by till deposits with Archean granitic bedrock outcrops prevalent throughout the area. There are numerous ponds, lakes and streams in the area, notably Kingaroo River and Sarcpa Lake. Undisturbed tundra is covered with sedges, and grasses. There is a large disturbed area around the airstrip where borrow material was obtained to construct the site and airstrip.

Sarcpa Lake is in the zone of continuous permafrost. No ground temperatures measurements were made at the site; however ground temperatures have been measured at Hall Beach, 85 km east of Sarcpa Lake (EBA, 1994). The mean annual ground temperatures at Hall Beach varied from - 9°C to -10°C.

2.3 CLIMATE

Climatic data is not available from Sarcpa Lake. The closest weather stations are Hall Beach, elevation 8 m, 85 km east of Sarcpa Lake, and Mackar Inlet, elevation 395 m, 100 km west of Sarcpa Lake. The mean annual air temperature at Hall Beach is -14.7°C, and at Mackar Inlet -14.4°C. The climate at Sarcpa Lake will be more continental than either of these two locations since both are on the coast. Climatic data for Hall Beach and Mackar is listed in Table 1.

TABLE 1
MEAN CLIMATIC DATA FROM NEARBY WEATHER STATIONS
(1961 - 1990)

	Mackar Inlet			Hall Beach				
	Mean Monthly Air Temperature (°C)	Precipitation (mm)	Month End Snow Cover (cm)	Mean Monthly Air Temperature (°C)	Precipitation (mm)	Month End Snow Cover (cm)	Average Wind (kph)	Solar Radiation (W/m2)
January	-31.1	2.7	37	-31.4	7.5	35	22	2
February	-31.6	2.1	38	-32.7	63	38	22	23
March	-28.5	3.2	38	-29.7	10.1	41	21	88
April	-20.2	7.7	39	-20.9	11.4	43	21	189
May	-9.8	17.2	32	-9.5	15.2	38	21	253
June	-0.4	13.6	6	0.3	16.7	5	18	274
July	6.0	33.6	0	5.8	31	0	17	218
August	3.6	42.9	1	4.5	44	0	19	151
September	-3.2	30.5	14	-0.5	26.4	4	23	71
October	-11.9	23	29	-10	22.1	18	25	30
November	-21.8	9.6	33	-20.8	15	29	24	5
December	-27	2.9	34	-27.6	8.9	33	21	0.1
Annual	-14.7	189		-14.4	215		21	

Note: Wind speed and solar radiation unavailable for Mackar Inlet.

3.0 EXISTING LANDFILLS

3.1 DUMP A

Dump A is located 200 m northeast of the module train as shown in Figure 2 and Photos 1 and 3. The dump was originally constructed by dumping debris over the edge of a small bedrock outcrop. Some of the debris was covered with silty sand with a trace of clay and gravel. Subsequently loose debris was piled on the landfill area. Most of the loose debris was removed from the area by the clean up team under the direction of Queens University during the summer of 1996.

The ground below the toe of the landfill is covered with a thin layer of peat and grasses. Testpits 4 and 5 were excavated at the toe of the landfill area as shown in Figure 6. The soil at the toe of the landfill consists of 2 to 5 cm of peat overlying wet sand and silt with a trace of clay and gravel. Occasional cobbles and boulders are present throughout the area. Testpit 6, excavated south of the landfill boundary on the edge of the slope, encountered 5 cm of organic soil overlying silty sand with a trace of sand and cobbles. Bedrock outcrops are prevalent beyond the western extent of the landfill.

EM-31 and Magnetometer geophysical surveys were carried out over the area. The survey results are presented in Appendix D. The anonolous readings are indicative of buried or surface metal debris. In general the zone of abnormally high or low readings agreed with visual observations and the surveyed landfill perimeter.

A small amount of effluent (water) was flowing out of the dump. It is believed that the majority of water was emanating from the thaw of frozen soil in the dump. The drainage was intercepted by an absorbent boom at the northeast corner of the dump. Drainage flows between the toe of the dump and a large bedrock outcrop located east of the dump and then flows towards small ponds 100 m north of the dump. The pond drains into Sarcpa Lake located 3 km east of the landfill.

At the time of the investigation the dump was in the process of being excavated by the clean up creew from Queens University. The dump contained barrels, equipment, domestic waste, electronic parts etc. The purpose of the excavation was to remove soil contaminated with PCB concentrations higher than CEPA standards. In general, all loose debris was removed from the landfill, and all soil that exceeded CEPA standards was removed, along with some Tier II soil (DEW Line Clean up Protocol). The CEPA soil was packed in polyethylene barrels, and the Tier II soil was packaged in plastic bags (wrangler packs). A detail description of the contaminated area is presented in reports by Queens University Analytical and Royal Military College Environmental Services Group. A report describing the 1996 excavation and remaining contaminants is currently being prepared by Queens University.

Following excavation a significant amount of debris and soil remains in the landfill. The remaining debris was embedded in frozen soil (permafrost). A unexcavated portion of the landfill is located south of the excavated area. This area contains surface debris including barrels, timbers, plastic parts, etc. It appears that most of the debris is on surface however some is buried.

Recommendations.

It is understood that the north portion of the landfill is to be removed because of the presence of CEPA contaminated material in the landfill.

It is understood that no elevated levels of contamination have been detected below the debris area south of the landfill, and therefore the protocol for the clean up of this area is limited to removing or covering the exposed debris. It is recommended that any partially buried debris be removed, or cut off and the area covered with a minimum of 0.5 m of fill. Fill at the toe of the landfill should be placed at a maximum slope of 3H:1V. Recommendations for fill material for landfill cover are presented in Section 6.0.

3.2 DUMP B

Dump B is located 170 m north of the module train as shown in Figure 5. The dump primarily contains building material from a demolished warehouse. The dump is constructed over a bedrock ledge 4 to 5 m high. The dump is shown in Photo 2. The debris contains steel beams, aluminum siding, gas cylinders, electrical parts, batteries, furniture, cable reels, etc. Some of the materials appear to be covered with asbestos. A small amount of debris at the northeast end of the dump is partially buried.

The soil at the top and bottom of the dump consist of silty sands. Bedrock outcrops are present through the toe of the landfill. Drainage from the area flows from the toe of the landfill down to ponds located 50 m north of the landfill. The ponds flow into Sarcpa

Lake, located 3 km east of the dump. No leachate from the dump was evident at the time of the site investigation.

Recommendations:

It is understood that no soils have been identified below the toe of Dump B that contain contaminant levels higher than the Tier I or Tier II DLCU levels or CEPA levels. The debris is largely unconsolidated, and relatively thin. It is recommended that the debris be removed from the area, sorted, and consolidated in an engineered landfill.

4.0 NEW NON-HAZARDOUS WASTE LANDFILLS

New landfills are required for non-hazardous debris, such as barrels, non contaminated building waste and site debris and "Tier I soil". It is understood that soils and building material with contaminates higher that CEPA standards will not be landfilled on site. Tier II soil and building materials considered to be contaminated above Tier II standards will be landfilled in separate area as described in Section 5.0. It is understood that the non-hazardous debris will occupy a volume of less than 2500 m^3, based on preliminary estimates from UMA. The following describes design considerations landfills for non-hazardous materials.

4.1 DESIGN CONSIDERATIONS

- **Waste characterization** - The waste material placed in new or extended landfills will consist only of non-hazardous debris which includes treated and untreated wood, metal wastes from demolition and equipment disposal, empty crushed barrels, and concrete. Asbestos, when packaged according to regulations, is also considered non-hazardous. It is understood that contaminated soils containing inorganic elements and/or PCBs at concentrations less than Tier II criteria (as defined by the Dew Line Clean Up Criteria (RRMC, 1993) will be treated as non-hazardous material and will also be deposited in the landfills.

- **Surface water run-on and run-off control** - The final landfill surface must be graded such that water ponding does not occur. Ponding and infiltration could increase the seasonal thaw depth or contribute to leachate generation. Percolation can only occur during the very short summer season when the active layer is thawed. The landfill surface must not be so steep that it promotes erosion of the cover materials which could expose debris. The fill material for landfill cap should be the sand and silt till available on site. This is a well graded material that is relatively erosion resistant, and will have moderate water infiltration.

- **Leachate Control** - The landfill material is non-hazardous, thus leachate needs to be controlled rather than eliminated completely. The following design factors will control the amount of leachate within the landfills.

- Only "Dry Waste" will be placed in the landfills
- The short arctic summer limits the amount of time that water infiltration can occur.
- The compacted cap material will promote surface run-off
- Landfills are located where natural overland runoff is minimal.

- **Frost Jacking** - Frost jacking of debris may occur within soils subject to seasonal freezing and thawing when debris is buried in frost susceptible (fine grained) soils, and access to free water is present. In order to prevent frost jacking, the landfill backfill material should be frost stable, and both groundwater and surface water must be controlled. Backfill material specifications that address these considerations are presented in Section 6.0.

- **Biological Odour and Methane Gas Control** - Odour and gas generation are typical of most domestic landfills in the south and are the result of decomposition due to biological activity, fungi and bacteria. These are not considered to be significant factors in the design of non-hazardous landfills at the Sarcpa Lake for two reasons. Firstly, the proportion of domestic waste to be landfilled will be insignificant in relation to the total volume of debris. Secondly, temperature of the waste and surrounding permafrost will limit decomposition and subsequently the rate at which gas is generated.

- **Settlement of Landfill Surface** - The debris should be placed in lifts with fill graded over the debris to fill the voids in order to reduce settlement and ground subsidence. It is recommended that a minimum fill thickness of 0.15 m be placed on top of the debris before the next lift is placed. The debris lift thickness is expected to vary between 0.5 m and 1.0 m, however it will depend on the type of debris being placed, and whether all voids can be filled. Quality assurance testing should be carried out to determine the optimum lift thickness and to confirm that there are no large voids in the landfill. Based on common practice and guidelines presented by Alberta Environment, 1981, it is recommended that the maximum thickness of landfill debris be 2.5 m, however this depth is dependent on the quality of the landfill construction.

4.2 ALTERNATIVE SITES FOR NON HAZARDOUS LANDFILLS

Two alternative sites were identified as potential landfill sites. The first site is located adjacent to Dump A; the second site is located in a low lying area north of the module train.

4.2.1 Dump A Proposed Landfill

A new landfill could be constructed over and/or adjacent to the Dump A site. Dump A excavation may be proceeding at the same time as new landfill construction; therefore the new landfill should be constructed over the southern portion of the area that is not scheduled for excavation.

The area is adjacent to small ridge and is shown in Photo 3. Testpits 4 and 5 were excavated in the lower area below the ridge. The lower area slopes gently to the east and is covered with grasses and a thin (2 to 5 cm) layer of organics overlying wet silty sand till with occasionally cobbles and boulders. The low area has poor trafficability.

The area above the ridge has bedrock outcrops throughout some portions and others have grasses overlying silty sand. Testpit 6 was excavated at the top ridge encountered 5 cm of organics overlying silty sand with a trace of sand and cobbles. A portion of the area above the rise is covered with unconsolidated and partially buried debris shown on Figure 6. Buried debris may be under the unconsolidated debris.

The area is on a topographic high therefore little drainage flows across the area. Drainage from the proposed site flows toward small ponds located 100 m northeast of the area. The pond drains into Sarcpa Lake located 3 km east of the landfill area.

4.2.2 Tower Landfill

A new landfill could be constructed in the low lying area between the module train and the POL area. The majority of the area is undisturbed between the road to the POL tank and the module fill pad. An old tower is located in the centre of the site, a small sand berm runs parallel to the POL road. The landfill could be constructed up against the POL road, and could blend into the natural topography of the area.

The area adjacent to the module train fill pad is wet and low lying. The area is shown Photo 4. Testpit 10 was excavated in the area encountered 10 cm of peat overlying 5 cm of gravel, overlying very wet silt and sand. Bedrock outcrops are present at the north west portion of the area adjacent to the POL tanks.

The area drains towards the north towards small ponds located 170 m north of the area. The ponds eventually drain to Sarcpa Lake located 3 km to the east.

4.3 DESIGN PARAMETERS

The non-hazardous landfills have been design on the premise that moisture migration into the landfilled material, need not be eliminated completely. As discussed above, the material is dry waste, and is not considered to generate leachate therefore it is not considered necessary to eliminate all moisture infiltration into and out of the landfill.

It is recommended that the landfills be constructed on grade to minimize constructability issues, and permafrost disturbance. The landfills should be constructed by first building containment berms around the perimeter of the landfill area. It is recommended that the containment berms have a maximum outside slope of 3H:1V and an inside slope of 1.5H:1V. The top of the berm should have a minimum width of 2.0 m.

The landfill should be capped with a 0.75 m thick layer of fill compacted to 95% of standard proctor density. The surface of the landfill should be graded to a slope between 2% and 4%. The landfill should be contoured to blend in with the surrounding terrain, and the maximum debris thickness in the landfill should be 2.5 m. Intermediate soil fill should be placed within the voids of the landfilled debris to minimize subsidence of the landfill cover.

It should be noted the design described above does not ensure landfill freezeback. Landfill freezeback could be achieved using a thicker landfill cover. The design could be modified if there is a risk of any of the landfilled materials degrading, and leaching resulting in adverse environmental impacts.

The cover and berms should be constructed with the locally available till. The intermediate fill should be a frost stable material. Recommended material specifications for the berm and cover and intermediate fill materials are presented in Section 6.0.

5.0 TIER II LANDFILLS

It is understood that there is approximately 350 m3 of Tier II contaminated soil plus there may be some building material that is covered paint containing PCB's concentrations above the Tier II standard. It is understood that the soils are contaminated with PCB's and heavy metals and the Tier II material is not leachable. It is recommended that a lined containment system be used to encapsulate Tier II soil. In addition the Tier II soil should be covered with sufficient cover to ensure that it freezes back and remains in a frozen condition, thereby further reducing the risk of migration.

A liner system has been chosen to minimize field welding, thereby simplifying construction, and allowing a higher degree of quality control. A double containment liner system is recommended. The liners considered are a Bentofix geocomposite clay liner overlying a reinforced modified nitrile oil resistant PVC liner (Arctic Liner). The liners are complementary in that the geocomposite clay liner is relatively thick and will protect the PVC liner against punctures. In the event that the PVC liner is damaged the geocomposite clay liner provides a low permeability barrier against migration. Saturated frozen soil around the landfill provides a third level of containment.

A leachate collection and monitoring system has not been incorporated in the design as it will not function well in a permafrost environment. It should be pointed out that the combination of freezeback of the landfilled material and the geomembrane cover and liner will result in little to no moisture migration into or out of the landfill.

A concept for the landfill is shown in Figure 7. Thermal analyses were carried out to determine the required cover thickness and freezeback time. A description of the thermal analyses is presented in Appendix E. It is estimated the active layer thickness will be 1.6 m during an average year and 2.1 m during a warm (1:100) year. It is recommended that the total cover on the landfill be 2.4 m thick (including bedding material). This is estimated to maintain the active layer within the cover material during mean and warm years and provides a safety factor for uncertainties in the thermal model.

6.0 BORROW MATERIAL

6.1 MATERIAL SOURCES

Borrow material at this site is predominately silty sand and gravel till with occasional cobbles and boulders. This material is prevalent around the station area. A large area has been disturbed during the construction of the site as shown on Figure 2. Some areas have been excavated down to bedrock; however there is a thin veneer of till over the bedrock remaining on much of the area. A total of seven shallow testpits were excavated in the material (TP3, TP7, TP8, TP11, TP12, TP13, TP14). Testpit logs are presented in Appendix B, and grain size curves and a moisture density relationship curve are presented in Appendix C on average samples of the till contained 11% clay, 21% silt, 32% sand, and 36% gravel. The material is suitable for landfill cover or for construction of berms for new landfill. There is sufficient quantity of the material for the project requirements.

There is a stockpile of sand and gravel at the old camp area, approximately 3.5 km from the station area. The material likely originated from the borrow area located across the lake as shown in Figure 1. A sample of material contained 55% gravel, 44% sand, and 1% silt. The sample contained 50 mm maximum particle sizes; however occasional 100 mm maximum particles are present in the stockpile. The stockpile contains approximately 1000 m^3 of material. The material is frost stable and therefore suitable for intermediate fill within new landfills.

There is an old borrow area at the west end of Sarpca Lake. The area is approximately 2 km south west of the station via a small trail. The trail would require upgrading for truck traffic. The materials are predominately sand and gravel till with some cobbles. There are small deposits of sand in the area near the lake shoreline.

6.2 FILL MATERIAL SPECIFICATIONS

6.2.1 Landfill Cover Material and Containment Berms

Fill material for covering landfills should be erosion resistant and should be well graded such that run-off flows over the landfill surface. In southern locations, landfill cover is generally clay soils. However, clay was not found at this site. It is recommended that the till be used for landfill cover. Samples of the sand and gravel till contained between

25 and 37% fines. It is recommended that cover for the landfill should conform to the following gradation curve:

Sieve Size (mm)	Percent Passing By Weight
150	100
50	70-100
5	50-70
.425	30-55
.08	15-40

Some boulders and cobbles must be removed from the material to achieve the specified gradation. The material should be compacted to a minimum density of 95% of Standard Proctor Density (ASTM D698). Moisture conditioning may be required to obtain the specified density.

6.2.2 Saturated Containment Berms

Fill material used for the frozen containment berm surrounding the Tier II landfill must be a non-saline well graded material that can be placed in a condition that is nearly saturated. It is recommended that the till material be used for this material. Cobbles larger than 100 mm should be removed from the material. The material should fall within the following gradation curve:

Sieve Size (mm)	Percent Passing By Weight
100	100
50	70-100
5	50-70
0.425	30-55
0.08	15-40

The material should be placed and compacted at degree of saturation greater than 95%, and have a minimum density of 95% of Standard Proctor Density (ASTM D698). Moisture conditioning may be required to obtain the specified saturation and density. The material should not be left exposed to the atmosphere such that it could dry out between lifts.

6.2.3 Landfill Backfill Material

Backfill material is required to fill voids in any new landfill debris. It is recommended that the material be 75 mm minus material. Backfill material within 2.0 m from ground surface should be frost stable to prevent the frost jacking of debris. Frost stable material should contain less than 8% of the material passing the 0.08 mm sieve.

7.0 QUALITY ASSURANCE

Construction monitoring and quality control are essential for satisfactory performance of the concepts presented in this report. Inspection by a geotechnical engineer with arctic experience is recommended during construction, to ensure that the required density and moisture conditioning critical to the design are achieved. It is imperative that the condition of the permafrost in key trenches be inspected and the presence of sound, ice saturated permafrost be verified.

Liner installation should be monitored by qualified construction quality assurance personnel. Supplied materials should be inspected to ensure conformance to specifications.

8.0 POST CONSTRUCTION MONITORING

8.1 GENERAL

A post-construction monitoring program is recommended for landfills. New landfills and closure landfills should be monitored visually for any signs of settlement, erosion, and ponded water. It is recommended that they be inspected three years after construction is complete. The monitoring program for the Tier II landfill should be carried out during the period required for the landfills to achieve thermal equilibrium. Three to five years duration is suggested initially, with the program suspended or substantially downgraded as acceptable performance is confirmed.

The monitoring program for Tier II remediated landfill should consist of:

- visual monitoring
- thermal monitoring
- surface water or active layer water monitoring

Suggested monitoring requirements are described below.

8.2 VISUAL MONITORING PROGRAM

A visual monitoring program should be carried out on an annual basis, by a Professional Engineer registered in NWT who is familiar with the requirements of the landfill remediation design. The inspector should look for any signs of distress, including:

1) signs of damage or potential damage from settlement, ponding, thermal instability, frost action, or erosion. The visual observations should be supported by simple elevation surveys and photography; and

2) damage to the above-ground portions of groundwater monitoring devices or thermistors.

8.3 THERMAL MONITORING

A thermal monitoring system should be implemented to allow verification of predicted ground temperatures within the landfill structure. It is recommended that two thermistor strings be installed within the central area of the landfill and two thermistor strings be installed in the containment berms around the landfill. Thermistor strings should be installed in drill holes, inside a 25 mm diameter PVC casing, and backfilled with dry sand to eliminate air voids. The EBA standard thermister string or an equivalent instrument with a long track record in the artic is recommended.

8.4 GROUND WATER OR SURFACE WATER MONITORING

Water quality should be monitored within 30 m of the facility. Monitoring should be carried out in existing surface waters or by using monitoring wells installed through the active layer. Samples of water should be obtained from the base of the active layer for testing at the end of the summer season. Baseline water quality data should be determined before any waste is placed in the facility. Representative background conditions should be measured approximately 200 m from the facility.

The results of monitoring during subsequent years should be analyzed and compared to the baseline data and monitoring data from previous years to identify any changes in water quality.

9.0 LIMITATIONS AND RISK

The design concepts presented in this report are based on analyses that demonstrate their feasibility. Certain assumptions pertaining to soil properties, active layer thickness and ground temperatures have been made based on regional knowledge of the terrain and engineering judgement. Engineering inspection during construction must be planned to observe and report site conditions such as active layer depth, soil texture and water content and groundwater conditions encountered during excavation. This data must be reviewed by the geotechnical engineer to confirm that the design intent will be met.

Freezeback times and long term thermal conditions have been predicted based on mean monthly climatic conditions. Natural variability will result in some deviation from the predicted performance, however, theses variations are not expected to impact adversely the function of the landfill design.

This report has been prepared for the exclusive use of UMA Engineering Ltd. and their client for specific application to the development described in Section 1.0. It has been prepared in accordance with generally accepted geotechnical engineering practices. No other warranty is made, either expressed or implied.

Respectfully submitted,
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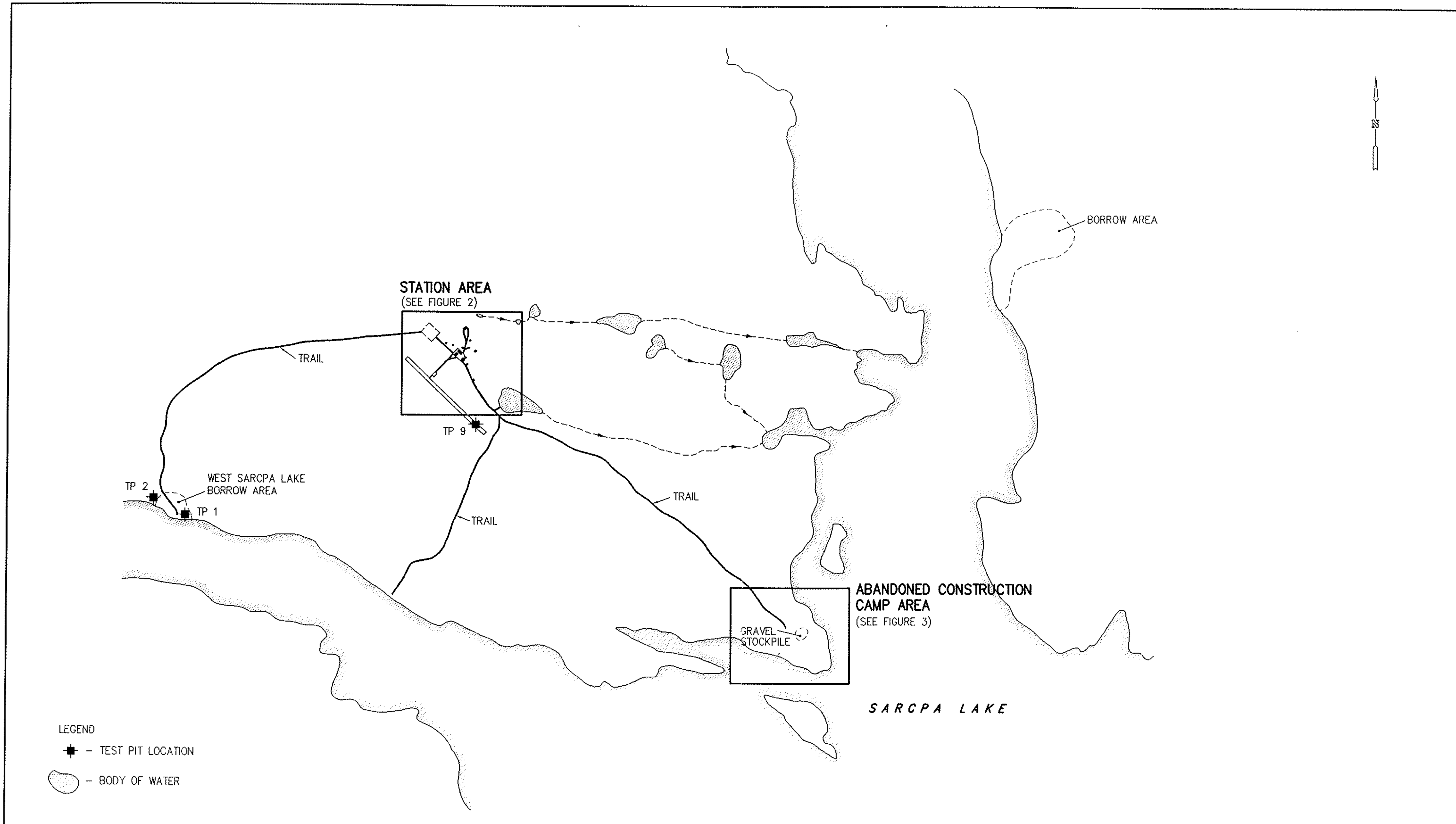
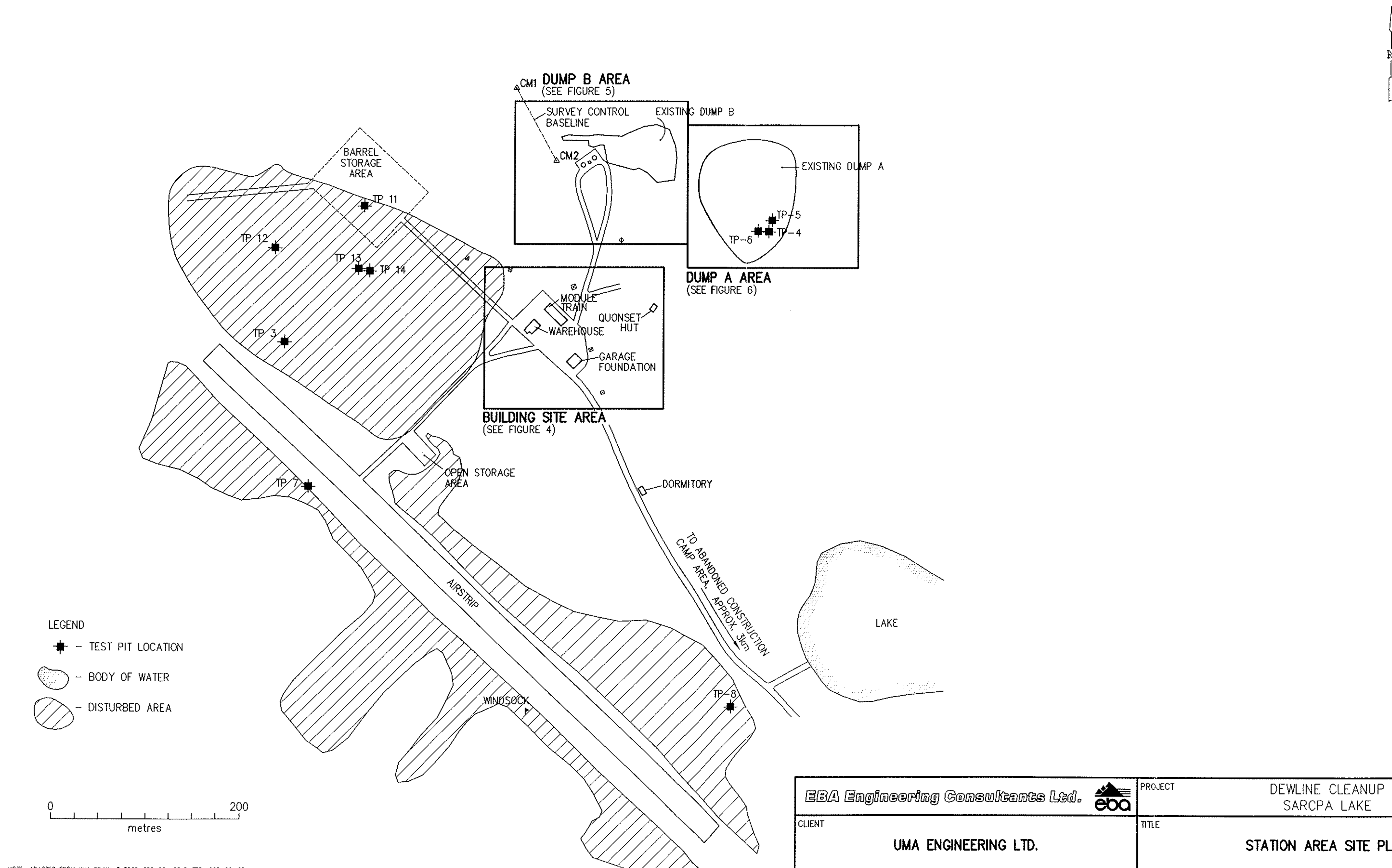


NOTE: ADAPTED FROM UMA DRAWING C228-003-00-101 DATED 1996-09-30

EBA Engineering Consultants Ltd. eba				PROJECT DEWLINE CLEANUP SARCPA LAKE	
CLIENT UMA ENGINEERING LTD.				TITLE OVERALL SITE PLAN	
DATE 96-11-07	DWN. LM	CHKD. WTH		FILE NO. 101-10995L01B	FIGURE 1



NOTE: ADAPTED FROM UMA DRAWING C228-003-00-102 DATED 1996-09-30

EBA Engineering Consultants Ltd.				PROJECT	DEWLINE CLEANUP SARCPA LAKE
CLIENT	UMA ENGINEERING LTD.			TITLE	STATION AREA SITE PLAN
DATE 96-11-07	DWN. LM	CHKD. WTH		FILE NO. 101-10995L02C	FIGURE 2

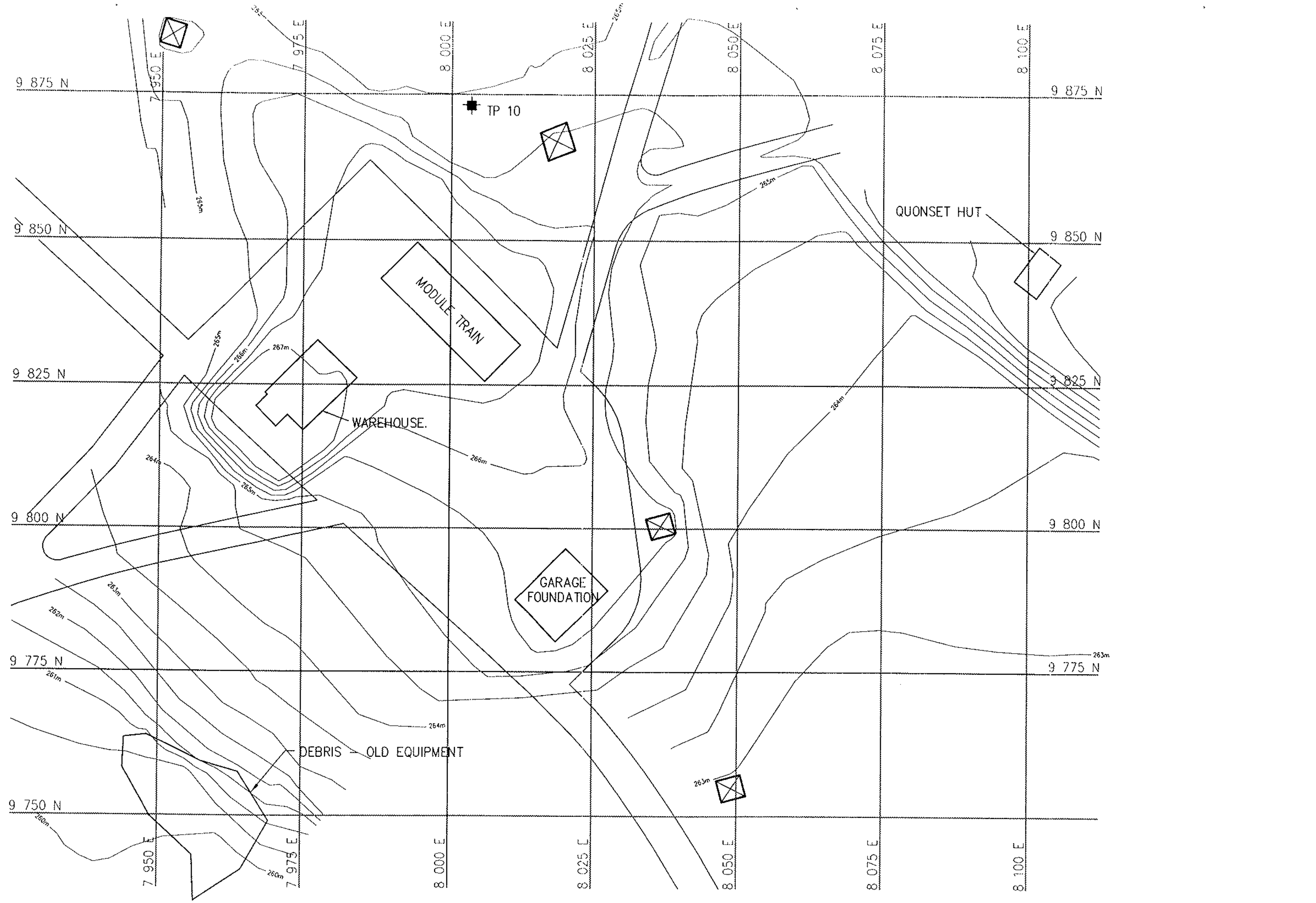
LEGEND

- TEST PIT LOCATION
- BODY OF WATER

0 50
metres

NOTE: ADAPTED FROM UMA DRAWING C228-003-00-103 DATED 1996-09-30

EBA Engineering Consultants Ltd.	PROJECT: DEWLINE CLEANUP SARCPA LAKE
CLIENT: UMA ENGINEERING LTD.	TITLE: ABANDONED CONSTRUCTION CAMP SITE PLAN
DATE 96-11-07 DWN. LM CHKD. WTH	FILE NO. 101-10995L03B FIGURE 3



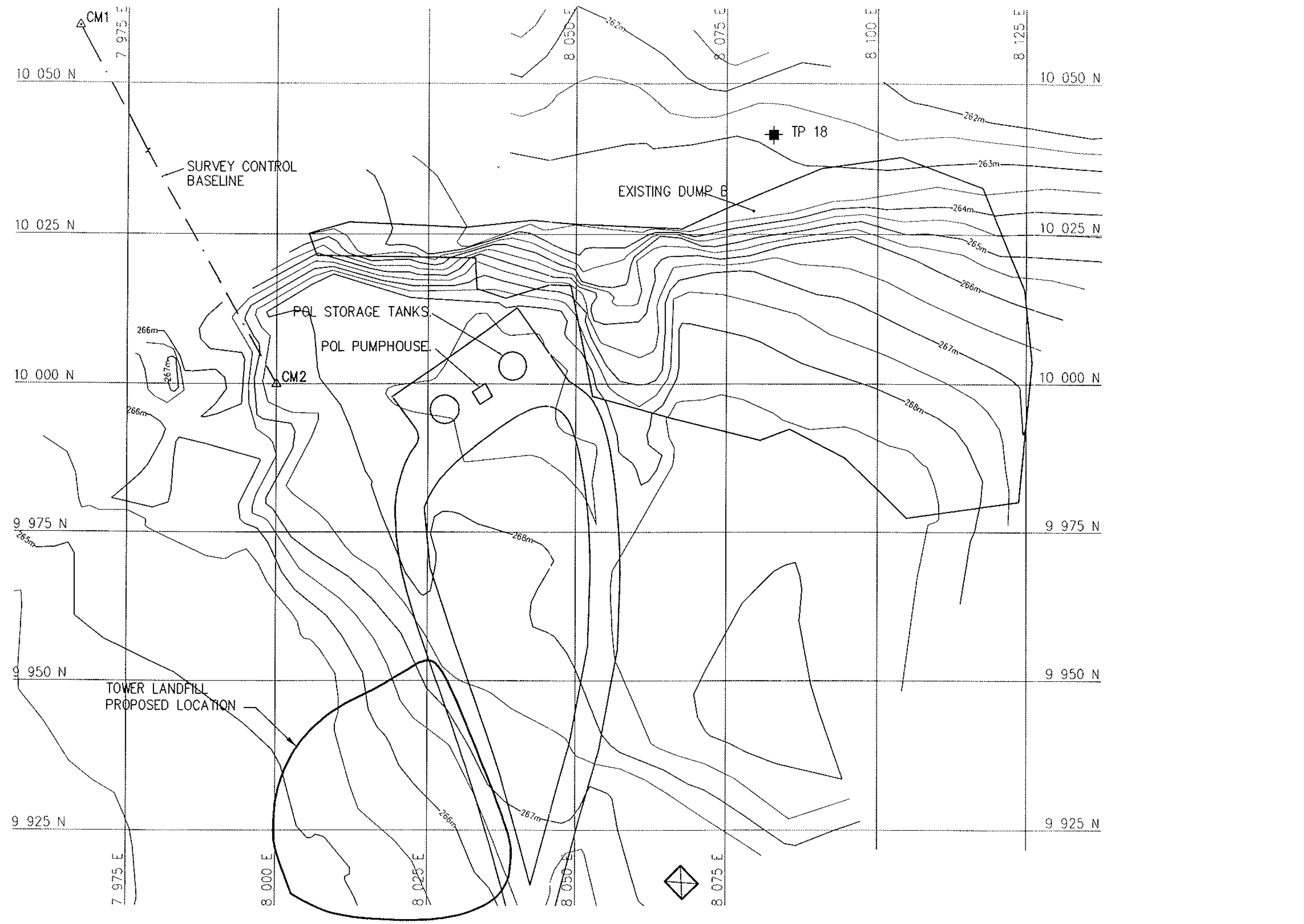
LEGEND

- TEST PIT LOCATION

0 50
metres

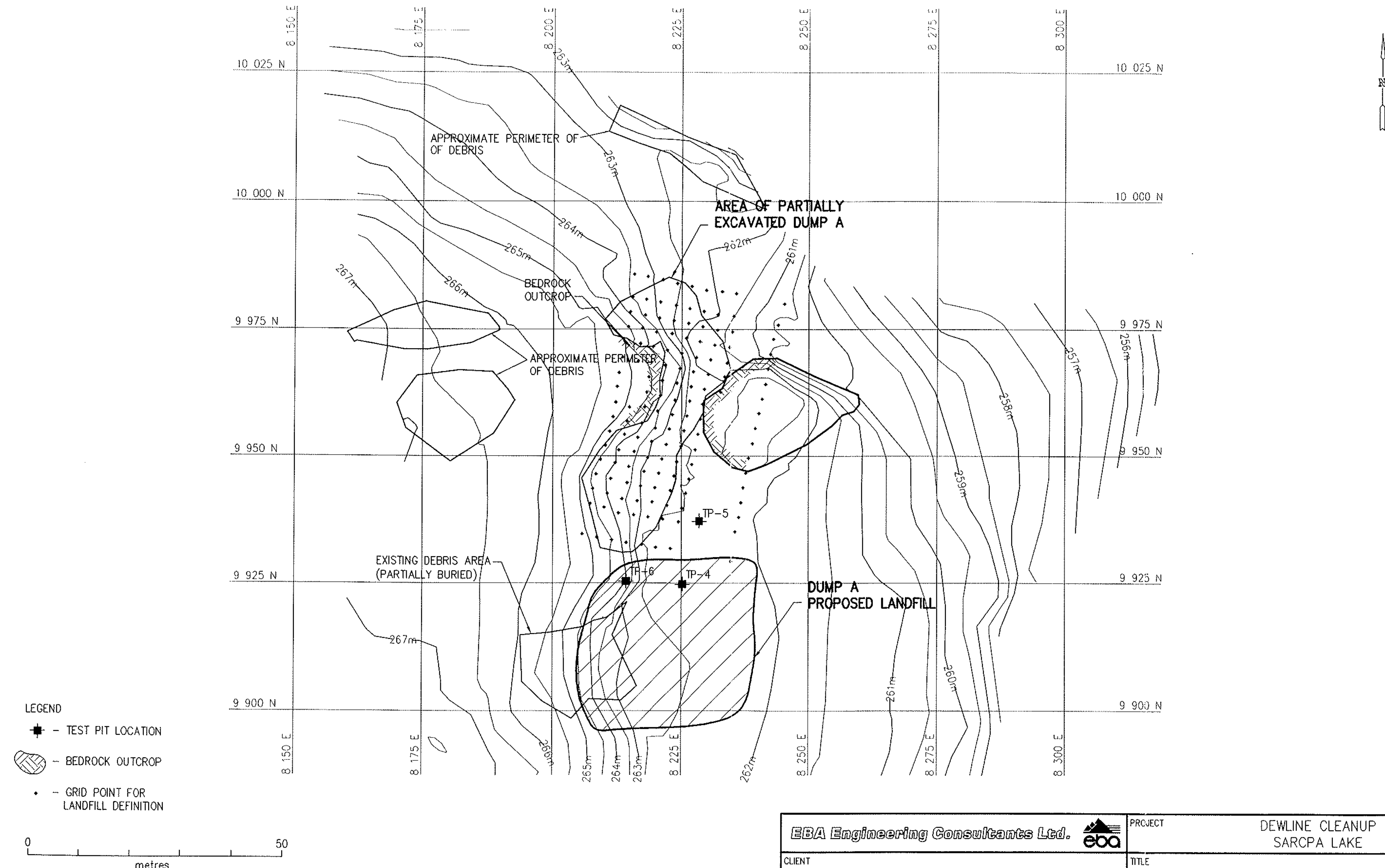
NOTE: ADAPTED FROM UMA DRAWING C228-003-00-104 DATED 1996-09-30

EBA Engineering Consultants Ltd.	PROJECT DEWLINE CLEANUP SARCPA LAKE
CLIENT UMA ENGINEERING LTD.	TITLE BUILDING AREA SITE PLAN
DATE 96-11-07 DWN. LM CHKD. WTH	FILE NO. 101-10995L04B FIGURE 4



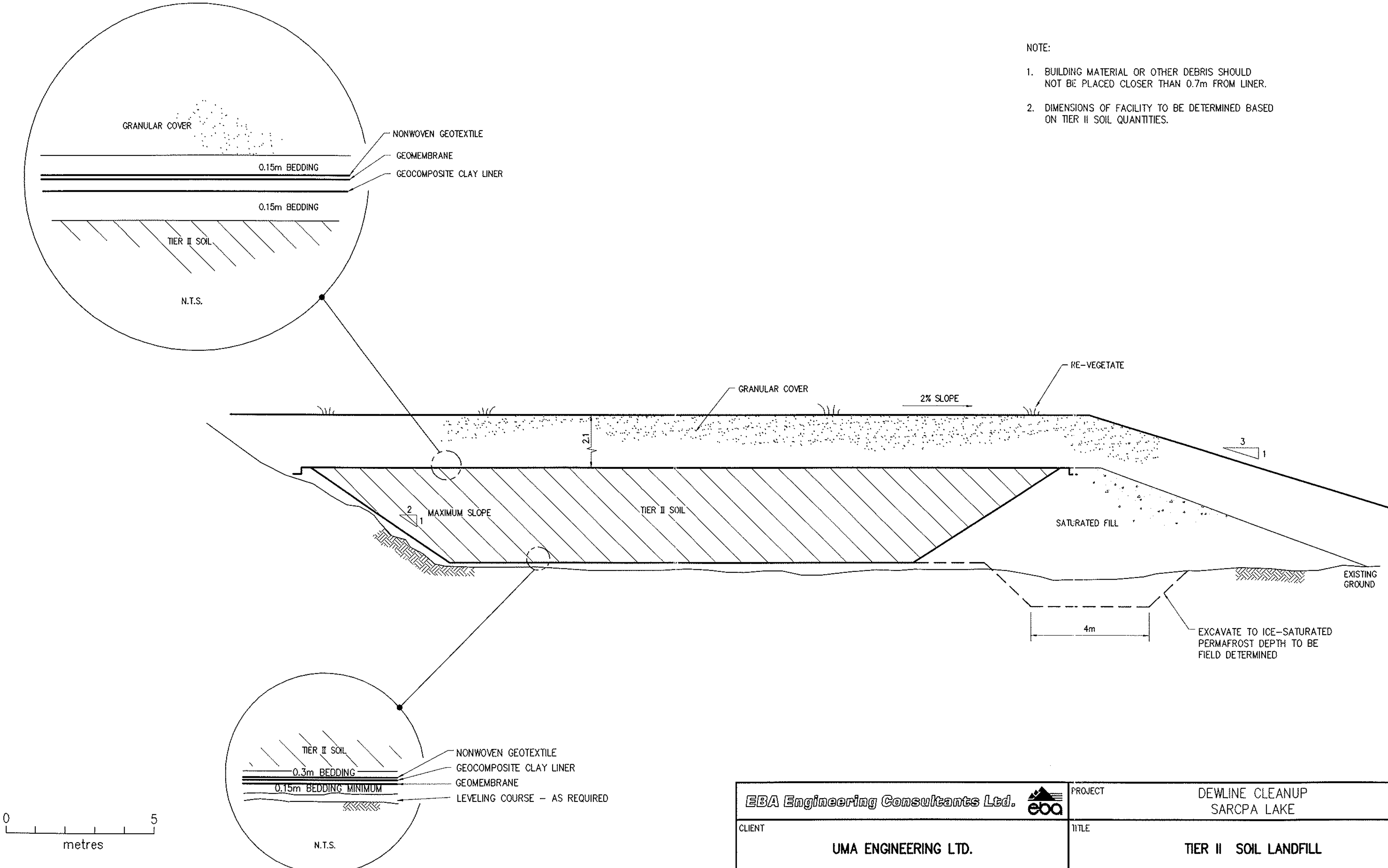
NOTE: ADAPTED FROM UMA DRAWING C228-003-00-101 DATED 1996-09-30

EBA Engineering Consultants Ltd.				PROJECT	DEWLINE CLEANUP SARCPA LAKE
CLIENT UMA ENGINEERING LTD.				TITLE	DUMP B AREA SITE PLAN
DATE 96-11-07	DWN. LM	CHKD. WTH		FILE NO. 101-10995L05B	FIGURE 5



NOTE: ADAPTED FROM UMA DRAWING C228-003-00-106 DATED 1996-09-30

EBA Engineering Consultants Ltd.				PROJECT	DEWLINE CLEANUP SARCPA LAKE
CLIENT UMA ENGINEERING LTD.				TITLE	DUMP A AREA SITE PLAN
DATE 96-11-07	DWN. LM	CHKD. WTH		FILE NO. 101-10995L06B	FIGURE 6



NOTE:

1. BUILDING MATERIAL OR OTHER DEBRIS SHOULD NOT BE PLACED CLOSER THAN 0.7m FROM LINER.
2. DIMENSIONS OF FACILITY TO BE DETERMINED BASED ON TIER II SOIL QUANTITIES.

EBA Engineering Consultants Ltd.		PROJECT DEWLINE CLEANUP SARCPA LAKE	
CLIENT UMA ENGINEERING LTD.		TITLE TIER II SOIL LANDFILL	
DATE 96-11-07	DWN. LM	CHKD. WTH	FILE NO. 101-10995L07C	FIGURE 7

APPENDIX A

PHOTOS

Photo 1: Dump A: Looking south - landfill excavation in progress.

Photo 2: Dump B - Looking north east from POL.

Photo 3: Dump A: Proposed Landfill Site. Dump A in background. Debris area in foreground.

Photo 4: Tower Landfill, Proposed site, looking north west.


Photo 5: Station borrow area, looking west.


Photo 6: Old Camp Stockpile.

APPENDIX B

TESTPIT LOGS

TERMS USED ON BOREHOLE LOGS

TERMS DESCRIBING CONSISTENCY OR CONDITION

COARSE GRAINED SOILS (major portion retained on 0.075mm sieve): includes (1) clean gravels and sands, and (2) silty or clayey gravels and sands. Condition is rated according to relative density, as inferred from laboratory or in situ tests.

DESCRIPTIVE TERM	RELATIVE DENSITY	N (blows per 0.3m)
Very Loose	0 to 20%	0 to 4
Loose	20 to 40%	4 to 10
Compact	40 to 75%	10 to 30
Dense	75 to 90%	30 to 50
Very Dense	90 to 100%	greater than 50

The number of blows, N, on a 51mm O.D. split spoon sampler of a 63.5kg weight falling 0.76m, required to drive the sampler a distance of 0.3m from 0.15m to 0.45m.

FINE GRAINED SOILS (major portion passing 0.075mm sieve): includes (1) inorganic and organic silts and clays, (2) gravelly, sandy, or silty clays, and (3) clayey silts. Consistency is rated according to shearing strength, as estimated from laboratory or in situ tests.

DESCRIPTIVE TERM	UNCONFINED COMPRESSIVE STRENGTH (kPa)
Very Soft	Less Than 25
Soft	25 to 50
Firm	50 to 100
Stiff	100 to 200
Very Stiff	200 to 400
Hard	Greater Than 400

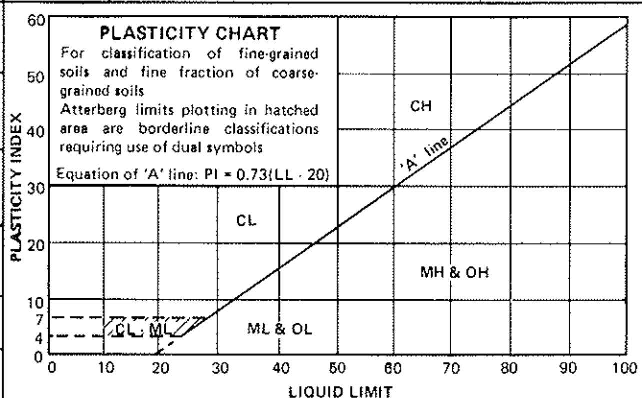
NOTE: Slickensided and fissured clays may have lower unconfined compressive strengths than shown above, because of planes of weakness or cracks in the soil.

GENERAL DESCRIPTIVE TERMS

Slickensided	- having inclined planes of weakness that are slick and glossy in appearance.
Fissured	- containing shrinkage cracks, frequently filled with fine sand or silt; usually more or less vertical.
Laminated	- composed of thin layers of varying colour and texture.
Interbedded	- composed of alternate layers of different soil types.
Calcareous	- containing appreciable quantities of calcium carbonate.
Well Graded	- having wide range in grain sizes and substantial amounts of intermediate particle sizes.
Poorly graded	- predominantly of one grain size, or having a range of sizes with some intermediate size missing.

eba

UNIFIED SOIL CLASSIFICATION†

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Classification on basis of percentage of fines: Less than 5% pass No. 200 sieve — GW, GP, SW, SP; More than 12% pass No. 200 sieve — GM, GC, SM, SC; 5% to 12% pass No. 200 sieve — Borderline classification requiring use of dual symbols	$C_u = D_{60}/D_{10}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW	
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			GC	Clayey gravels, gravel-sand clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines		$C_u = D_{60}/D_{10}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			SP	Poorly-graded sands and gravelly sands, little or no fines		Not meeting both criteria for SW	
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS	Liquid limit 50% or less	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	SILTS AND CLAYS	Liquid limit greater than 50%	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts			
			CH	Inorganic clay of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS			PT	Peat, muck and other highly organic soils	*Based on the material passing the 3 in. (75 mm) sieve †ASTM Designation D 2487, for identification procedure see D 2488		

GROUND ICE DESCRIPTION

ICE NOT VISIBLE

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION	
N	Nf	Poorly-bonded or friable	
	Nbn	No excess ice, well-bonded	
	Nbe	Excess ice, well-bonded	

NOTE:
1. *Dual symbols are used to indicate borderline or mixed ice classifications*
2. *Visual estimates of ice contents indicated on borehole logs ± 5%*
3. *This system of ground ice description has been modified from NRC Technical Memo 79, Guide to the Field Description of Permafrost for Engineering Purposes*

LEGEND
Soil ▩ Ice ■

VISIBLE ICE LESS THAN 50% BY VOLUME

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION	
V	Vx	Individual ice crystals or inclusions	
	Vc	Ice coatings on particles	
	Vr	Random or irregularly oriented ice formations	
	Vs	Stratified or distinctly oriented ice formations	

VISIBLE ICE GREATER THAN 50% BY VOLUME

ICE	ICE + Soil Type	Ice with soil inclusions	
	ICE	Ice without soil inclusions (greater than 25 mm (1 in.) thick)	

Testpit Logs

TP1 West Sarcpa Lake Borrow Area - Small Stockpile at east end of area

0.0 Sand (SW), some gravel,some cobbles, well graded, moist , brown (moisture content 3.6%)

0.4 End of testpit

TP2 West Sarcpa Lake Borrow Area - Native ground adjacent to stockpile at west end of area

0.0 Peat, organics, roots, grass, moist, brown

0.05 Sand and Silt (SW), some gravel, trace cobbles, moist, brown (moisture content 9.3%)

0.4 End of testpit

TP3 Borrow Area at Northwest end of Airstrip

0.0 Silt (Till), sandy, trace gravel, trace clay, trace cobbles, some boulders in vicinity (moisture content 8.3%)

0.3 End of testpit - Refusal on cobble

TP4 Dump A - south east of landfill boundary

0.0 Peat, organics roots, grasses, black, moist

0.05 Silt, sandy, trace clay, trace gravel, some cobbles and boulders in vicinity, wet, brown (moisture content 14.1%)

0.50 End of testpit

TP5 Dump A - east of landfill boundary

0.0 Organics, grasses, mosses roots - 6 mm diameter cable buried and intertwined with organic mat

0.02 Sand, silty, trace clay, trace gravel, wet, brown (boulders on surface nearby to testpit.

0.5 End of testpit - refusal on 200 mm diameter cobble.

Note: scattered debris on ground surface nearby to testpit

TP6 Dump A - 5 m south of landfill grid, up on slope crest

0.0 Organics, grasses, roots, blackish brown, moist

0.05 Sand, silty, fine grained, trace gravel, dry, brown

0.30 Cobble, 250 mm diameter

0.50 End of testpit

TP7 Borrow Area - South, Central Airstrip

0.0 Sand & Silt (Till), trace gravel, trace clay, occasional boulder, in the area (moisture content 5.7%)

0.50 End of testpit - refusal on cobble

Note: Some bedrock outcrops in area

TP8 Borrow - Northeast End of Airstrip

0.0 Sand & Gravel (Till), silty, some clay, well graded occasional boulder, in the area (moisture content 5.6%)

0.50 End of testpit

TP9 East End of Airstrip - Airstrip Surfacing Material

0.0 Sand & Gravel (Till), some silt, 50 mm minus (moisture content 4.3%)

0.3 End of testpit

Note: some 150 mm cobbles in airstrip surface material

TP10 Proposed Landfill Adjacent to fallen Tower

0.0 Organics, peat, grasses, mosses

0.10 Gravel, trace sand, 50 mm maximum, wet

0.15 Silt and Sand, very wet, grey

0.40 End of testpit, hole sloughing in

TP11 Borrow - East of Station

0.0 Sand & Gravel (Till), silty, some clay, trace cobbles, well graded, moist, brown (moisture content 7.3%, salinity 1ppt)

0.90 Bedrock

0.90 End of testpit

TP12 Borrow - East of Station

0.0 Sand & Gravel (Till), silty, some clay, some cobbles and boulders, well graded,moist, brown

0.90 End of testpit - Note small Kuboto excavator had difficult excavating due to cobbles and boulders

TP13 Borrow - East of Station

0.0 Sand & Gravel (Till), silty, some clay, some cobbles and boulders, well graded,moist, brown

0.75 End of testpit - Note small Kuboto excavator had difficult excavating due to cobbles and boulders

TP14 Borrow - East of Station

0.0 Sand & Gravel (Till), silty, some clay, some cobbles and boulders, well graded,moist, brown

0.20 Boulder, 500 mm diameter

0.75 Bedrock

0.75 End of testpit - Note small Kuboto had difficult excavating due to cobbles and boulders

TP15 Potential Landfill - Old Camp

0.0 Sand & Gravel, silty, trace clay, trace cobbles, moist, brown (moisture content 6.3%)

0.40 End of testpit

Note: Some boulders in area

TP16 Potential Landfill - Old Camp

0.0 Sand & Gravel (SM), silty, trace clay, trace cobbles, moist, brown (moisture content 9.3%)

0.40 End of testpit

Note: Some boulders in area

TP17 Sand and Gravel Stockpile at Old Camp

0.0 Sand & Gravel (GP) trace silt, 100 mm max, clean, moist, pinkish brown (moisture content 1.4%)

0.4 End of testpit

TP18 Below Dump B

0.0 Organics, grasses, mosses roots

0.05 Sand, silty, some gravel, well graded wet, grey brown (boulders and cobbles on surface nearby to testpit.

0.4 End of testpit - refusal on 200 mm diameter cobble.

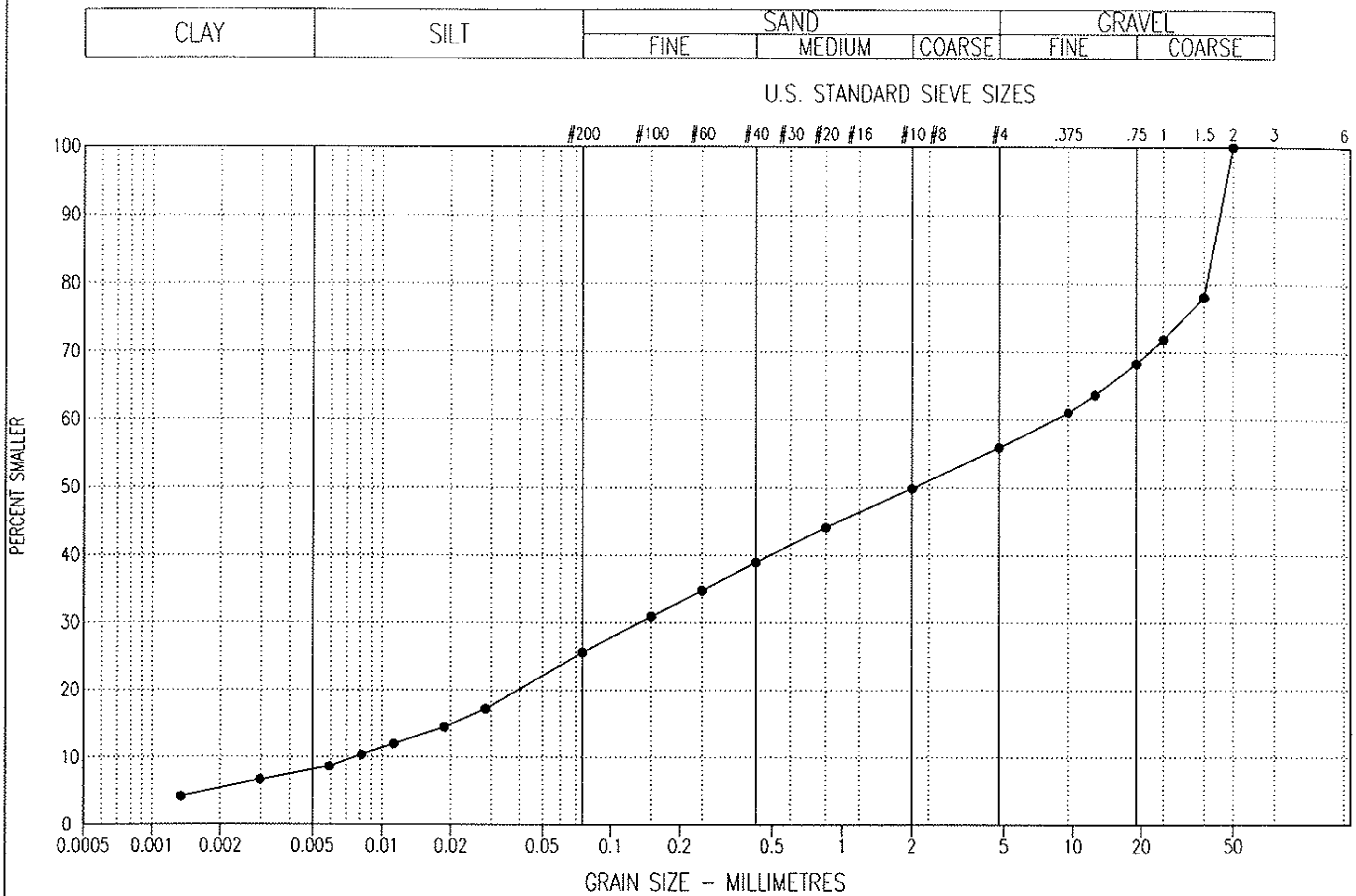
Note: Depths in metres

APPENDIX C

LABORATORY TEST RESULTS

EBA Engineering

PARTICLE SIZE - ANALYSIS OF SOILS



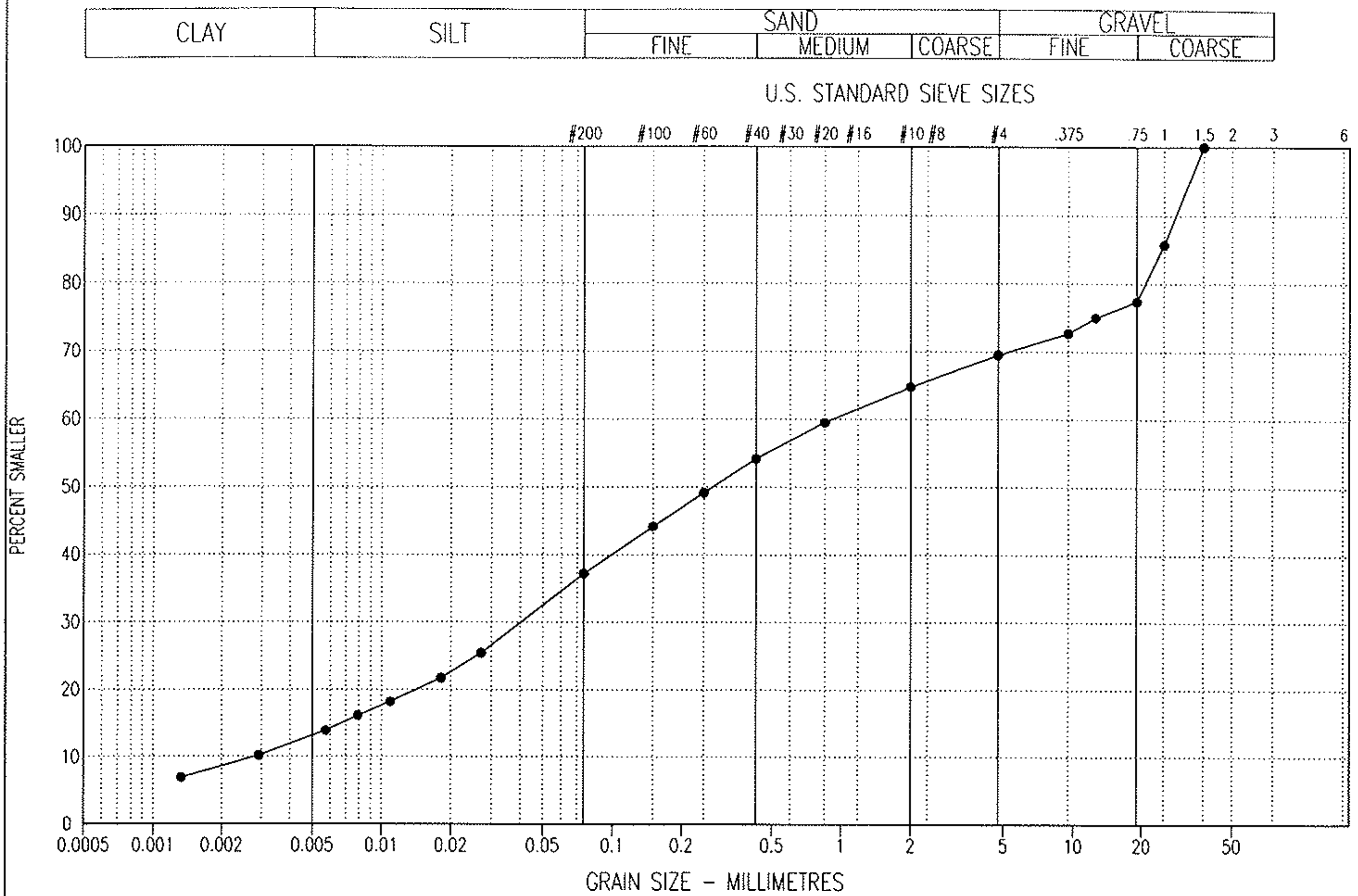
SYMBOL	BOREHOLE NUMBER	DEPTH (ft)	DESCRIPTION				Cu	Cc	U.S.C
			CLAY %	SILT %	SAND %	GRAVEL %			
●———●	TP3	0.00	8.0	17.6	30.3	44.1	1106.7	0.3	GM

Project: 0101-10995.21 Date Tested: 96/09/18 BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

EBA Engineering

PARTICLE SIZE – ANALYSIS OF SOILS



SYMBOL	BOREHOLE NUMBER	DEPTH (ft)	DESCRIPTION CLAY %	SILT %	SAND %	GRAVEL %	Cu	Cc	U.S.C
●——●	TP8	0.00	12.9	24.3	32.3	30.5	338.1	0.8	SM

Project: 0101-10995.21

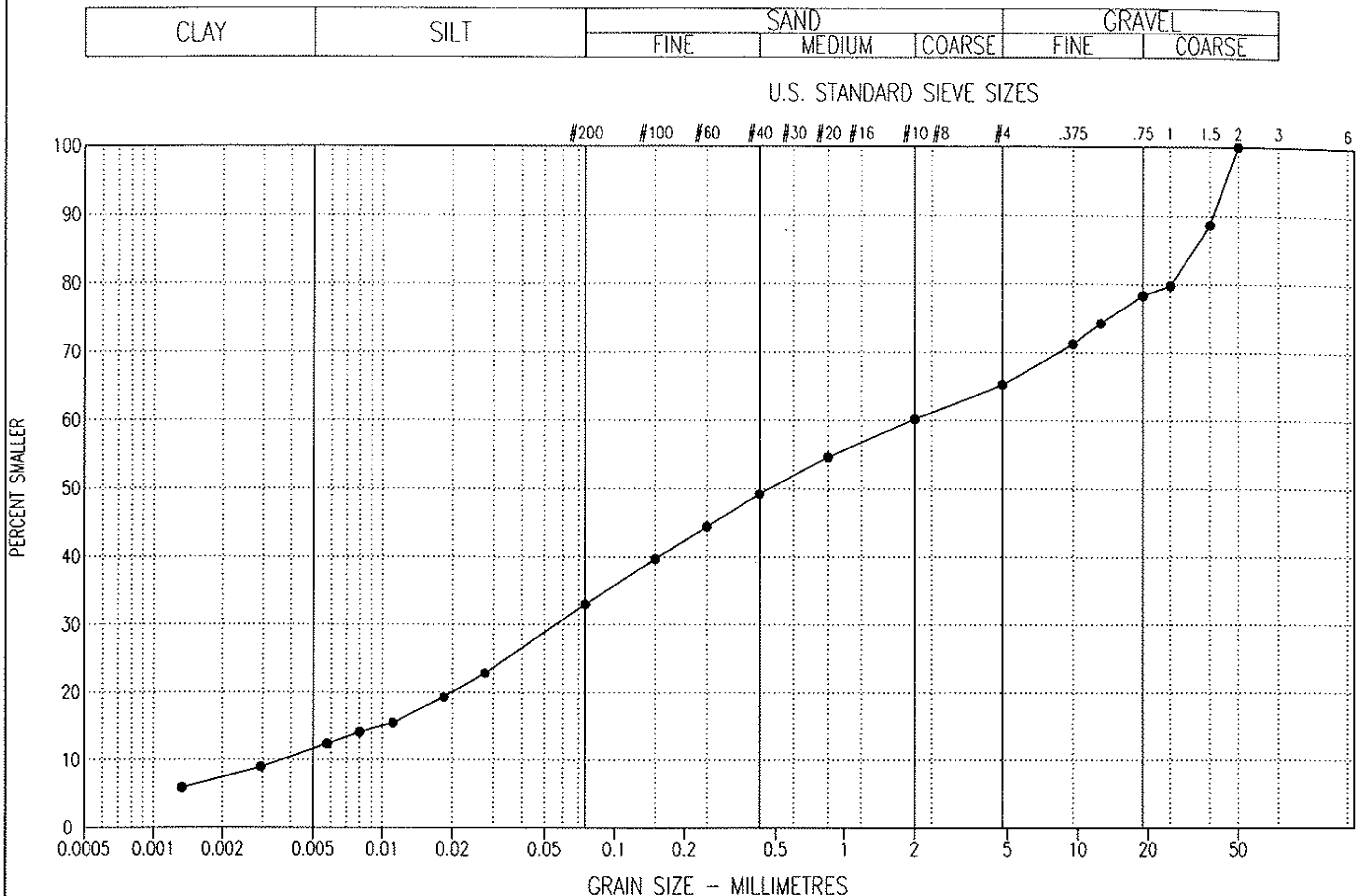
Date Tested: 96/09/18

BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

EBA Engineering

PARTICLE SIZE – ANALYSIS OF SOILS



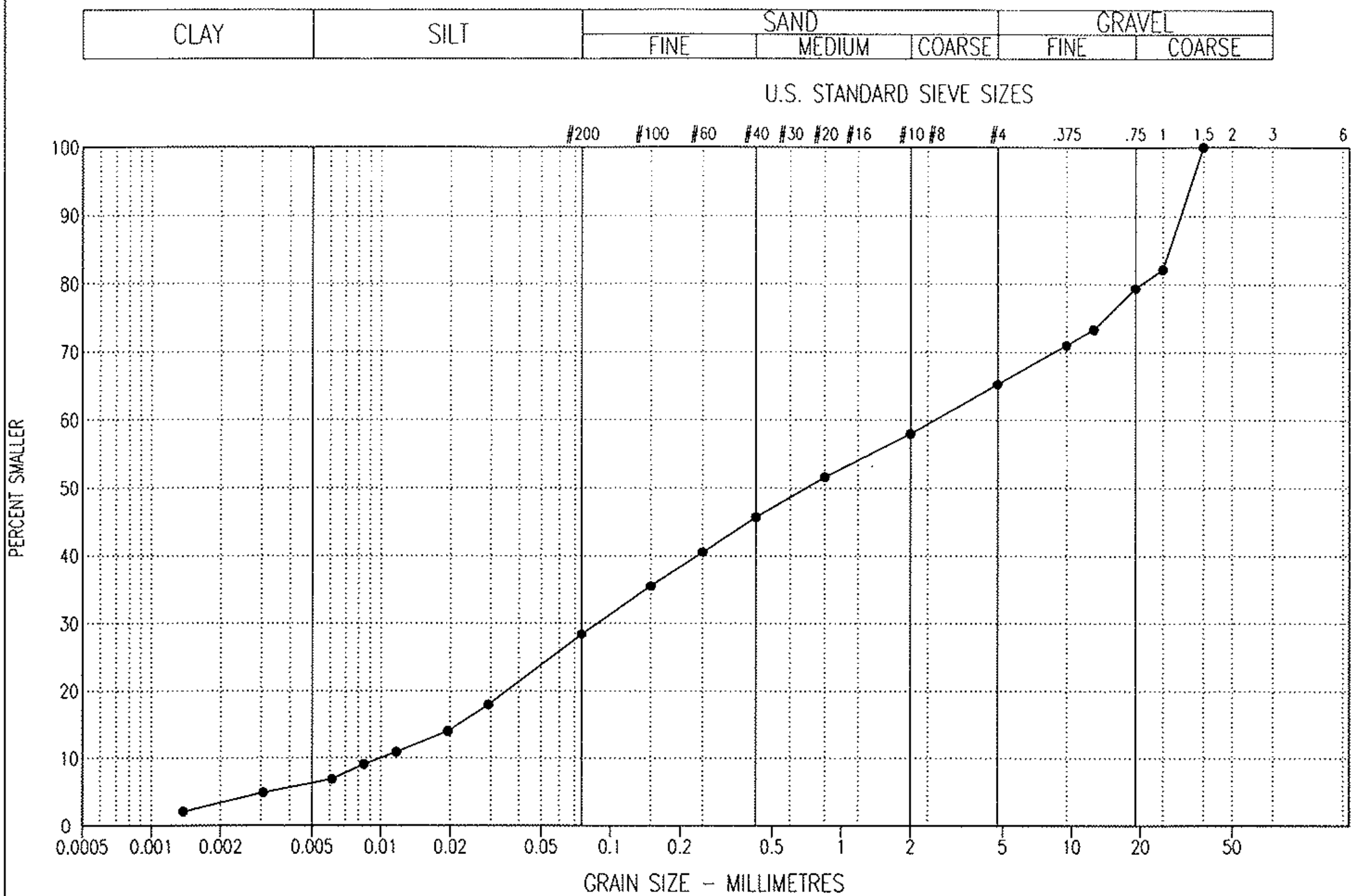
SYMBOL	BOREHOLE NUMBER	DEPTH (ft)	DESCRIPTION CLAY %	SILT %	SAND %	GRAVEL %	Cu	Cc	U.S.C
●——●	TP11	0.00	11.4	21.6	32.2	34.8	518.6	0.5	GM

Project: 0101-10995.21 Date Tested: 96/09/18 BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

EBA Engineering

PARTICLE SIZE - ANALYSIS OF SOILS



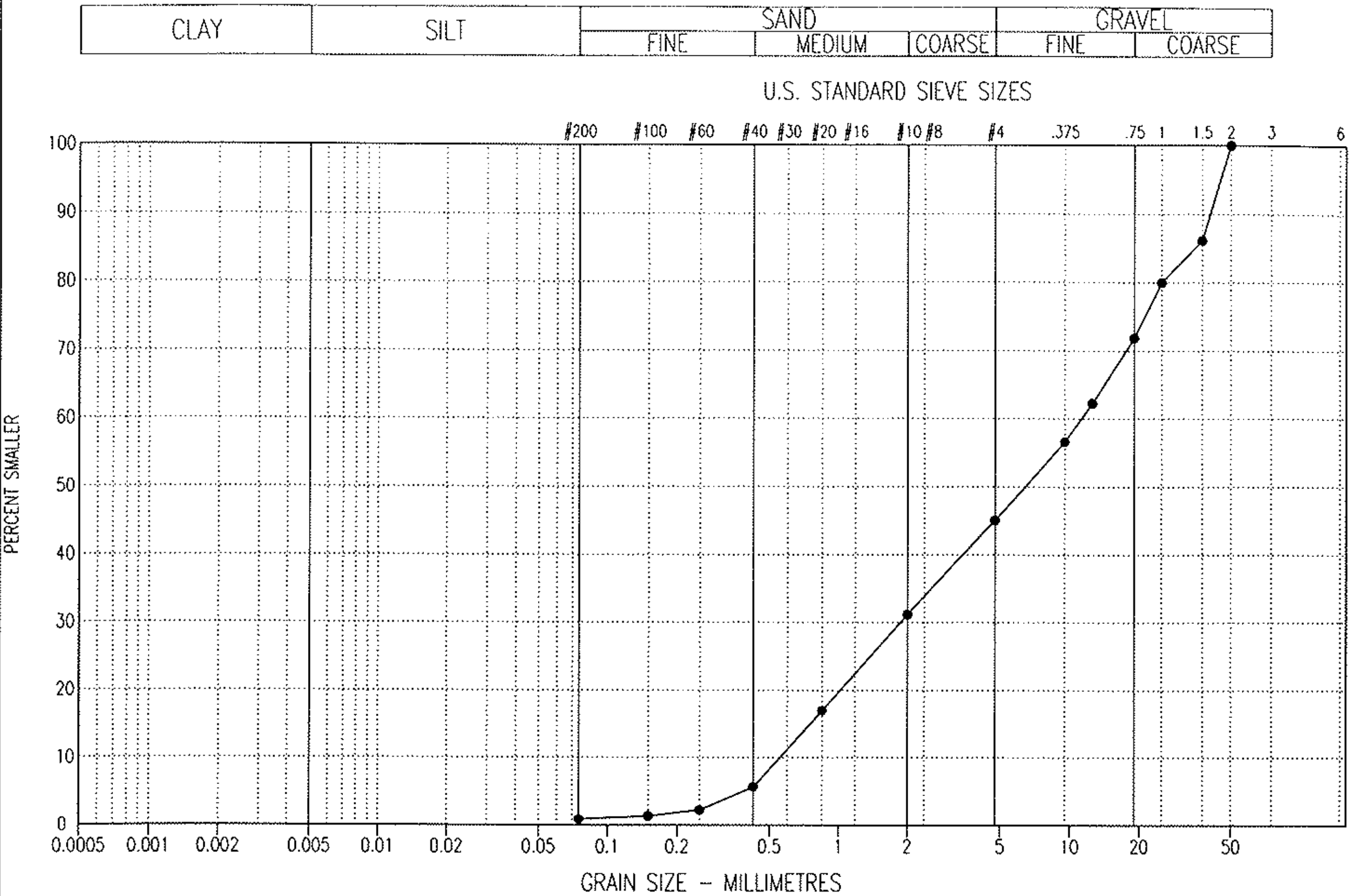
SYMBOL	BOREHOLE NUMBER	DEPTH (ft)	DESCRIPTION CLAY %	SILT %	SAND %	GRAVEL %	Cu	Cc	U.S.C
●——●	TP15&16	0.00	6.2	22.2	36.9	34.7	274.8	0.3	SM

Project: 0101-10995.21 Date Tested: 96/09/18 BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

EBA Engineering

PARTICLE SIZE - ANALYSIS OF SOILS



SYMBOL	BOREHOLE NUMBER	DEPTH (ft)	DESCRIPTION CLAY & SILT %	SAND %	GRAVEL %	Cu	Cc	U.S.C
●—●	TP17	0.00	0.8	44.2	55.0	19.2	0.5	GP

Project: 0101-10995.21

Date Tested: 96/09/17

BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

EBA Engineering Consultants Ltd.

MOISTURE - DENSITY RELATIONSHIP

ASTM D698, D1557, or D2049

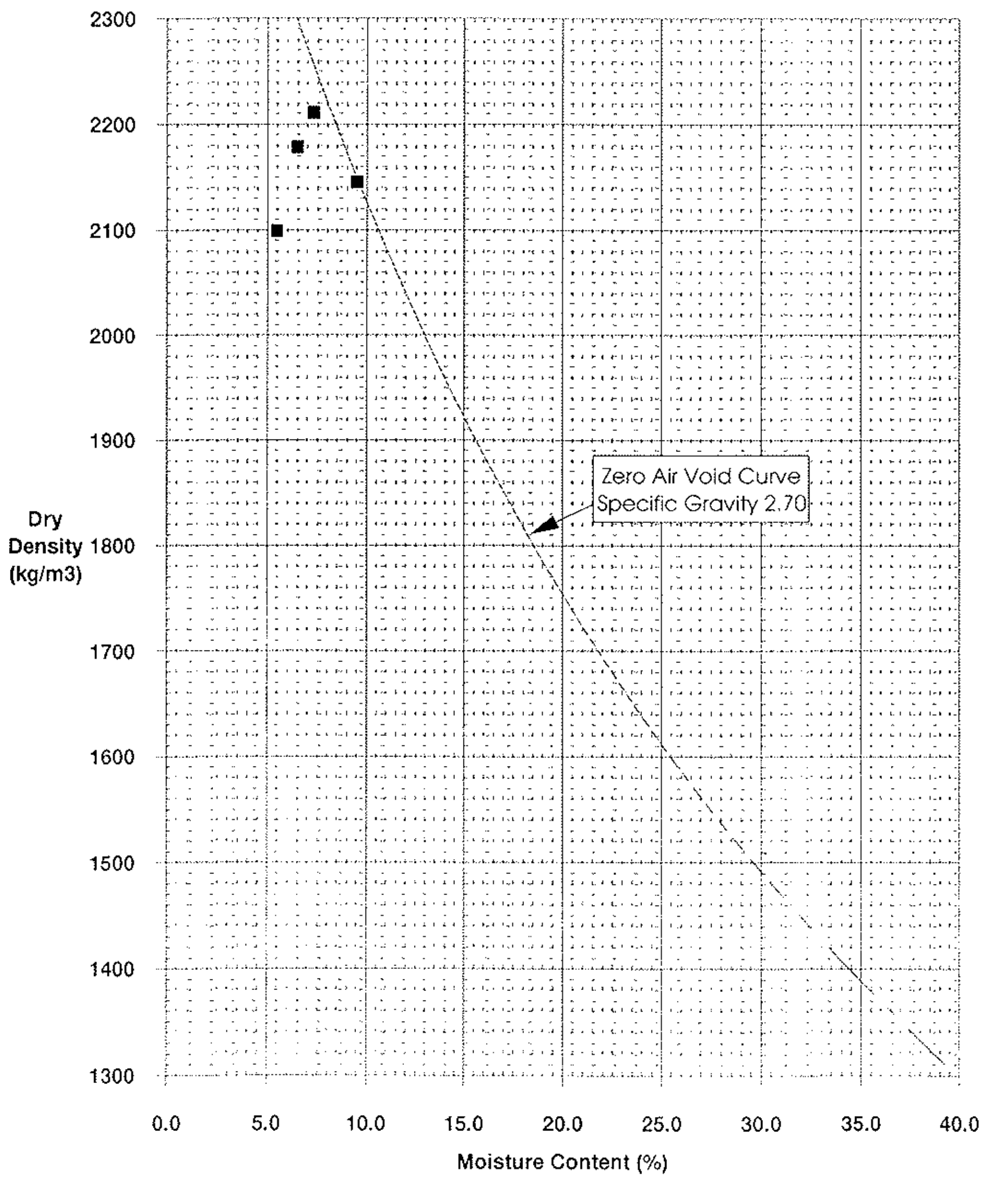
PROJECT:SARCPA LAKE - CAM-F STATION | SAMPLE NUMBER:TP11

PROJECT NO.:0101-95-10995.21 | DATE TESTED: 960918

CLIENT:UMA ENGINEERING LTD. | MOISTURE CONTENT (as Received): 7.3

DESCRIPTION: SAND & GRAVEL,(50 mm max.), silty, some clay | MAXIMUM DRY DENSITY: 2215

SAMPLE LOCATION : | OPTIMUM MOISTURE CONTENT: 7.0



STANDARD PROCTOR

ASTM D698

Hammer Mass: 2.494 kg

Hammer Drop: 304.8 mm

Number of Layers: 3

Number of Blows/Layer: 56

Diameter of Mould: 152.3 mm

Height of Mould: 116.5 mm

Mould Volume: 0.00212 m3

Compactive Effort: 590.3 kJ/m3

REVIEWED BY:

__________ P.Eng.

APPENDIX D

DUMP A GEOPHYSICAL SURVEY

D.1 Procedure

A geophysical survey was carried out over the Dump A area. The primary purpose for carrying out the survey was to identify the extent of the landfill.

Two geophysical tools, a Geonics EM-31 and a Geometrics Magnetometer were used. A summary of theory of these two tools is presented in the following sections. The survey was carried out by taking readings over a 5 m grid over the dump area. Readings were taken with the EM-31 orientated in the north south direction, and east west directions and the magnetometer oriented to the north. The grid was extended approximately 10 to 20 m beyond the suspected landfill boundaries.

D.2 Magnetometer Function

The theory behind magnetometer data is relatively simple. A point measurement of the Earth's total magnetic field strength at a specific location is taken at an instant in time. The earth is surrounded by a magnetic field, the strength of which varies by time and location. The variation in time (diurnal variations) are primarily caused by the influence of solar activity and are random in nature, but are at their highest level during periods of intense solar flaring (sunspot activity) and conversely are at their lowest level when the sun is quiet. Usually these variations are less that a few hundred gammas (nanoTesla, nT) in magnitude. Variations due to location on the earth's surface are solely a function of relative position with respect to the earth's magnetic poles. As the magnetic poles drift, so do the location readings. The earth's magnetic field varies by approximately 20000 gammas from the poles to the equator.

Magnetic data is useful in locating objects such as buried steel tanks due to the fact that small areas the earth's magnetic field can be distorted by the presence of magnetized rocks, soils, and ferrous (iron) objects. This is because these object also possess an intrinsic magnetic field and the two fields will combine and produce a resultant total magnetic field strength that is a function of the two magnetic fields. By subtracting the earth's magnetic field from field data and contouring the remainder metalic objects can be detected. In general, the effect from natural materials such as rocks and soils is small over small areas and is usually less than 1 gamma/m. Concentrated ferrous debris however, can cause magnetic field distortions of up to 30000 gammas/m.

D.3 EM-31 Function

The EM-31 belongs to a family of geophysical systems called inductive electromagnetic conductivity systems that include the EM-16, EM-34, and the EM-38. The average ground conductivity (in millimhos/m) is measured using the following technique. A electrical current is induced in the ground by a magnetic field generated by a transmitter coil (Maxwell's theory). This magnetic field is called the primary magnetic field. The ground current created by the primary magnetic field in turn generates its own field or secondary magnetic field which is measured by a receiver coil separated a fixed distance from the transmitter.

As the received signal is usually out of phase and has a different field direction to the primary field, the received signal is by convention divided into two different measurements. The first measurement is the portion of the signal that is in-phase with the generated primary signal. This component is usually sensitive to isolated conductors and hence is sensitive to buried metals. The second measurement is the portion of the signal that is out-of-phase (quadrature) with the generated primary signal. This measurement is generally proportional to the overall average ground conductivity between the transmitting and receiving coils. Both measurements are expressed as a percentage of the primary field strength.

In the case of the EM-31 the transmitter and receiver are separated by a distance of 3.7 metres and operate at a frequency of 9.8 KHz. This results in an effective sounding range of 0.5 to 6 metres and an ability to measure conductivity values between 1 and 200 millimhos / m. The EM-31 can be operated in two modes. These modes are defined by the orientation of the primary and secondary magnetic field lines. The vertical dipole mode is the standard mode of operation and is sensitive to deeper conductivity variations. The horizontal dipole mode is used when the EM-31 is rotated 90° onto its side. In this mode the sounding depth is essentially halved and the instrument becomes more sensitive to shallow variations in the ground conductivity.

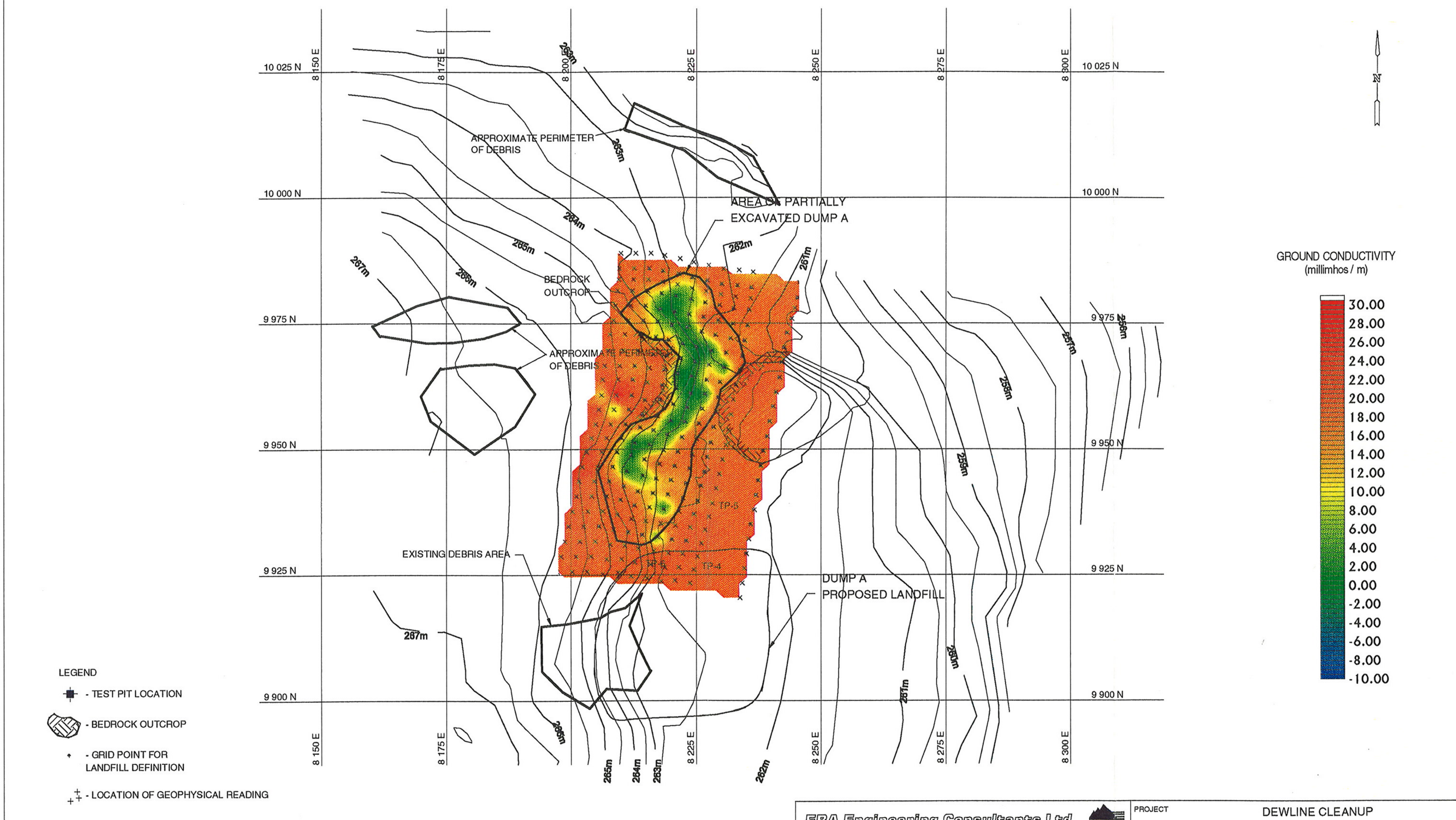
A linear relationship exists between the strength of the received signal and the true ground conductivity provided the soil is both homogenous and horizontally stratified in the vicinity and between the transmitter coil and the receiver coil. In the presence of non- homogeneous and non-horizontal stratigraphy the underlying linear relationship between the quadrature measurement and true ground conductivity fails. This is the reason that the presence of metallic objects near the EM-31 is often detected by rapidly varying and often both extremely high and sometimes negative conductivity values.

D.4 Results

The results of the geophysical survey are shown in the Figures D-1 through D-3. Generally the extent of the dump is identified as low readings from the EM-31, and high deviations (both high and low) from the background readings with the magnetometer. The dump area identified from the geophysical results agrees with the surveyed permiter based on a visual assessment.

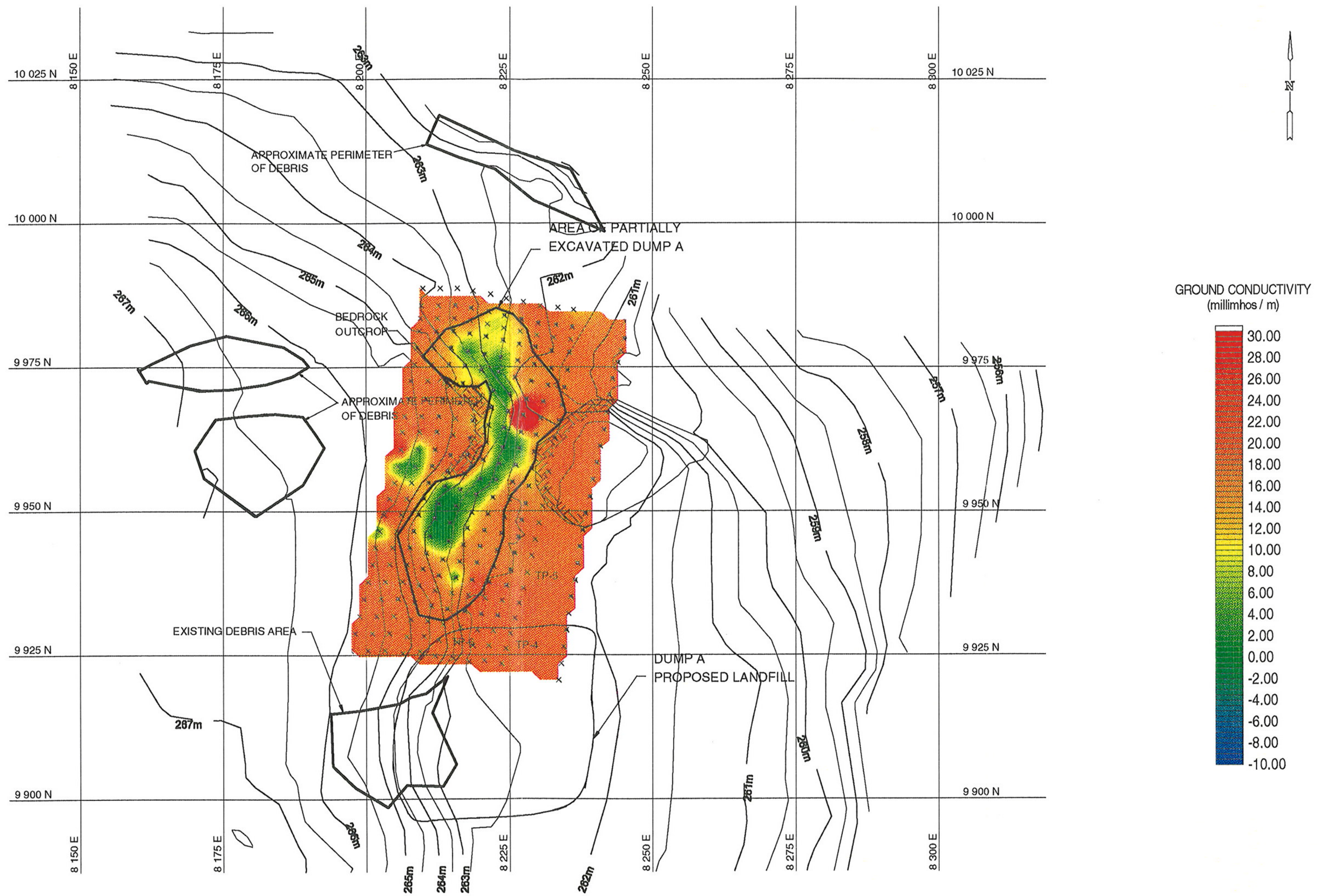
It should be noted that the dump area had scattered metal debris on the surface. This surface debris influences the results of the survey. Of particular note is a cat track at coordinates 9965 N 8239 E and barrels located at 9955 N, 8210 E.

The magnetic data could be further analyzed to provide an approximate indication of the amount of ferrous metal in the landfill.



NOTE: ADAPTED FROM UMA DRAWING C228-003-00-106 DATED 1996-09-30

EBA Engineering Consultants Ltd.		PROJECT	DEWLINE CLEANUP SARCPA LAKE
CLIENT UMA ENGINEERING LTD.		TITLE	EM-31 SURVEY RESULTS (NORTH - SOUTH) DUMP A
DATE 96-11-07	DWN. LM / CHKD. WTH	FILE NO. 101-10995NSP01	FIGURE D-1



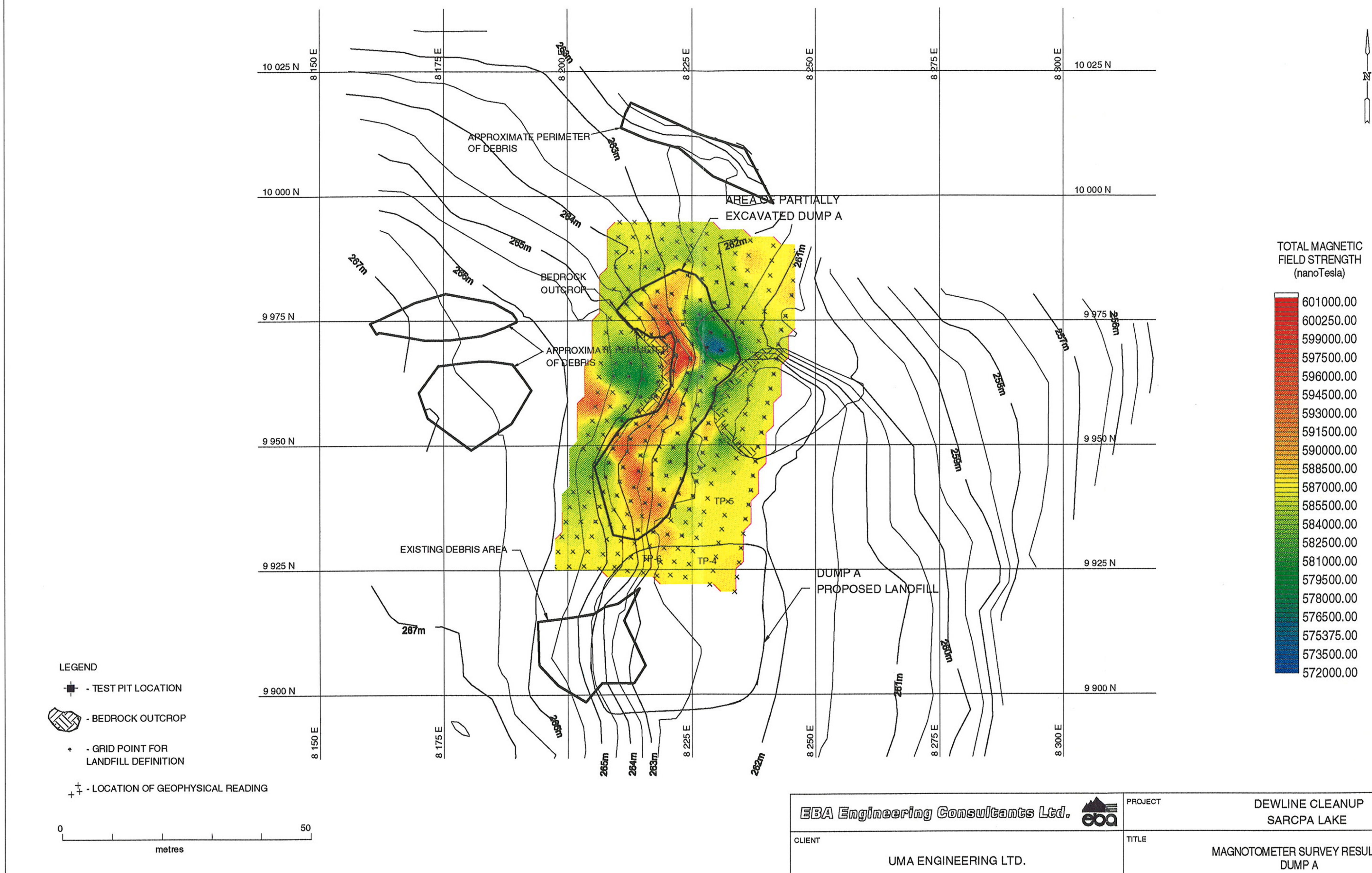
LEGEND

- TEST PIT LOCATION
- BEDROCK OUTCROP
- GRID POINT FOR LANDFILL DEFINITION
- LOCATION OF GEOPHYSICAL READING

0 50
metres

NOTE: ADAPTED FROM UMA DRAWING C228-003-00-106 DATED 1996-09-30

EBA Engineering Consultants Ltd.		PROJECT	DEWLINE CLEANUP SARCPA LAKE
CLIENT	UMA ENGINEERING LTD.	TITLE	EM-31 SURVEY RESULTS (EAST - WEST) DUMP A
DATE 96-11-07	DWN. LM / CHKD. WTH	FILE NO. 101-10995NSP02	FIGURE D-2



NOTE: ADAPTED FROM UMA DRAWING C228-003-00-106 DATED 1996-09-30

EBA Engineering Consultants Ltd.		PROJECT	DEWLINE CLEANUP SARCPA LAKE
CLIENT UMA ENGINEERING LTD.		TITLE	MAGNOTOMETER SURVEY RESULTS DUMP A
DATE 96-11-07	DWN. LM / CHKD. WTH	FILE NO. 101-10995NSP03	FIGURE D-3

APPENDIX E

GEOTHERMAL ANALYSES

E.1 PURPOSE AND METHODOLOGY

Geothermal analyses were carried out to predict the long term ground temperatures caused by construction of the Tier II Landfills. The following design information was obtained from the analyses:

- Length of time for freezeback of the landfilled soil;
- Long-term and short term thermal regime in the ground surrounding the facilities; and
- Depth of the active layer in the cover material during construction, over the long term, and during warm years.

Analyses were carried out using the two-dimensional finite element computer model, GEOTHERM developed at EBA. The model simulates transient, two-dimensional heat conduction with change of phase for a variety of boundary conditions. The heat exchange at the ground surface is modelled with an energy balance equation considering air temperatures, wind velocity, snow depth, and solar radiation. The model facilitates the inclusion of temperature phase change relationships for saline soils, such that any freezing depression and unfrozen water content variations can be explicitly modelled.

The theoretical formulation of the model is discussed in detail by Hwang (1976). Its results have been verified by comparison with closed form analytical solutions and many different field observations. The model has formed the basis for the design of a substantial number of projects in the arctic and subarctic regions. These have included the thermal design of pipelines, utilidor systems, and dams, as described by Kent and Hwang (1979), Boga et al. (1980), Hayley (1981), Zirjacks and Hwang (1983), and Cathro et al. (1992).

The analyses parameters were calibrated by modelling the existing conditions and comparing the results to assumed ground temperatures.

E.2 INPUT DATA

E.2.1 Soil Thermal Properties

The following soil thermal properties are required to carry out geothermal analyses using the EBA model:

- Porewater composition,
- Latent heat,
- Specific heat (frozen and unfrozen), and

- Thermal conductivity (frozen and unfrozen).

These properties were determined indirectly from well established correlations with soil index properties (moisture content, grain size distribution, salinity, etc.) (Farouki, 1986; Johnston, 1981). Soil index properties were estimated from the laboratory of samples obtained during site investigation. Values assumed for the analyses are summarized in Table .

The unfrozen water content in the soil is due to adsorbed moisture in the soil minerals and to unfrozen moisture in pockets within pore ice. The quantity of unfrozen water due to adsorbed water is estimated by a procedure outlined by Anderson and Tice (1972), which is based on the specific surface area of the soil particles. The quantity of unfrozen moisture within brine pockets of pore ice is estimated using a sea ice model presented by Ono (1966). The resulting estimated unfrozen moisture content for the cover soils, Tier II soils, and foundation soils are presented in Figure E.1.

TABLE E-1
ASSUMED SOIL PROPERTIES FOR THERMAL ANALYSES

Material	Water Content (%)	Dry Density (Mg/m3)	Porewater Salinity	Frozen Thermal Con-ductivity (W/m°C)	Unfrozen Thermal Con-ductivity (W/m°C)	Frozen Specific heat (KJ/kg°C)	Unfrozen Specific heat (KJ/kg°C)	Latent Heat (MJ/m3)
Bedrock	0.5	2.60	0.0	2.50	3.05	0.74	0.75	4.0
Till founda-tion	14.1	1.93	1.0	3.07	2.18	0.92	1.16	85.0
Peat	60.0	0.50	0.0	0.93	0.55	1.25	2.03	99.0
Granular cover	7.0	2.18	1.0	2.78	2.51	0.84	0.96	44.0
Tier II soil	8.0	2.20	1.0	3.23	2.67	0.85	0.99	52.0
Saturated Berm	8.0	2.20	1.0	3.23	2.67	0.85	0.99	52.0

E.2.2 Climatic Data

Climatic data required for the thermal model includes air temperature, wind velocity, solar radiation, and snow cover. There was no long term climatic records available from the site. It was assumed that the climatic conditions are similar to Hall Beach, located 85 km east of the site. The climatic data for Hall Beach is presented in Table E.2.

TABLE E.2
METEOROLOGICAL DATA SUMMARIES

Month	Mean Monthly Temperature (°C)	1:100 year Temperature (°C)	Wind Velocity (km/hr)	Snow Depth (m)	Solar Radiation (W/m°)
January	-31.0	-27.3	22.2	0.34	2.2
February	-32.1	-28.3	22.5	0.35	22.9
March	-29.5	-26.0	21.3	0.38	87.8
April	-20.9	-18.4	20.8	0.41	188.2
May	-9.1	-8.0	18.7	0.42	252.5
June	0.0	0.0	16.9	0.15	274.4
July	5.4	11.8	18.9	0.00	217.8
August	4.6	10.0	24.1	0.00	150.7
September	-0.6	-0.5	25.2	0.00	70.6
October	-10.5	-9.3	23.4	0.11	30.3
November	-21.5	-19.0	20.8	0.22	4.8
December	-27.4	-24.2	21.3	0.28	0.1
Yearly Average	-14.4	-11.6	21.3	0.30	

Climatic Data - Hall Beach
Climatic Normals 1951 - 1980

Analyses were carried out to determine the influence of exceptionally warm climatic conditions. Warm freezing and thawing indices with a return period of 1 in 100 years were obtained using a relationship presented by McCormick (1991). To model the 1 in 100 year events, winter air temperatures were increased by the ratio of mean freezing index to the 1 in 100 year freezing index. Similarly, summer air temperatures were increased by the ratio of the 1 in 100 year thawing index to the mean thawing index. The 1 in 100 warm year annual temperatures at are 2.8 C° warmer than the respective mean annual temperatures.

E.3 RESULTS OF THE ANALYSES

E.3.1 Calibration Analyses

Thermal analyses of the existing conditions were analyzed and compared to the assumed ground temperatures. No ground temperatures have been measured at the site. It was assumed the ground temperatures are similar to the temperatures measured at Hall Beach (EBA, 1994). The mean annual temperature at Hall Beach was between -9°C and -10°C. The mean climatic conditions used in the thermal analysis resulted in a mean active layer of -9°C, and an active layer of 0.7 m in the native ground (5 cm of peat overlying wet sandy till). This is a reasonable result.

E.3.2 Post Construction

The thermal analysis of the facility is based on constructing it during late summer. The ground underlying the facility will be thawed. It was assumed that the fill and Teir II soil was placed at -5°C. Thermal analyses were carried out to determine the temperature response of the soil in and around the facility during construction, and over the short and long term. The geometry modelled and the initial temperatures are shown in Figure E.2.

Figure E.3 shows the position of the -1°C isotherm over time in the centre of the landfill. The -1°C isotherm is conservatively used to represent the unfrozen-frozen interface in the cover soil. It is assumed that approximately 35% of the moisture in the cover material and Tier II soil will be frozen at -1°C as shown in Figure E.1. Figure E.3 illustrates that it takes approximately 1.5 years for the Tier II soil to freeze back to -1°C. After 3 years, the seasonal thaw penetration stabilizes at a depth of 1.6 m. Further analyses indicate that the -1°C isotherm is 2.1 m deep following 10 consecutive warm (1 in 100) years.

Figures E.4, E.5, E.6 and E.7 show the predicted isotherms after 1, 3, 5 and 10 years respectively. Figure E.4 illustrates that after 1 year the central portion of the Tier II soil is at a temperature of -2°C; and the temperature at the base of the facility is -2.5°C. Figure E.5 shows that after 3 years the temperature of the Tier II soil is less than -2°C, and the base of the facility is less than -5°C. The temperature in the base of the facility is less than -6°C after 5 years, as shown in Figure E.6.

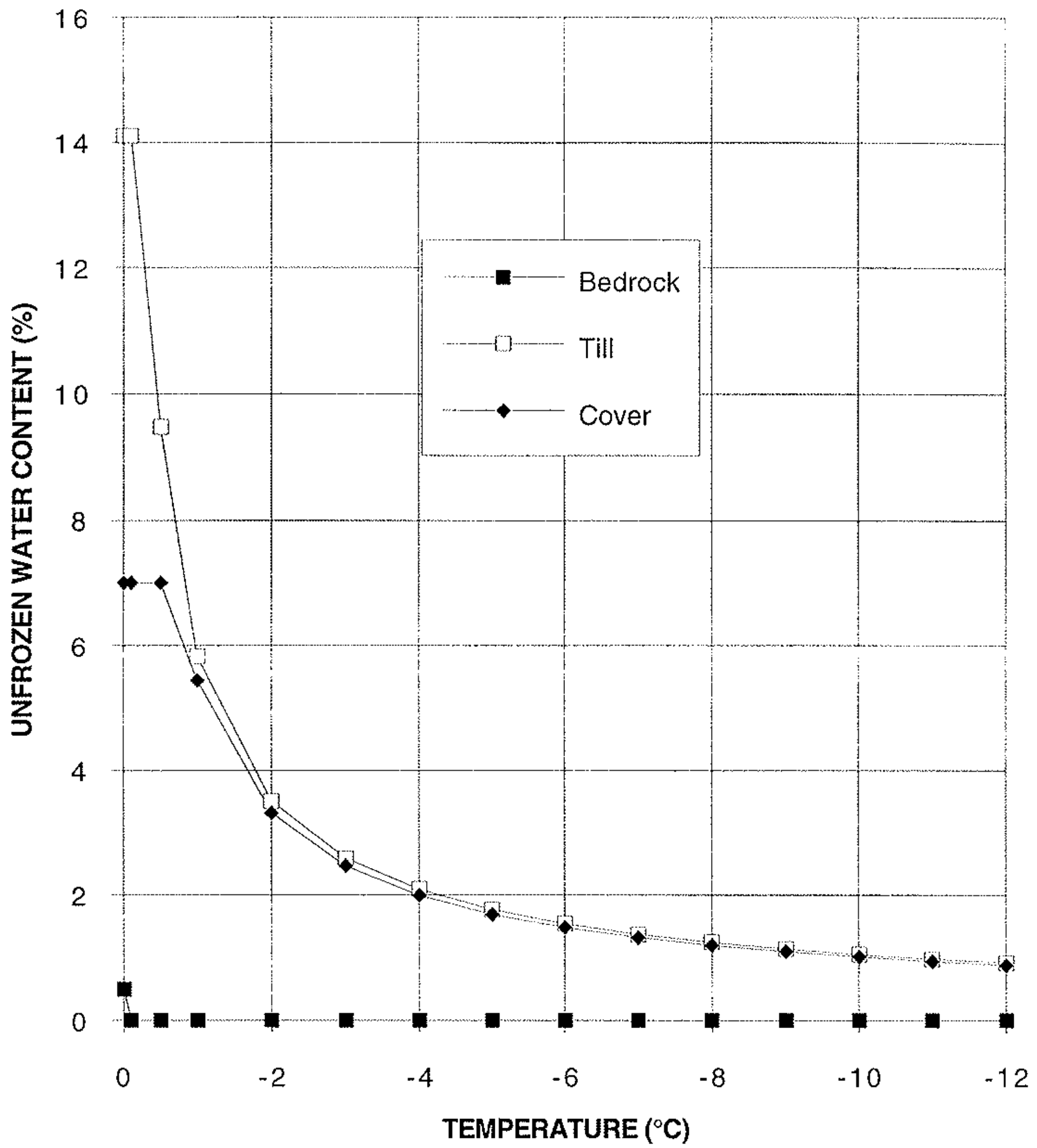


FIGURE E.1 UNFROZEN MOISTURE CONTENT ASSUMED FOR SOILS

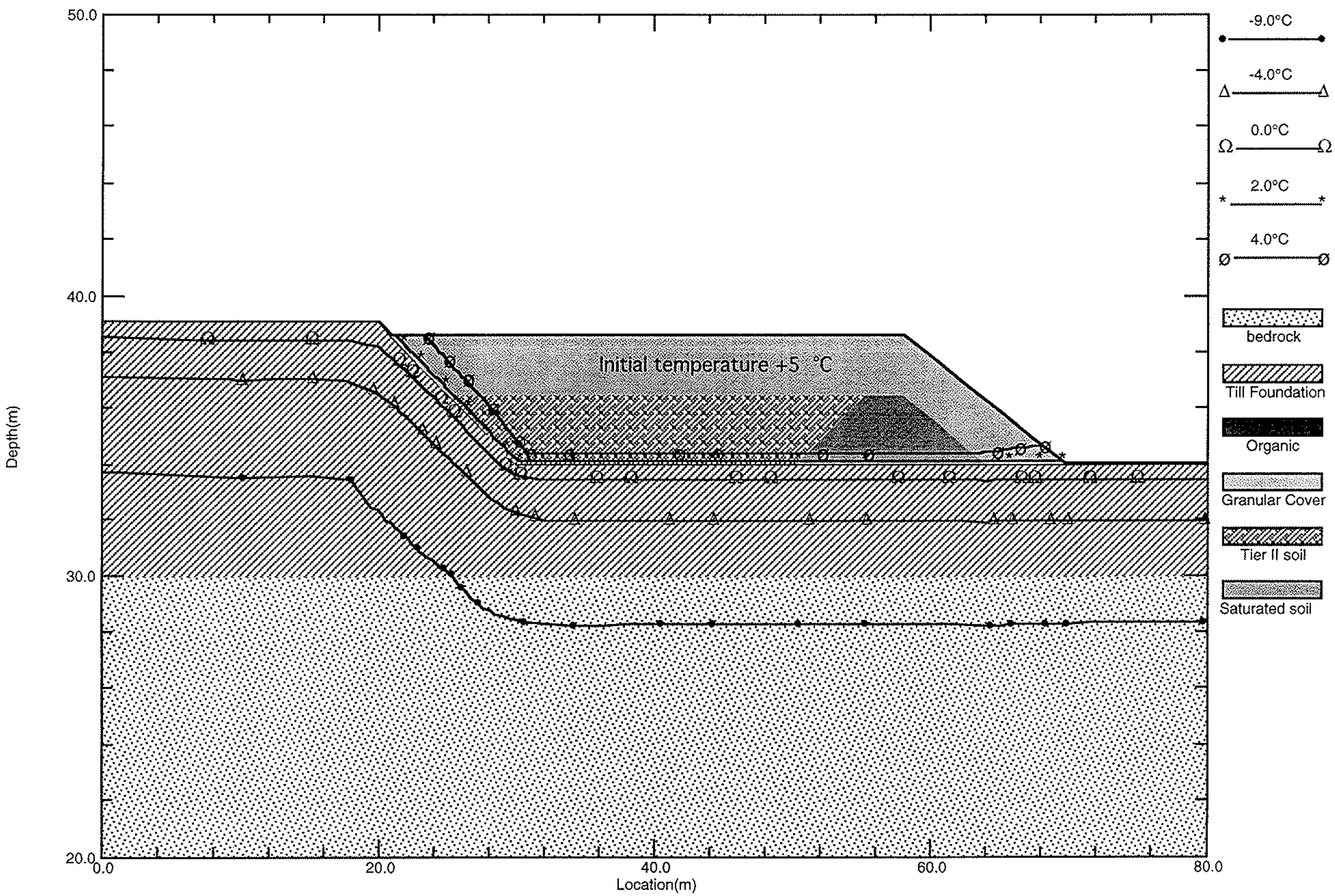


FIGURE E.2 GEOMETRY AND INITIAL CONDITIONS

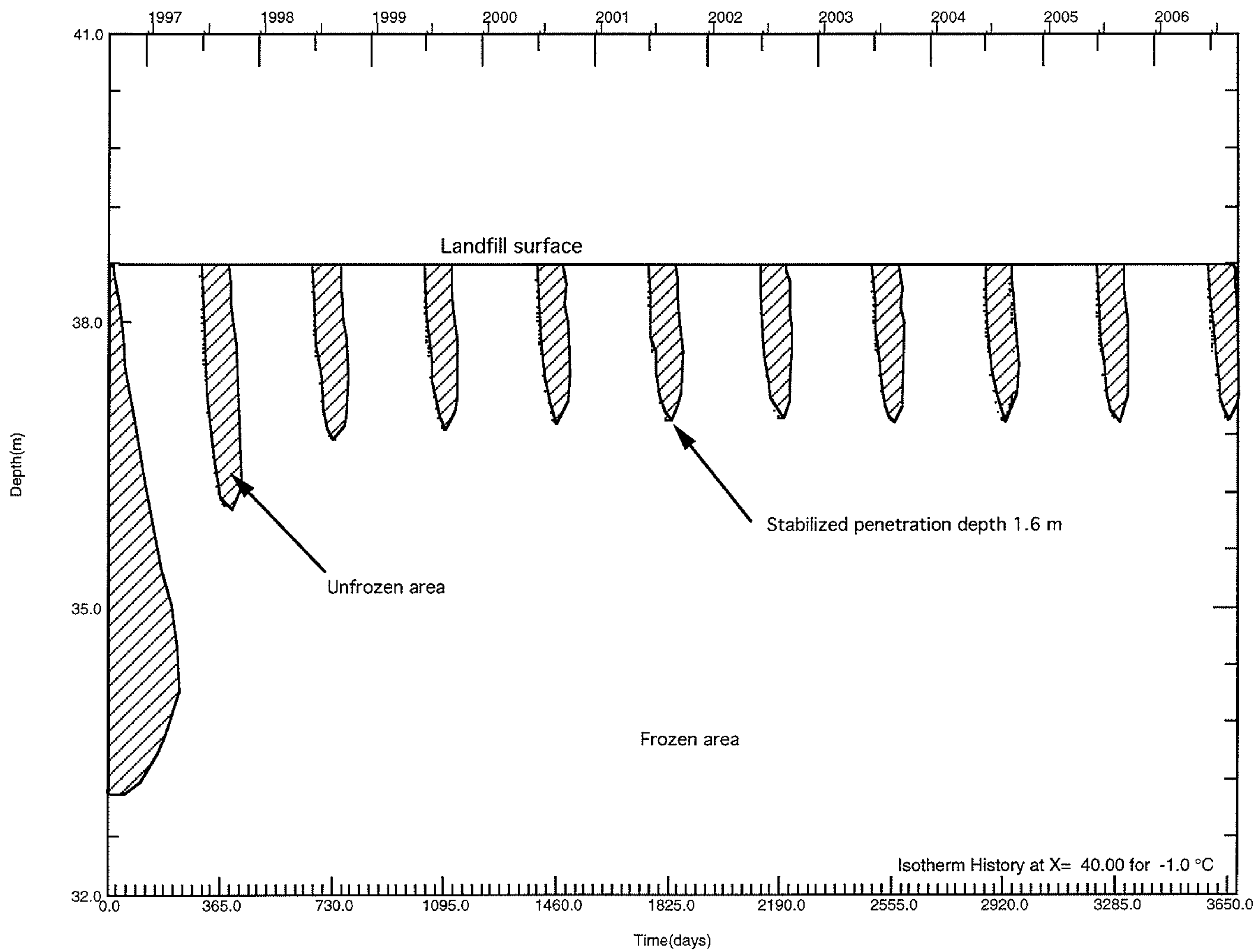


FIGURE E.3 -1 °C ISOTHERM HISTORY

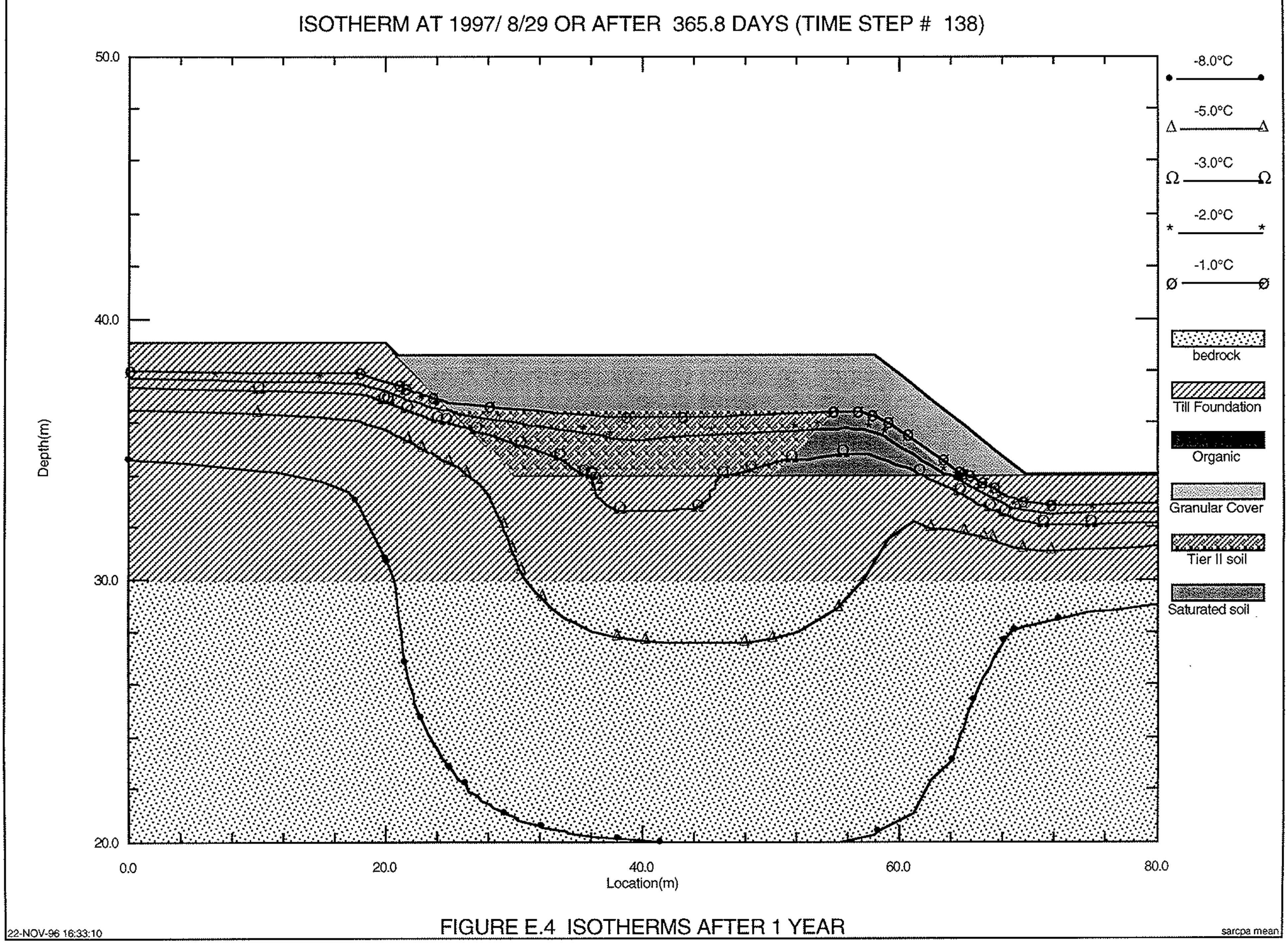


FIGURE E.4 ISOTHERMS AFTER 1 YEAR

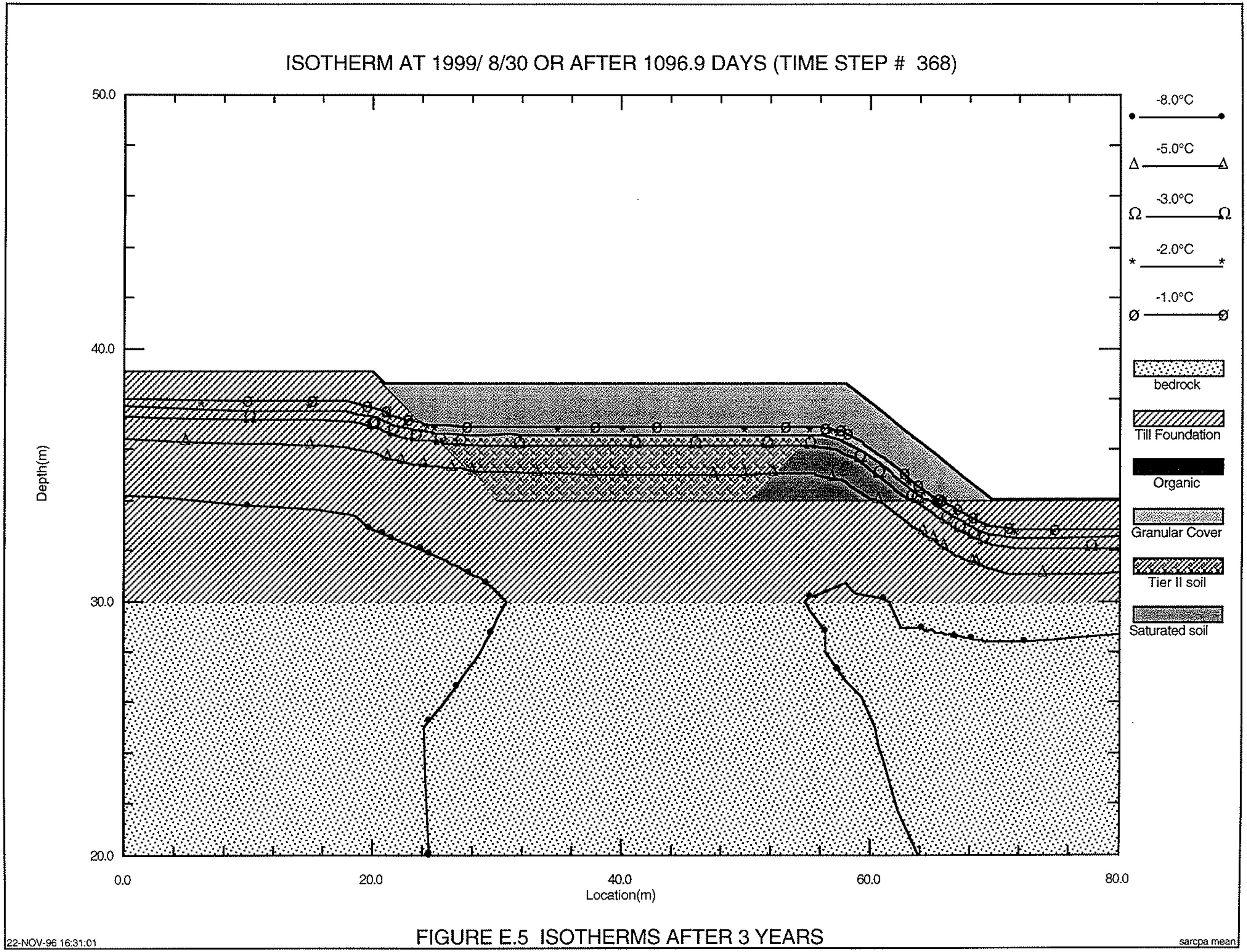


FIGURE E.5 ISOTHERMS AFTER 3 YEARS

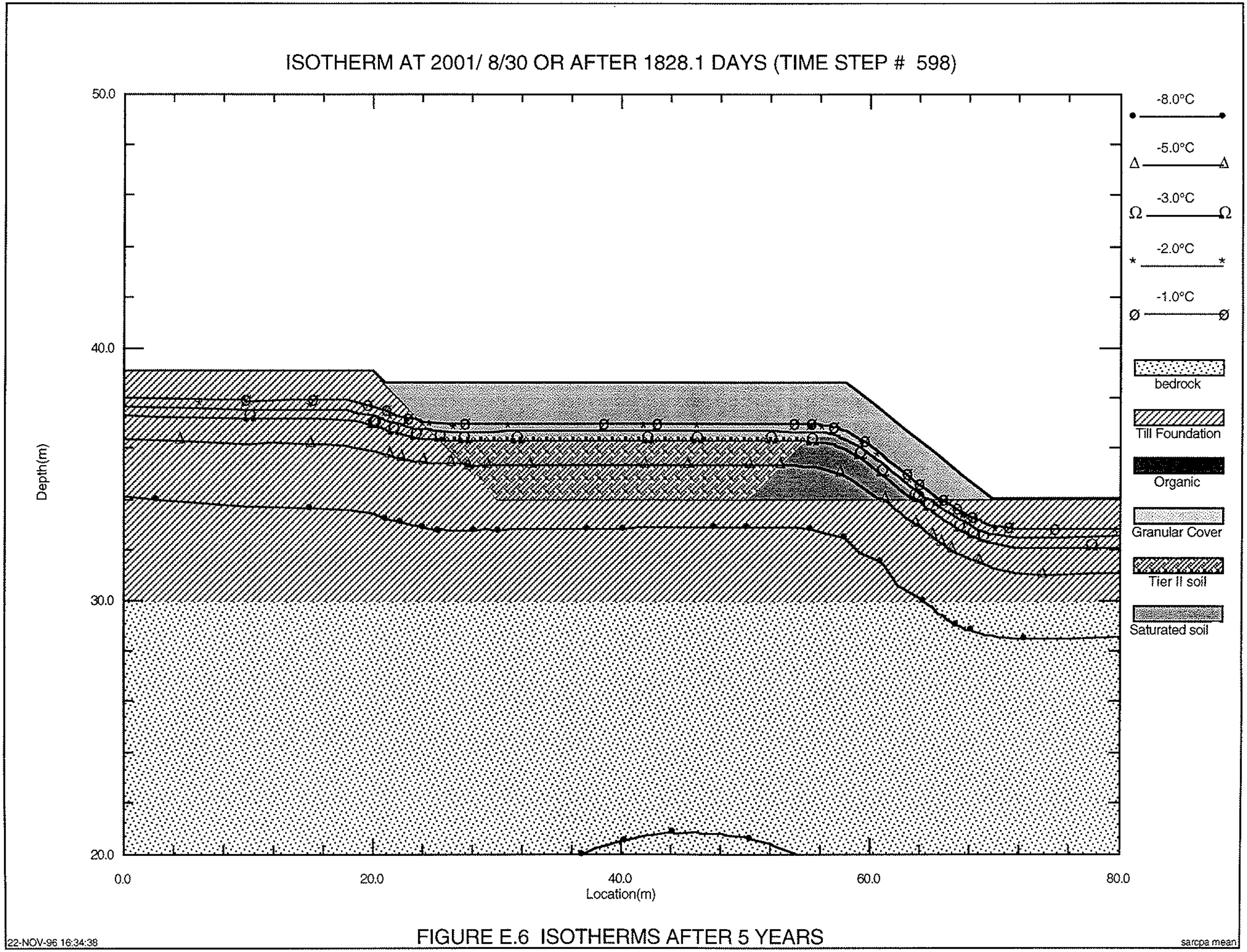


FIGURE E.6 ISOTHERMS AFTER 5 YEARS

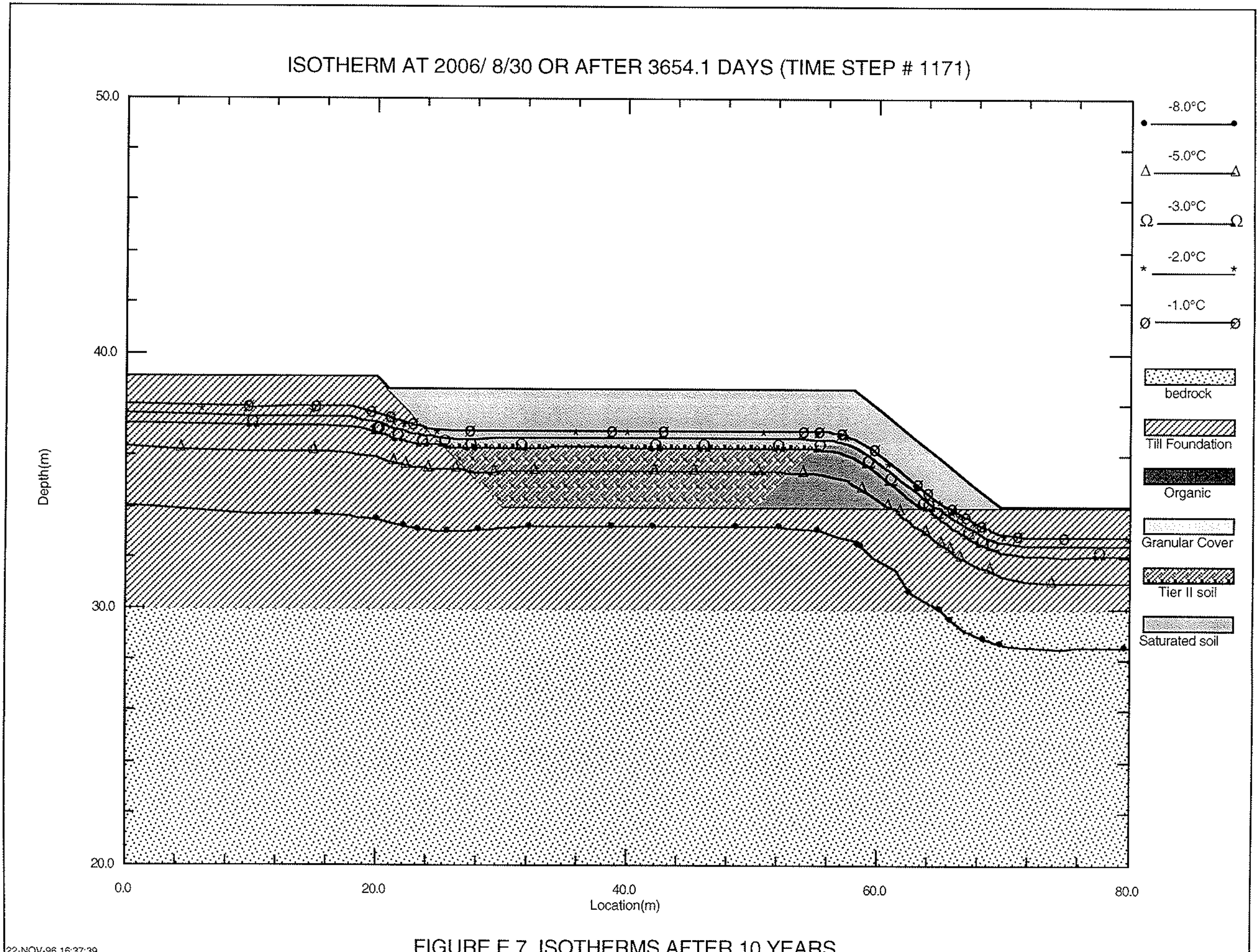


FIGURE E.7 ISOTHERMS AFTER 10 YEARS