Gartner
Lee

Polaris Mine
Polaris Landfill Closure Report

Prepared for
Cominco Ltd.

Prepared by:
Gartner Lee Limited

GLL 20-935

March 2001

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1. Introduction

1.1 Background

The Polaris Mine, located on Little Cornwallis Island within the new Nunavut Territory, is an underground lead and zinc mine operated by Cominco Ltd. Construction of the mine began in 1979 and production started in 1981. Based on forecast of ore reserves, the mine is scheduled to be decommissioned and closed in the year 2002. The closure and reclamation plans for the mine will be subject to review and approval of Nunavut agencies and the Department of Indian and Northern Development (DIAND).

This report has been prepared to address issues associated with closure of the on-site landfills, which include the Construction Landfill, the Operational Landfill, the Little Red Dog Quarry (this former quarry will be filled with demolition waste) and the Reclamation Landfill (obsolete equipment is currently being buried in the Reclamation Landfill).

The Operational and Construction landfills are located approximately one kilometre south of the accommodations complex. The Reclamation Landfill is located west of the New Quarry and approximately 1 km northeast of the accommodations complex. The Little Red Dog Quarry/Landfill is located approximately 800 m north of the accommodations complex. A site plan showing the location of the various landfills is shown on Figure 1.

The Construction Landfill is approximately 200 m long and 40 m wide. No records of the waste materials are available, but mine personnel indicated that it generally consisted of construction wastes from the mine start up between 1979 and 1981. After its closure in about 1981, the Construction Landfill was used as an open storage area. The Operational Landfill started in 1981 northeast of the Construction Landfill. Filling progressed from west to east starting in Zone A and ending in Zone B in 1999. A third designated Zone C, located west of Zone B, has not yet been filled. The Operational Landfill is approximately 400 m long by 70 m wide and 10 m high. The waste includes dry chemical bags (empty), drums, construction materials, used vehicles and parts, and municipal type solid waste. Currently, the municipal type waste and waste oil are burned at the west end of Zone A in a burn pit. The residue is pushed over the side and covered with soil. Electrical cable is also burned near the burn pits for salvaging copper wire.

This report contains details for the relocation of the Construction Landfill and closure of the Construction, Operational and Little Red Dog landfills which will require engineered covers. The Reclamation Landfill does not require an engineered cover.

1.2 Objectives and Scope

As part of the mine decommissioning and reclamation, the landfills will be closed. The main objectives for closure are minimizing the impact that the landfills may have on the environment and returning the land to its natural state, wherever possible. As outlined in the previous UMA (1999) and GLL (1999) reports, the environmental impacts of the Construction and Operational landfills in their current state are related to preventing the leachate from leaving the landfills and entering Polaris Bay. Therefore, the main objective for closure of the landfills is to prevent leachate generation and migration. Due to its location and climate, migration of leachate is only possible for a short period in the summer during the thaw period. Hence, potential contaminants from the landfills will be contained if the waste remains frozen over the entire year. This may be achieved by developing an engineered cover system that maintains the wastes below the active layer.

As the Construction Landfill is close to Polaris Bay and would require shoreline protection after applying a final cover, options for its relocation were reviewed.

The scope of work required for closure of the landfills is outlined in our proposal dated March 1, 2000, and is summarized below:

- Review of available records from Cominco Ltd.
- Determine volume of waste from the Construction Landfill to be relocated
- Assess relocation options for the Construction Landfill
- Complete a preliminary cover design
- Geothermal assessment
- Complete a final cover design and final landfill contours
- Complete a summary report.

2. Site Conditions

2.1 Physical Setting

The Polaris Mine is located at 75° 23’ north latitude and 96° 57’ west longitude at the southern end of Little Cornwallis Island. The area around the mine site consists of very gently rolling low-relief hills and plains rising out of the ocean. Several large elliptical lakes (Garrow, Frustration, and Lois Lakes) are located near the mine. The mine site is located on a peninsula characterized by large hills with steeper slopes than the surrounding area.

The landscape and surficial materials are dominated by marine and glacial processes. During glaciation, the current mine site was likely below sea level (Hodgson 1989) and experienced isostatic rebound as the glaciers retreated. Evidence of the uplift is provided by the raised beaches in the area. The subdued and rounded topography is typical of continental glaciation.

2.2 Geology

The description of the geology for the Polaris mine area is based on the work of Sharp et al (1996).

The Polaris Mine and other lead-zinc showings in the Cornwallis Islands area, District of Franklin, occur in lower Paleozoic carbonate rocks within the Cornwallis Fold Belt. The favored host strata for the lead-zinc mineralization is the Thumb Mountain Formation, an Ordovician limestone characterized by a lower member that accumulated in a shallow water tidal flat environment and an upper member that formed on a shallow water shelf environment. The Thumb Mountain Formation outcrops extensively on Cornwallis and Little Cornwallis Islands. Overlying the Thumb Mountain Formation are the Irene Bay Formation and the Cape Phillips Formation, both of which are exposed on surface. Erosion has removed any younger strata on Little Cornwallis Island.

Deposits of pebbles, mud and sand of variable thickness characterize the surface geology of the Polaris Mine area. The unconsolidated deposits have been extensively reworked into raised beaches formed during isostatic rebound following deglaciation. The Thumb Mountain and Irene Bay Formations weather into material characterized as well drained gravel. The Cape Phillips Formation weathers to form a much higher proportion of fines (sands and silts).

Outcrops of the lower member of the Thumb Mountain Formation are present near the Ocean on the west side of the peninsula by Crozier Strait. The hillside between the barge and the accommodations building is covered with micritic and fine-grained limestone, with fossil *Tetradium* corals becoming more abundant upward in the section. Surface showings of sphalerite, galena and marcasite stringers and disseminations associated with dolomitized rocks of the upper member of the Thumb Mountain Formation occur in three areas of the mine site. The main sulphide deposit does not outcrop at the surface of the mine site.

The Irene Bay formation is a poorly exposed, recessive weathering unit. It can be seen exposed in the southeast wall of the Old Quarry, where it lies in contact with the basal units of the Cape Phillips Formation. The Irene Bay formation consists of interbedded green mudstone (shale), argillaceous gray-green limestone and massive gray limestone. Large intact fossils of gastropods and corals are present, as well as crinoid, brachiopod and trilobite fragments. Marcasite nodules are common and often replace fossils in the lower green mudstone. Approximately 1-2% disseminated pyrite occurs throughout the green mudstone.

The Cape Phillips Formation is a black bituminous carbonate mudstone and is exposed in the New Quarry. Orange weathering patches extend along frost shattered fractures. A third quarry area, known as the Little Red Dog Quarry, is located to the southwest of the north showing of the upper member of the Thumb Mountain Formation. This quarry was developed to supply dolomite for use as cemented backfill material in the underground.

2.3 Thermal Regime

The Polaris mine site is located in the continuous permafrost region of northern Canada (Brown 1966). The current active layer thickness ranges from 0.10 m to 1.36 m for various ground surface covers and strata including snow, moss, mineral soil, and shale bedrock. The depth of mean annual temperature fluctuation is approximately 17 m. The mean annual ground surface temperature ranges from –15.6 to –13.5°C.

2.4 Water Balance

The annual precipitation at the mine site is approximately 250 mm, of which, about 50 mm is in the form of rain and 200 mm is snow. The area is classified as a "polar desert" and although there is not significant vegetation for evapotranspiration, it is assumed that approximately 50% of the precipitation evaporates as a result of the dry air. Based on this assumption, the excess for runoff and ground infiltration is about 65 mm. Most of the excess water is in the form of snow and runs off during the summer melt. Due to the low amount of excess moisture, no significant runoff occurs except during the summer, which is the only time when erosion of the landfill is a concern.

3. Relocation Options for Construction Landfill

As indicated in Section 1.2, the Construction Landfill must be relocated to move the waste away further from Polaris Bay. This section outlines the process followed in determining the best relocation option for the Construction Landfill.

3.1 Waste Volumes

Prior to exploring the relocation options, it was necessary to determine the volume of waste to be relocated. Records of construction wastes during the mine startup were not kept so it was necessary to estimate the waste volume by using AutoCAD. The volume was calculated between two surfaces representing the existing ground surface and the natural ground surface. Survey data with ground elevations before landfilling started were not available, therefore, the original ground surface beneath the landfill was assumed to be uniform with the ground surface outside of the landfill (the ground surface beneath the Construction Landfill was interpolated between the ground surface outside the landfill). This resulted in a calculated volume of approximately 23, 000 m^3.

Cominco Ltd. also completed a volume estimate for the Construction Landfill using the two surface method with an assumed original ground surface. Their volume estimate was 27,000 m^3. This is reasonably close to GLL volume calculation using the two surface method. It was decided to use a volume of 27,000 m^3 as the volume of the Construction Landfill for the following reasons:

- Cominco Ltd. provided a volume estimate in reasonable agreement with GLL
- Cominco Ltd. are more likely to accurately predict the original ground surface contours given their knowledge of pre-landfill conditions

The 27,000 m^3 of waste is the estimated insitu volume. Since the waste is likely to consist of relatively bulky construction materials, it is assumed that the waste will not be fully compactable after relocation. Hence, an assumed 10% bulkup factor has been applied to the waste volume, which has been rounded to the nearest thousand cubic metres or 30,000 m^3.

3.2 Relocation Options

The relocation options for the waste from the Construction Landfill that were considered were:

- above the Operational Landfill
- at Zone C at the east end of the Operational Landfill
- at the toe of the Operational Landfill
- any combination of the three options above

The merits of each option were considered as well as any disadvantage. It was assumed that the waste would be moved using excavators/loaders and dump trucks. Once moved, it was assumed that a dozer would grade the waste. A Year 2000 contour plan showing the Construction and Operational landfills is provided in Figure 2. The plan identifies the locations of Zones A, B and C.

Relocation Above Operational Landfill

Relocation of the Construction Landfill waste to above the Operational Landfill is likely the easiest to execute due to the existing road between the two landfill sections. It would also be the easiest location to place the construction waste due to the nearly flat surface at the top of the Operational Landfill. The haul distance for this option would be shorter than relocating to Zone C (assuming end dumping from the top of the Operational Landfill at the east end), but longer than relocating to the toe of the landfill.

Using this relocation position would add about 3.5 m to the height of the existing landfill, which would increase to approximately 5.3 m with a final cover. This would raise the landfill height to approximately 15 m. The higher landfill height would result in the potential for increased erosion of the final slope. In addition, the slope of the Operational Landfill is presently at a slope of about 1.5H:1V, which is considered undesirable for closure. The slope should be regraded to between 4H:1V or 5H:1V in order to minimize long term erosion potential. This would require moving a significant volume of the existing Operational Landfill. Assuming that the top and bottom of the landfill are flat and an average height and length of 10 m and 400 m, respectively, approximately 13,000 m^3 of waste would have to be cut to regrade the slope to 4H:1V assuming a cut/fill line halfway up the existing slope. If a 5H:1V slope is desired, then a larger volume would have to be cut and regraded.

Adjacent to the toe of the Operational Landfill is a containment berm. This berm acts as a dam to capture runoff from the landfill. Depending on the final slope, the containment berm may also have to be removed to return the land to its original topographic condition.

Relocation to Zone C

Relocation of the Construction Landfill to Zone C would also be relatively easy assuming that the waste was hauled up to the top of the Operational Landfill and end dumped on the slope. There is limited space available for end dumping. The haul distance could be shortened by extending the lower road into Zone C. However, there would likely be less turning space for the trucks compared to the top of the Operational Landfill. A turning area could be constructed, but it would likely have to be continuously moved as the waste is relocated. Hence, there could be considerable road building or haul costs associated with relocation to Zone C, depending on the haul route chosen. If it is decided to haul to Zone C from the lower road and road extension, the trucks may have to dump the material near the toe of the Operational Landfill due the steepness of the ground surface at Zone C. Dumping at the toe would then require the waste to be pushed uphill, which is likely to slow production and increase equipment and labour costs. If this relocation option is chosen, the entire existing slope of the Operational Landfill would also have to be regraded to a final slope of 4H:1V or 5H:1V. The containment berm would also have to be removed to return the land to its natural state.

Relocation to Toe of Operational Landfill

Relocation of the construction waste materials to the toe of the Operational Landfill presents the shortest haul distance. However, due to the containment berm, it is likely that access roads have to be constructed at each end of the berm from the existing road. Alternatively, short access roads could be constructed to the top or through the containment berm at two locations starting from each end of the Construction Landfill. Either method will still result in the shortest haul distance of the three options. The available volume for material at the toe of the landfill is more than the required 30,000 m^3 if a final slope of 4H:1V is used. By relocating the waste to the toe of the Operational Landfill, there is an opportunity to grade the slope for final closure as it is being filled. Since the slope would be regraded as the waste is located, cost savings will be realized by not having to regrade the entire slope of the Operational Landfill. If a 4H:1V slope is used, the final slope runs into the containment berm, which could be used as such. Hence, additional savings would be realized by not having to remove the containment berm.

Combination of Relocation Options

Relocating the Construction Landfill using a combination of the options described above would result in additional and unnecessary road construction costs. It would also make the relocation project inefficient. There are no economical advantages of relocating the waste to several locations.

3.3 Preferred Relocation Option

The preferred relocation option is to the toe of the Operational Landfill for the following reasons:

- ability to regrade slope of landfill to a shallower slope suitable for landfill closure as waste is placed. This will minimize the volume of material on the slope that will have to be regraded compared to the other options, which will require most of the slope to be cut and regraded. Hence, a significant economic advantage is available using this option.
- the containment berm will not have to be removed since it is incorporated into the final slope – thereby offering an economic advantage over the other options.
- shortest haul distance, which would likely result in costs savings.

Cominco Limited has reviewed the relocation options and has agreed with the preferred option discussed above. The process of relocating the Construction Landfill to the toe of the Operational Landfill is currently in progress. It is planned to complete the relocation prior to spring so that all of the contents are relocated in a frozen condition. As the material is being relocated, the contents of the Construction Landfill are being documented. To date, no hazardous materials or substances have been identified. If hazardous materials or substances are located, they will be removed and disposed of in accordance with the appropriate regulations.

4. Ongoing Landfill Operations

The mine will continue to operate until the ore reserves are exhausted, which will occur in 2002. As an ongoing operation, the mine will still require the use of the Operational Landfill. The amount of waste to be generated between now and closure must be accounted for in the closure plan for the landfill. Records of waste volume or mass are not available to assist in determining an appropriate volume of waste to be generated until closure. Mine personnel have indicated that the volumes of waste disposed has been reduced through burning much of the waste. However, an estimate of the annual volume of waste generated from operations was made. The total Operational Landfill volume was roughly calculated to be 100,000 m^3, which translates to approximately 5,000 m^3 per year assuming the mining operation began in 1981. Based on this calculation, it is assumed that ongoing operations will generate 5,000 m^3 per year of waste, which will have to be landfilled. This is a conservative estimate.

The best location for the waste from operations from an economical perspective is also the toe of the Operational Landfill. As previously discussed, the available space at the toe of the landfill exceeds the amount of waste to be relocated. In order to regrade the existing slope for final closure, a significant volume of waste will have to be cut from the crest of the slope and pushed down to the toe. Any additional waste placed at the toe between now and closure will reduce the volume of waste that will have to be cut. Hence, placing the operational waste at the toe of the landfill will eventually result in realized cost savings for the landfill closure.

5. Landfill Cover Design

As part of the closure plan for the Operational and Little Red Dog Quarry landfills, a final cover must be designed to isolate the waste, which will protect the environment from release of contaminants. There are generally two main issues to be considered for conventional final cover design:

1) Choice of cover materials - geosynthetic materials and/or natural materials
2) geotechnical considerations – slope stability, compaction, permeability and erosion

For the Polaris Mine, the climate or geothermal regime is a third major consideration.

5.1 Options For Cover Design

One of the main design issues for a conventional landfill cover is whether geosynthetic materials or natural materials should be used. In many cases, it is not possible make a decision about which materials to use without taking into account geotechnical considerations as they are interrelated.

5.1.1 Geosynthetic Versus Natural Materials

This is usually the first consideration in designing a landfill cover. Landfill covers are often multi-layer systems that utilize either low permeability soils or relatively impermeable synthetic geosynthetic materials or a combination of these two. Geosynthetic materials (geotextiles, geomembranes, geonets, and geocomposites) generally offer several economic advantages over natural materials including airspace savings (tipping fee landfills), they are lightweight (may be installed with small equipment), and often have a lower unit area cost. However, for the Polaris Mine landfills, airspace is not a consideration, equipment is already onsite and the remote location does not make geosynthetics more cost effective.

Another important consideration is the life of a geomembrane. The maximum design life for many of the geomembranes or geosynthetic liner systems is considered to be between 50 and 100 years. However, geomembranes have been in used in engineering applications for about 20 years and little data is available for longer time periods.

In summary, a geomembrane or geosynthetic liner system is unlikely to provide an economic advantage at the Polaris Mine and likely does not provide the permanent lifespan required. Therefore, no further consideration to the use of geosynthetics is given.

5.1.2 Geotechnical Issues

GLL have completed a review of the available geotechnical reports – two by EBA Engineering Consultants Ltd. (EBA) and one by Mining Research Laboratories (CANMET), Energy, Mines and Resources , Canada. The two EBA reports are “Design Documentation For Garrow Lake Dam – Little Cornwallis Island, NWT” dated April 1988 and “Construction Plan Garrow Lake Dam – Little Cornwallis Island, NWT” dated March 1990. The CANMET report is titled “Frozen Backfill Strength Determinations – Polaris Mine”; no date was provided, but was likely completed in 1991. The EBA reports included information on site conditions, dam design (material properties, grain size distribution, etc.) slope stability, thermal considerations, monitoring, and other geotechnical issues. The CANMET report included grain size distribution and strength data. The information presented in these reports provides base information (including the thermal data, which was used by BGC Engineering Inc. for the geothermal modelling) for addressing geotechnical issues related to landfill closure.

After eliminating the possible use of geosynthetics for use in the cover, the geotechnical issues were addressed for natural materials only and include:

- source
- permeability
- durability
- slope stability, and
- erosion.

Source

It is likely that the material for landfill cover will come from the New Quarry, which is located within the Cape Phillips Formation and consists of carbonate shale. Another potential source for materials is the hillside adjacent to the landfill. Another potential source is the Garrow Lake Dam, which we understand will be partially removed; however, it is probable that it will be drilled and blasted, which would result in pieces too large for use in the cover. Other possible sources include rejects from the cement rockfill (CRF) plant, which is placed in the old quarry and raised beach material.

Although the cover material is likely to come from the New Quarry, a brief description of the types of aggregate derived from quarry operations, borrow areas, and mine backfilling operations is useful. The EBA (1988 and 1990) report indicates the main zones for dam construction are comprised of rip rap, shell, bedding and core. Grain size distribution envelopes were provided for each zone; the 1990 report included three additional grain size distribution curves for quarry floor material, crusher plant material and mine backfill. The rip rap was made of cobble and boulder sized limestone, the dam shell material was made from gravel, cobbles and boulders available from the quarry, bedding made of sand and gravel was obtained from terrace deposits, and the core consisted of a well graded clay-silt-sand-gravel made from crushing operations. The CANMET report indicates that the mine backfill consists of waste rock mixed with till material and water, which is sand (about 35%) and gravel (about 58%) with a trace of silt (EBA grain size analysis). Material from the crusher plant (different than the core material) had a grain size distribution very similar to the waste rock.

The properties of the cover material will depend largely on the grain size distribution. A well-graded material such as that used for the core would likely make the best cover from a permeability (low) and thermal (insulation) perspective; however, it would likely be the material most susceptible to erosion. Crushing a large volume of core type material would, however, be prohibitively expensive. Using coarse aggregate would not provide a low permeability barrier and would not provide good insulation (high porosity), which would mean that a thicker cover would be required. A coarse material, however, would provide better durability, slope stability and erosion properties. A coarse material would not be susceptible to frost heave.

Permeability

Generally, a landfill cover is required to be constructed of low permeability material in order to prevent leachate generation from infiltration of precipitation (in other words, promote surface runoff). The permeability of the final landfill cover must typically meet regulatory requirements. Currently, there are no landfill criteria (including landfill covers) for the Nunavut Territory.

Typically, the permeability of a final cover would be important for most landfills. However, the geothermal regime at the Polaris Mine provides the opportunity to use a permeable, insulating cover, which will keep the waste in a frozen state. A permeable cover will also have other technical advantages (durability and erosion protection). This is discussed in more detail in Section 5.2.

Durability

The landfill cover will be subjected to annual freeze-thaw cycles, which may result in degradation of the soil (breakdown into finer particles). Significant degradation of the particles would likely increase the likelihood of erosion, if the particles are broken into fine sand and silt. Therefore, in order to reduce potential erosion from particle breakdown, it is recommended that the cover be made from large particles (e.g. gravel, cobbles, and boulders).

Slope Stability

The southern portion of the Operational Landfill currently has a slope of approximately 1.5H:1V or 34 degrees. It has not exhibited signs of slope failure. The existing cover soil is mainly angular sand, gravel and some cobbles, which probably resembles material from the crusher plant. EBA (1988) had completed a slope stability analysis for the construction of the dam; soil parameters used in the analysis for the dam shell, core and riprap material were presented in their report. No values were presented for the mine backfill or crusher plant material. The dam shell material is coarser than the crusher plant material and the existing landfill cover material, hence, the internal angle of friction of the existing cover material should be similar to the dam shell material or slightly lower. The internal angle of friction for the shell was assigned values of 28 and 36 degrees, for winter and summer compaction, respectively. The existing cover material is not well compacted, so it would have a lower friction angle likely to be between 26 and 34 degrees. The slope has not shown signs of slope failure or creep partially because it is frozen over most of the year, which provides a cohesion value. Minor ravelling likely occurs during the short thaw period over the summer.

Based on the assumed friction angles and conditions above, the Operational Landfill likely has a factor of safety (FS) above unity during the winter (due to cohesion from freezing), but probably has a FS below unity during the summer. Although the landfill is probably stable over most of the year and unstable only over a short period under existing conditions, it is possible that the thermal regime could change to make the long-term stability questionable (refer to the Geothermal Assessment in Section 5.2). Therefore, the slope should be reduced prior to construction of a final cover. Besides increasing the stability of the landfill, reducing the slope will permit compaction of the final cover, which is not possible in its current condition.

Erosion

Erosion of the final cover could result in moving the active layer depth into the landfill, which could result in thawing of the landfill waste, which in turn would increase the mobility of potential contaminants. Hence, erosion of the final landfill cover must be prevented. It is important to note that, as described in Section 2.4, excess runoff is estimated to only be 65 mm per year which results in minimal erosion. A low permeable final cover will likely contain a significant amount of silt and fine sand, which are highly erodible, particularly on steep slopes. Furthermore, freeze-thaw cycles are likely to result in some breakdown of the individual particles. Therefore, it is advisable that the final cover contain a large portion of coarse materials in order to reduce the potential particle degradation and potential erosion.

Two significant erosion gullies have developed downstream of the Operational Landfill. Discussions with mine site personnel indicate that the erosion channels were likely formed due to rapid runoff from snow piles (from snow clearing operations) that had previously been placed in the vicinity of the Operational Landfill. Since discontinuing this practice, the erosion gullies have not been observed to contain water during the spring thaw period.

5.1.3 Preferred Landfill Cover Design

Typically, a final landfill cover system would be made from a low permeable soil in order to limit infiltration and promote surface runoff. The existing geothermal regime, however, permits an alternative to the conventional low permeable landfill cover. It is proposed that the final landfill cover for the Operational and Little Red Dog landfills consist of a relatively thick layer of coarse-grained material, which would provide sufficient insulation to keep the waste below the active layer in a perpetual frozen state. A coarse-grained (particle size from sand to cobbles) cover would be less susceptible to erosion and provides a permanent solution. The thickness of the coarse-grained cover should be at least equal to the thickness of the active layer, which was determined by geothermal modelling.

5.2 Geothermal Assessment

As noted above the migration of potential contaminants and protection of the environment can be achieved by designing a cover that is equal or greater than the active layer thickness at the Polaris Mine site. In order to estimate the active layer thickness both now and into the future, a geothermal assessment was completed by BGC Engineering Inc. and is described in the following sections. Baseline analyses were undertaken to validate input parameters and establish insitu ground temperature profiles. The geothermal regime for typical terrain conditions at the site is shown on Figures 3, 4 and 5.

5.2.1 One-Dimensional Geothermal Analyses

THERM1, written by Dr. J. Derick Nixon, P.Eng., of Nixon Geotech Ltd., was used for geothermal analysis. This program solves one-dimensional heat transfer problems involving freezing and thawing. An alternating direction explicit finite difference method is used to solve for temperatures at each time step. A power law function represents the relationship between unfrozen water content and temperature in each soil unit. The program requires a variety of standard physical properties as input, but it is versatile in accommodating several alternative combinations of meteoric input. In the analyses reported here, mean monthly air temperatures, solar radiation, wind velocity, and snow pack thickness were specified and a surface energy balance routine was used to calculate the ground and snow surface temperatures.

The majority of THERM1 input can be categorized as either meteoric or physical properties. The sources of these data, data analyses – if any, and the values used are described in respective subsections below.

5.2.2 Meteorological Input

Climatic data were taken from EBA (1988). The data were collected from Resolute, located approximately 90 km southeast of Polaris on Cornwallis Island, N.W.T., and comprised over 40 years of data, prior to 1988. Comparative studies on temperature and wind speed records between Polaris and Resolute were undertaken by EBA (1988) and it was reported that the climate on Little Cornwallis Island is similar to that of Resolute. The mean annual air temperature (MAAT) for Resolute is –16.6°. Snow cover data were modified for the analyses for configuring the calibration model using EBA (1988) data to actual ground temperature conditions. Climatic data and surface properties are reported in Table 1.

For the purposes of numerical analysis, the dates of the first and last snow cover were estimated as September 4 and June 25, respectively, on the basis of data presented in the National Atlas of Canada (1974).

Table 1. Climatic Data (EBA 1988)

Month	Mean Temperature	Wind Velocity	Snow Cover		Solar Radiation
			Thick*	Thin	
	(°C)	(km/hr)	(cm)	(cm)	(W/m°C)
January	-32.9	22.5	25	8	0.0
February	-34.0	21.3	25	8	7.3
March	-32.1	20.8	30	8	60.6
April	-23.4	19.7	30	8	170.4
May	-10.6	21.4	30	5	266.8
June	0.2	21.7	15	0	288.3
July	5.1	20.8	0	0	216.3
August	3.3	20.8	0	0	127.7
September	-4.5	24	10	4	60.4
October	-15.0	23.4	20	8	14.8
November	-24.9	21.2	20	8	0.8
December	-29.9	20.5	25	8	0

* EBA 1988

5.2.3 Physical Properties

Snow Pack

A snow cover thermal conductivity of 0.25 W/m°C was used. This corresponds with a snow pack density representative of a wind-toughened snow (Johnston 1981). A snow cover albedo of 0.75 was used (Savigny et al., 1995).

Mineral soils

Relationships between the thermal conductivity of a soil and its porosity and degree of saturation are reported by Kersten (1949) and others, mainly on the basis of experimental data. The thermal conductivity of ice is much higher than that of water; hence the thermal conductivity of a frozen soil generally exceeds its unfrozen equivalent. As soil porosity approaches 100%, frozen and unfrozen thermal conductivity values in a saturated system approach those of ice and water, respectively. Conversely, as the porosity of a soil approaches zero, frozen and unfrozen thermal conductivities converge on average values related to mineral constituents. Soil thermal conductivities and other soil properties for the soil layers used in the geothermal analyses are listed in Table 2.

The insitu soil moisture content for the shale gravel was estimated based on published data (Judge, 1973).

Unfrozen water content

The power law relation in equation [1] represents the relationship between unfrozen water content and temperature in each soil and rock unit.

$$w_u = A(-T)^B/w_{tot} \qquad [1]$$

where w_u = unfrozen water content (fraction of total water content),
A = gravimetric unfrozen water content at –1°C,
B = exponent in power law function,
T = temperature in °C (negative), and
w_{tot} = total water content.

Values of the A and B parameters used in the geothermal analysis are shown in Table 3. A ground surface albedo of 0.15 was used in the analyses.

Table 2. Thermal Conductivities of Soil Layers used in Geothermal Analyses

Soil Description	Moisture Content (%)	Dry Density (Mg/m^3)	A	B	Thermal Conductivity Thawed W/m°C	Thermal Conductivity Frozen W/m°C
Moss	2.0	0.45	0.1	-0.70	0.4	1.5
Shale gravel	0.1	1.77	0.05	-0.40	2.46	2.89
Fragmented shale	0.1	1.77	0.05	-0.40	172*	1.98*
Shale bedrock	0.2	2.10	0.05	-0.30	1.5	1.95

* EBA (1988).

Geothermal gradient

A geothermal gradient of 0.0396 was used based on measurements reported by Brown (1966).

5.2.4 Model Calibration

The one dimensional geothermal model was calibrated to current site conditions using real temperature data for up to and including October 10, 2000 from Thermistor 2, which penetrates landfill material to an approximate depth of 1.5 m, and natural ground to a depth of 5 m. Thermistor 2 was selected for the calibration model because it passes through the least amount of fill compared to the other thermistor installations in the landfill. The model was calibrated to shale gravel material overlying shale bedrock, as shown on Figure 6. It was assumed that the landfill material (upper 1.5 m) comprises shaley gravel material.

The trumpet curves on Figure 6 show both the thermal regime measured by Thermistor 2, and the predicted geothermal regime for the same dates. The actual and calibration data span the period from December 13, 1999 to October 10, 2000, with no readings taken after December 13, 1999 until May 22, 2000. Consequently, the coldest part of the year is not represented. This accounts for the anomalous warming of the near surface temperatures.

5.2.5 Current Active Layer Conditions

The active layer thickness ranges from 0.41 m to 1.36 m for ground surface covers including moss, mineral soil, and shale bedrock for wind blown or thin snow cover conditions. The active layer thickness ranges from 0.10 m to 1.22 m for thick snow cover conditions for ground surface covers including moss, mineral soil, and shale bedrock.

5.2.6 Future Active Layer Conditions

Two climate change scenarios were analyzed to determine the range in the active layer over a 100 year period: a best estimate case, and a high estimate case (i.e. warmest or most adverse to permafrost). Estimates of the rate of the annual increase in ambient temperature for each case were interpolated from tables showing temperature change projections by latitude (AES 1998). These two climate change scenarios were carried out for both thin and thick snow cover conditions.

Best Estimate Case

A value of 2.9°C/100 years was selected as the rate of increase in the ambient air temperature for a latitude of 76° for the best estimate case. Using this value and thin snow cover conditions, an active layer depth of 0.52 m to 1.67 m is predicted in the year 2100, depending on the soil cover material present. This is an increase of 23% to 28% compared to existing active layer conditions for the various soil cover conditions. For thick snow cover conditions, an active layer depth of 0.31 m to 1.52 m is predicted in the year 2100 depending on the soil cover material present. This is an increase of 23% to 210% compared to existing active layer conditions for the various soil cover conditions (comparing maximum changes).

High Estimate Case

Using a high estimate value of 5°C/100 years as the rate of increase in the ambient air temperature, latitude of 76° for the high estimate case. Using this value and thin snow cover conditions, an active layer depth of 0.65 m to 1.80 m is predicted in the year 2100, depending on the soil cover material present. This is an increase of 32% to 59% compared to existing active layer conditions for the various soil cover conditions. For thick snow cover conditions, an active layer depth of 0.47 m to 1.74 m is predicted in the year 2100 depending on the soil cover material present. This is an increase of 39% to 370% compared to existing active layer conditions for the various soil cover conditions (comparing maximum changes).

5.2.7 Alternative Cover Materials

Shaley Gravel

The active layer depths quoted above apply to this material as a landfill cover.

Silty Sand (SM)

Preliminary analyses of the thermal regime were undertaken using a saturated SM[1] (silty sand material including 30% fines) for a landfill cover. It was determined that a cover material consisting of finer grain size and increased moisture content will result in a significantly reduced active layer depth, as much as by 50% when compared to the shale gravel cover material analyzed in Figures 3, 4 and 5.

It was understood that the SM material is not available onsite and would have to be processed. Processing the material from the quarry would require another crusher to be delivered to the site and is not considered to be economically feasible. Hence, analyses using this type of material was not pursued further.

5.2.8 Pore Fluid Salinity

The foregoing results treat the pore fluid as 'fresh water'. Consideration was given to the possible presence of saline pore fluid, however it is BGC's experience in the arctic that when surface fills originating in rock quarries are placed, they have virtually no moisture content. Ice saturation slowly develops below the active layer as a consequence of runoff infiltration. The saturation level typically creates an ice aquitard near the top of permafrost before thicker fills become fully ice saturated.

Although small active layer salinity concentrations may develop over time because of the proximity of the site to the ocean, they are not sufficient to change the active layer thickness to any great extent. This is because of the steep geothermal gradient along the warm side of the trumpet curve as shown in Figures 4 and 6. In short, small concentrations have little impact on the freezing temperature suppression because the ground temperatures become very cold with little change in depth below the active layer.

[1] unified soil classification

5.3 Final Cover Design And Final Landfill Contours

5.3.1 Final Cover Design

The issues for final cover design discussed in Sections 5.1 and 5.2 and are summarized below:

- Geosynthetic materials would not provide a technical or economic advantage over natural materials material at the mine site.
- The natural materials available for landfill cover would likely come from the New Quarry.
- Ideally, the cover material should meet regulatory requirements for landfill covers. Currently, there are no regulations for the Nunavut Territory and the Northwest Territories regulation are qualitative only. The British Columbia MOELP criteria was reviewed for guideline purposes. The British Columbia MOELP criteria requires a landfill cover to be 1 m thick and have a permeability of 1 x 10^{-3} m/s or lower. However, given the geothermal regime of the site, the permeability of the cover soil is not a governing factor.
- Durability of the cover material is important to withstand the freeze-thaw cycles without degradation. Degradation of the cover material would increase its susceptibility to erosion. EBA (1990) completed durability tests on the limestone riprap material, which showed no degradation. It is recommended that if shale is used as cover material, consideration for completing additional durability tests should be given.
- No formal analysis was completed to address slope stability of the Operational Landfill. However, an assessment of the landfill slope was completed using material properties provided by EBA (1988), the existing slope of the landfill, and climatic conditions. It was concluded that the slope is stable during most of the year, but unstable during the summer and the annual unstable period could increase due to global warming. On this basis, the existing slope should be reduced to 4H:1V or 5H:1V. Slope stability is not an issue at the Little Red Dog Quarry landfill.
- Reducing the slope at the Operational Landfill has the additional benefit of reducing erosion. Erosion of the cover material must be prevented or the landfill waste may thaw, which would increase the mobility of potential contaminants. Erosion may be prevented by providing a coarse "non-erodible" final cover.

- The geothermal assessment was completed using a one-dimensional geothermal model. The results of the modelling indicated that the existing active layer thickness ranges from 0.1 m to 1.36 m depending on snow cover and strata conditions. Future active layer thicknesses were modelled using temperature increases of 2.9°C/100 year and 5.0°C/100 year, which represent a best estimate case and a high estimate case. The geothermal modelling predicted an active layer thickness for the year 2100 ranging from 0.31 m to 1.67 m for the best estimate case and 0.47 m to 1.80 m for the high estimate case, depending on snow and cover soil conditions.

- The soil cover conditions depicted in Figure 4 are the most realistic for the landfill cover. Given the precipitation and temperature data for the site, a thin snow cover is the most conservative. Hence, the predicted future active layer thickness is 1.67 m to 1.80 m for the best and high estimate case, respectively. In order to be conservative it is recommended that a 1.80 m cover thickness be used in the design.
- The final cover should be comprised of a coarse shale or comparable material, which is not highly susceptible to erosion or to frost heave.

5.3.2 Final Landfill Contours

Development of final Operational Landfill contours must incorporate the relocation of the Construction Landfill, the remaining waste from continuing operations, and must take into account geotechnical and geothermal considerations. The preferred option for relocation of the Construction Landfill is the toe of the Operational Landfill as outlined in Sections 3.2 and 3.3. Polaris Operations has started the relocation of the Construction Landfill in accordance with these recommendations. The waste from ongoing operations is best located at the toe of the existing landfill from an economic perspective. Figure 2 shows the limits and year 2000 ground contours at the Operational and Construction landfills.

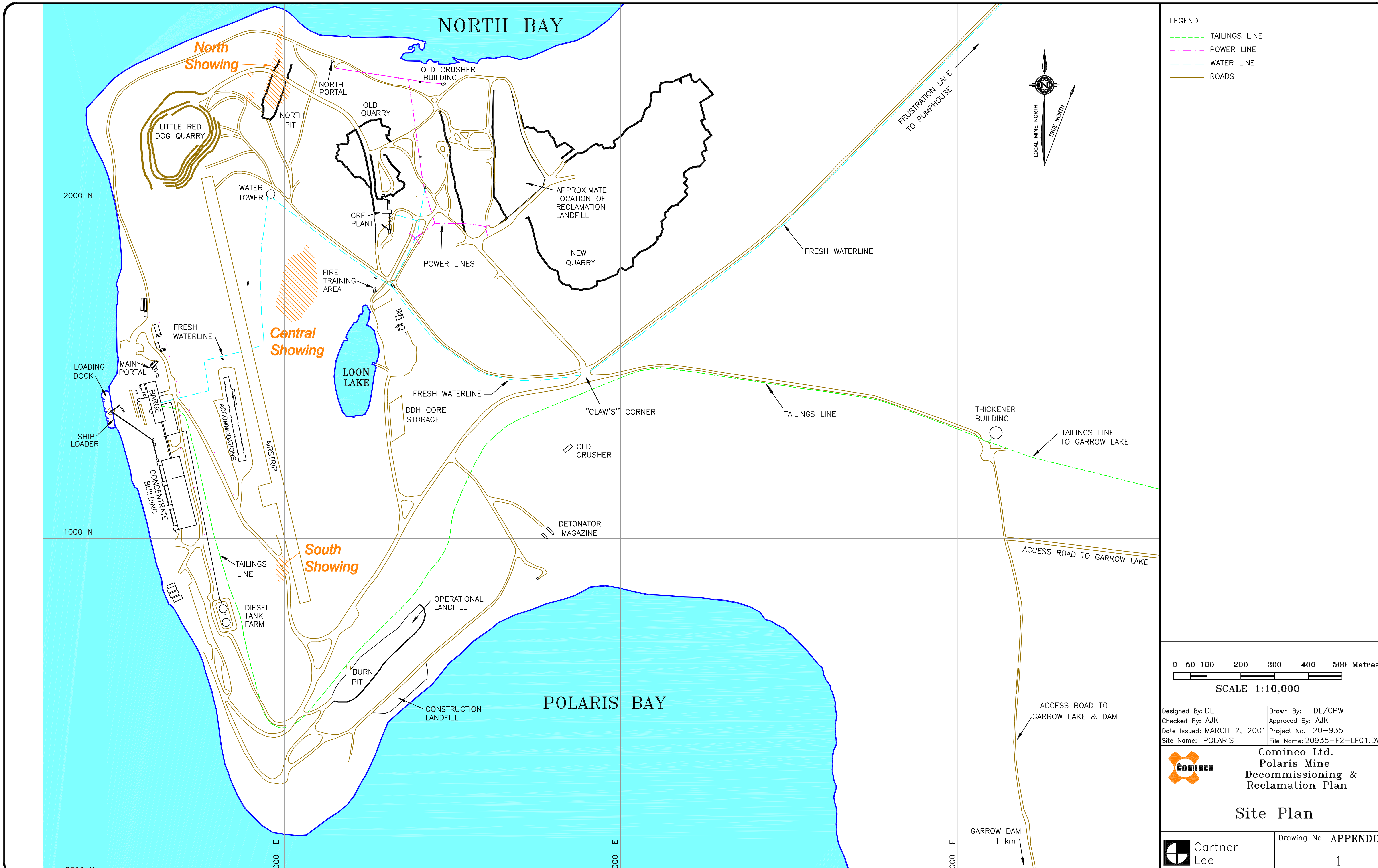
The estimated volume of waste to be placed along the toe of the Operational Landfill is 35,000 m^3, which includes an estimated 10% bulkup factor for the construction waste, and 5,000 m^3 for waste from ongoing operations. After considering the geotechnical issues, a final slope of 4H:1V is recommended. Consideration was given for a 5H:1V final slope, however, this was not practical as a significant portion of the existing waste would have to be cut and regraded. Placing the Construction Landfill and ongoing waste at a 4H:1V slope will result in an efficient operations and closure plan.

For the final contours shown on Figure 7, the crest of the slope will meet the crest of the existing landfill between section lines 8 and 20 and no cutting and regrading of the waste will be required over that section. The required cut and regrading areas are located at the ends of the landfill; the bulk of which is between sections 4 and 8. The volume of cut and regrading of the Operational Landfill required is approximately 8,000 m^3, which represents about 8% of the approximate 100,000 m^3 volume. The gross capacity for waste varies from about 40,000 m^3 to about 49,000 m^3. The gross capacity includes the volume of operational waste that must be cut and regraded, which is approximately 8,000 m^3. Hence, the net capacity for construction waste and ongoing operational waste is between 32,000 and 41,000 m^3. Figure 7 shows the final contours for a volume of 32,000 m^3 (assumes no bulkup factor). A cross section of the proposed final slope for the waste is shown on Figure 8. If there is a bulkup factor, or if additional waste from mine reclamation is placed in the landfill, the additional volume of waste could be placed in the center area up to the total capacity of 41,000 m^3. The effect of any additional waste or a larger bulkup factor would be to straighten the final contours in an east-west direction at the center of the landfill.

The final cover will be placed above the waste after the relocation of the Construction Landfill. As recommended in the preceding section, a conservative approach for future global warming should be adopted, which means the final cover thickness should be 1.8 m. A similar minimum thickness is proposed for the Little Red Dog Quarry Landfill when it is filled.

5.3.3 Surface Drainage

Given the high permeability and low susceptibility to erosion of a coarse grained shale cover material, construction of special drainage works are not required for either the Operational or Little Red Dog landfills.


NORTH BAY
POLARIS BAY
North Showing
Central Showing
South Showing
LITTLE RED DOG QUARRY
NORTH PIT
NORTH PORTAL
OLD CRUSHER BUILDING
OLD QUARRY
WATER TOWER
CRF PLANT
APPROXIMATE LOCATION OF RECLAMATION LANDFILL
NEW QUARRY
POWER LINES
FIRE TRAINING AREA
FRESH WATERLINE
LOADING DOCK
MAIN PORTAL
BARGE
SHIP LOADER
ACCOMMODATIONS
AIRSTRIP
CONCENTRATE BUILDING
LOON LAKE
FRESH WATERLINE
DDH CORE STORAGE
"CLAW'S" CORNER
TAILINGS LINE
OLD CRUSHER
THICKENER BUILDING
TAILINGS LINE TO GARROW LAKE
FRESH WATERLINE
FRUSTRATION LAKE TO PUMPHOUSE
DETONATOR MAGAZINE
ACCESS ROAD TO GARROW LAKE
TAILINGS LINE
DIESEL TANK FARM
OPERATIONAL LANDFILL
BURN PIT
CONSTRUCTION LANDFILL
ACCESS ROAD TO GARROW LAKE & DAM
GARROW DAM 1 km
LOCAL MINE NORTH
TRUE NORTH
2000 N
1000 N
0000 N
1000 E
2000 E
3000 E
LEGEND
TAILINGS LINE
POWER LINE
WATER LINE
ROADS
0 50 100 200 300 400 500 Metres
SCALE 1:10,000
Designed By: DL
Drawn By: DL/CPW
Checked By: AJK
Approved By: AJK
Date Issued: MARCH 2, 2001
Project No. 20-935
Site Name: POLARIS
File Name: 20935-F2-LF01.DWG
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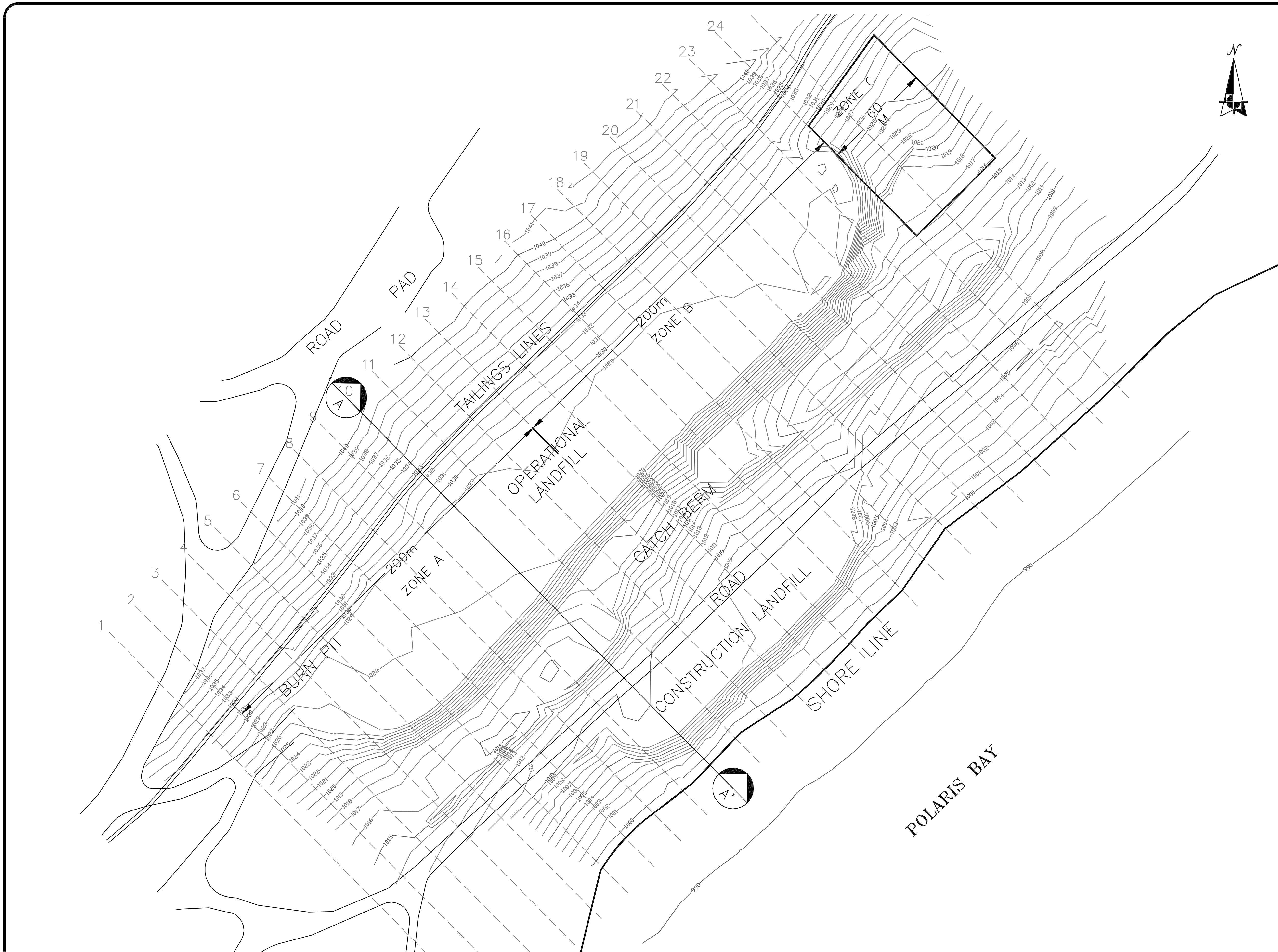
Site Plan
Gartner Lee
Drawing No. APPENDIX
1



LEGEND

CONTOUR, INDEX	———
CONTOUR, INTERMEDIATE	———
REFERENCE GRID LINE	— — —
CROSS SECTION	A

SCALE 1:2000
metres

0 10 20 30 40 50 100

Contour interval one metre

REVIEWED BY:	PJM, HC, AJK
DRAWN BY:	BB/CPW
DATE ISSUED:	MARCH 2, 2001
PROJECT NUMBER:	20-935
FILE NAME:	20935-F2-LF02.DWG
REVISION:	0

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Operational and Construction Landfill Contours (Year 2000)

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Figure No. APPENDIX 2

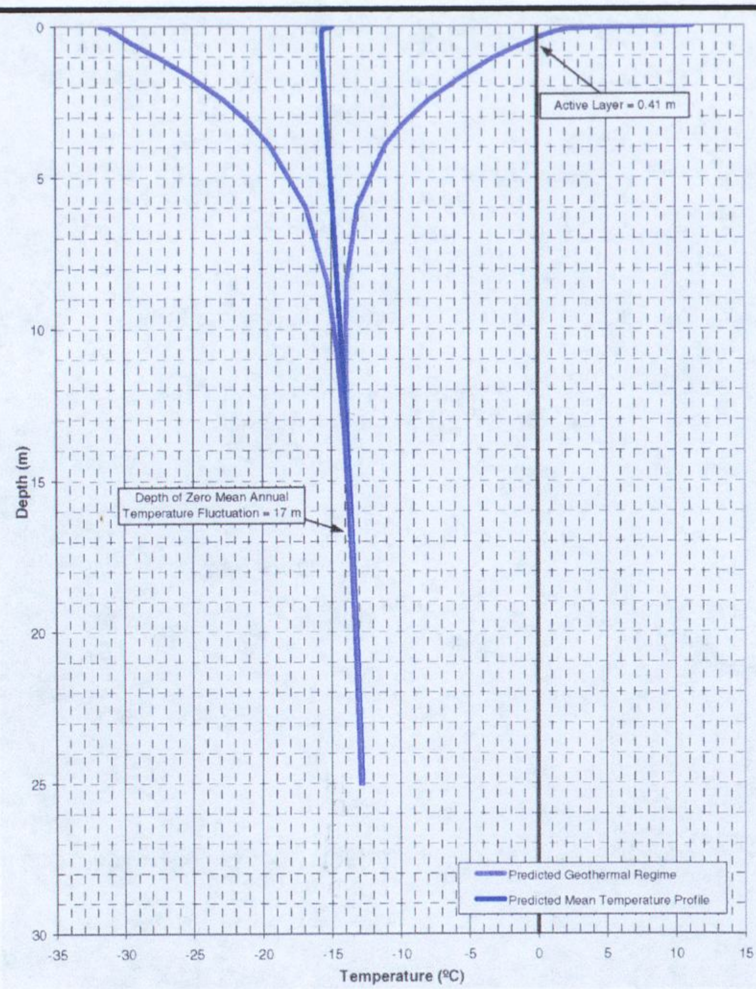


FIGURE A
PREDICTED BASELINE GEOTHERMAL REGIME (THIN SNOW COVER CONDITIONS)

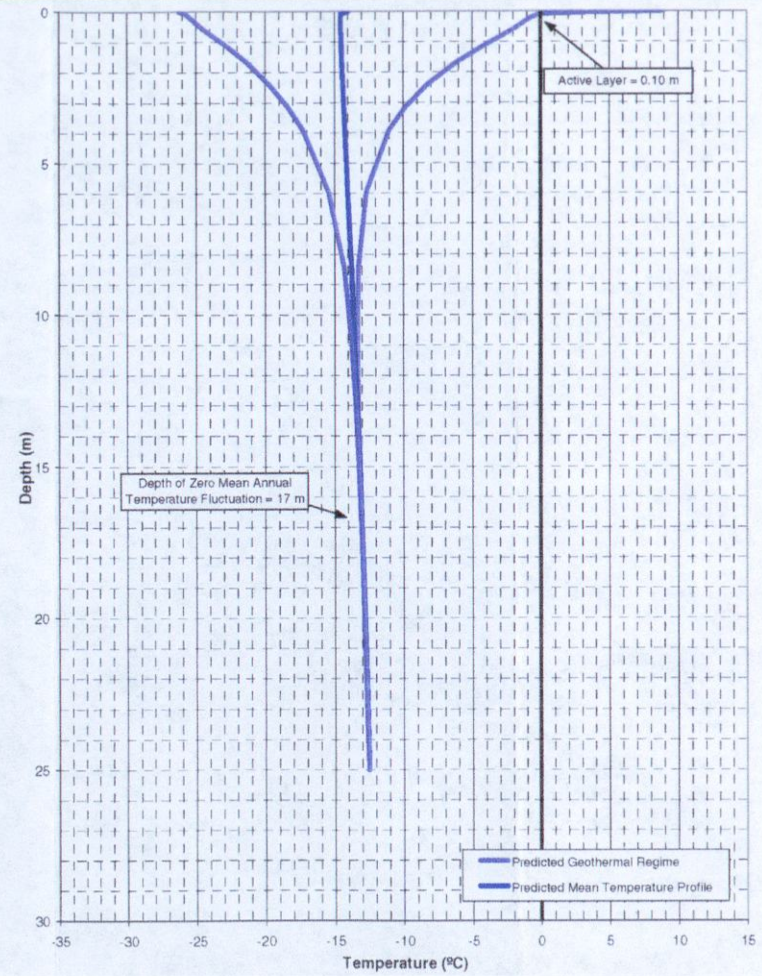


FIGURE B
PREDICTED BASELINE GEOTHERMAL REGIME (THICK SNOW COVER CONDITIONS)

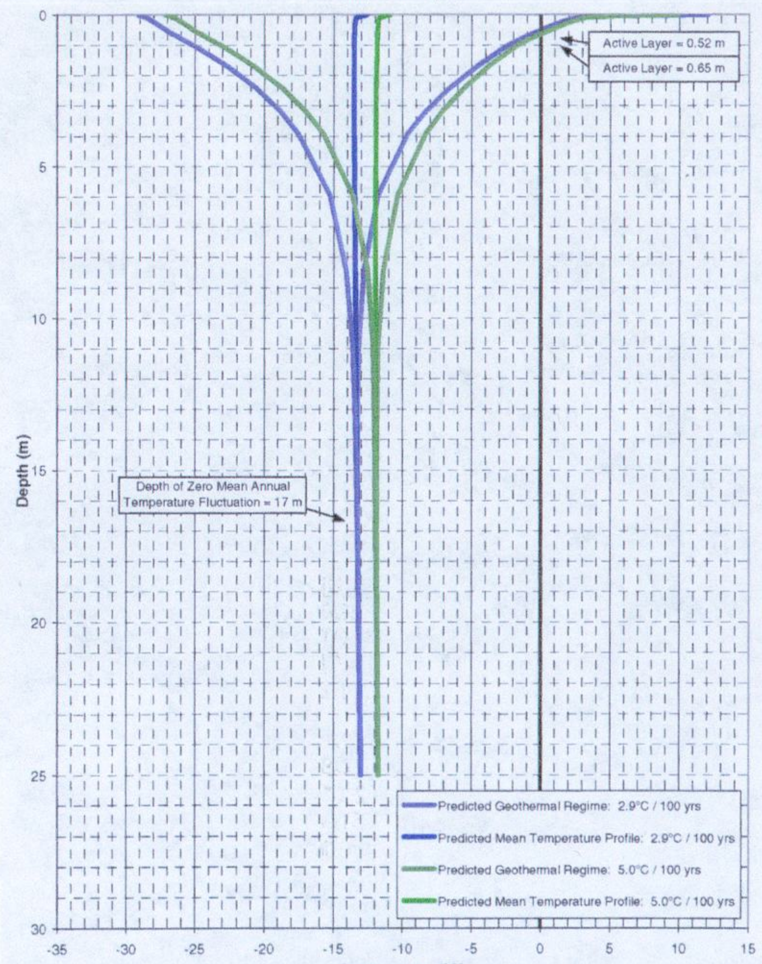


FIGURE C
PREDICTED FUTURE GEOTHERMAL REGIME FOR THIN SNOW COVER CONDITIONS (2100 AD)

FOR BEST ESTIMATE GLOBAL WARMING (2.9°C/100yr) AND HIGH ESTIMATE GLOBAL WARMING (5.0°C/100yr)

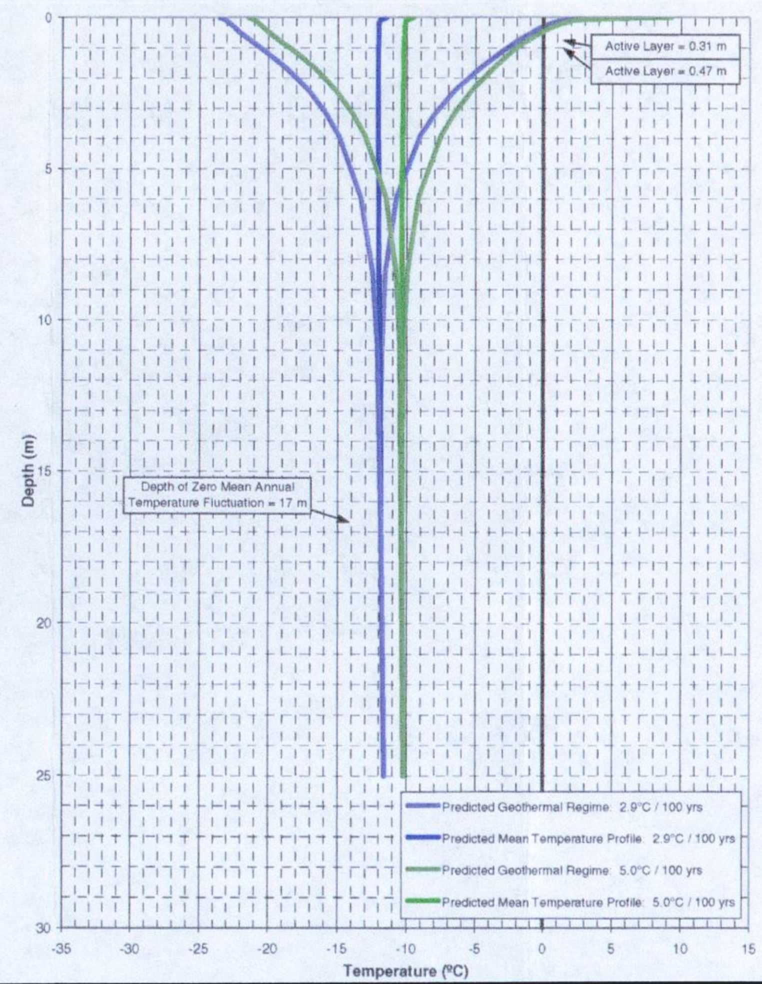
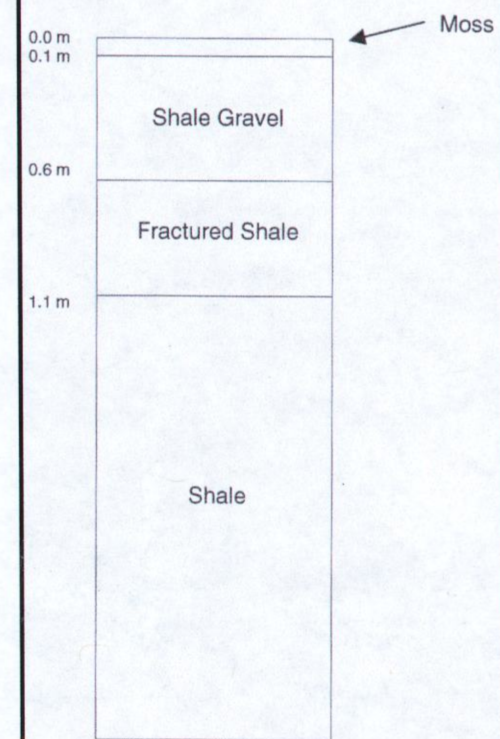


FIGURE D
PREDICTED FUTURE GEOTHERMAL REGIME FOR THICK SNOW COVER CONDITIONS (2100 AD)

FOR BEST ESTIMATE GLOBAL WARMING (2.9°C/100yr) AND HIGH ESTIMATE GLOBAL WARMING (5.0°C/100yr)

LEGEND

Model Stratigraphy



SOURCE OF DRAWING:
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REVIEWED BY:	PJM, HC, AJK
DRAWN BY:	BB/CPW
DATE ISSUED:	MARCH 2, 2001
PROJECT NUMBER:	20-935
FILE NAME:	20935-F2-LF03.DWG
REVISION:	0

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Existing and Predicted Geothermal Regime (Moss and Gravel Cover)

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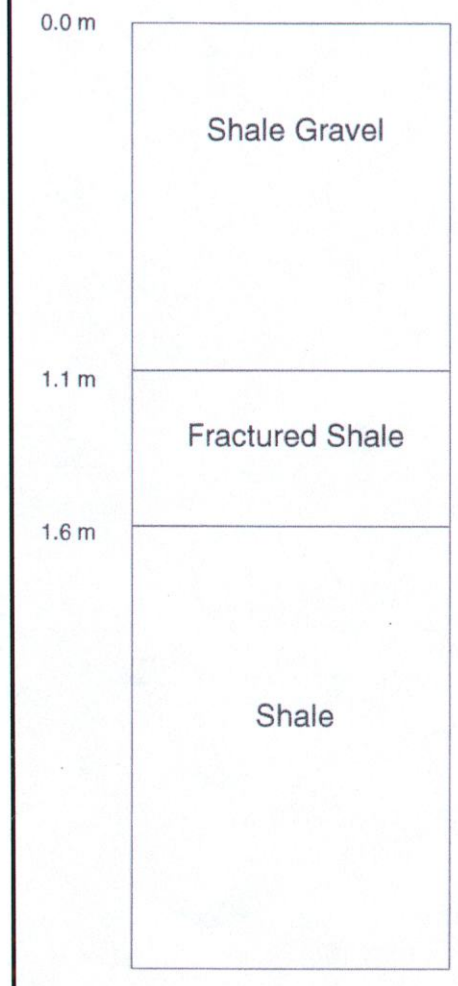
Figure No. APPENDIX 3

LEGEND

Model Stratigraphy



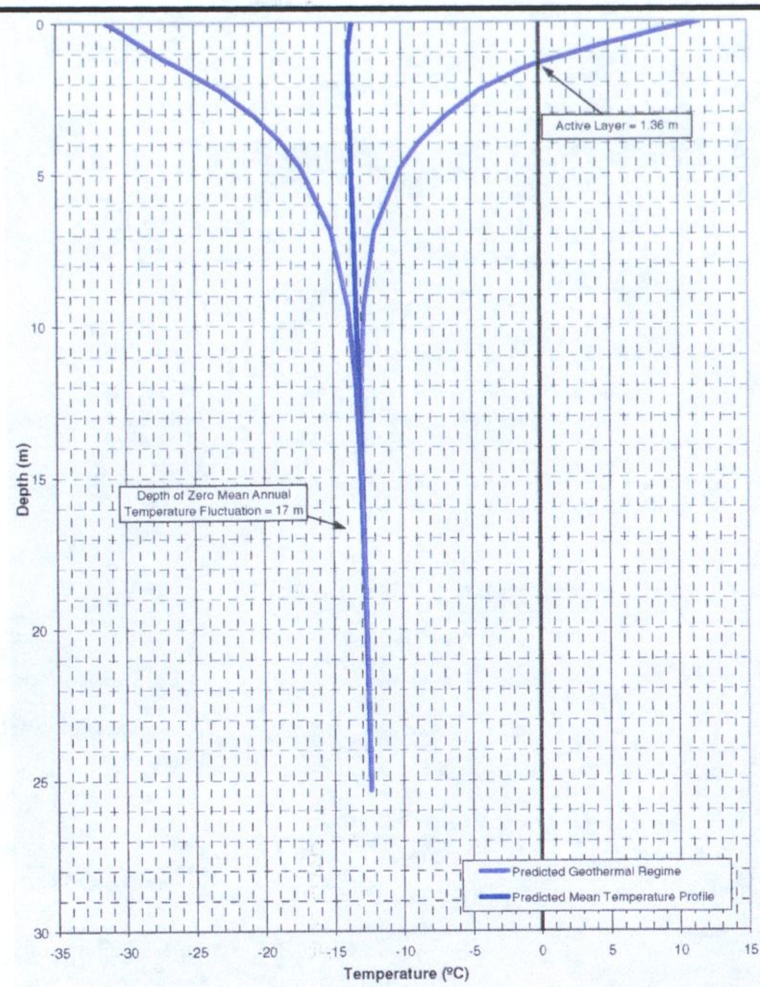


FIGURE A
PREDICTED BASELINE GEOTHERMAL REGIME (THIN SNOW COVER CONDITIONS)

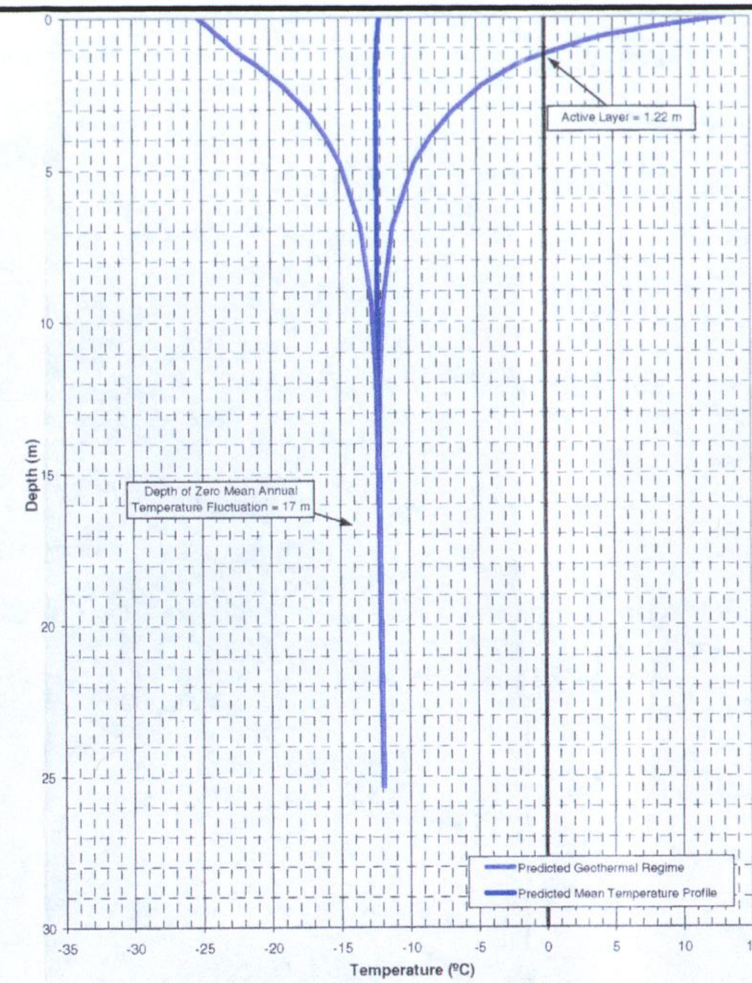


FIGURE B
PREDICTED BASELINE GEOTHERMAL REGIME (THICK SNOW COVER CONDITIONS)

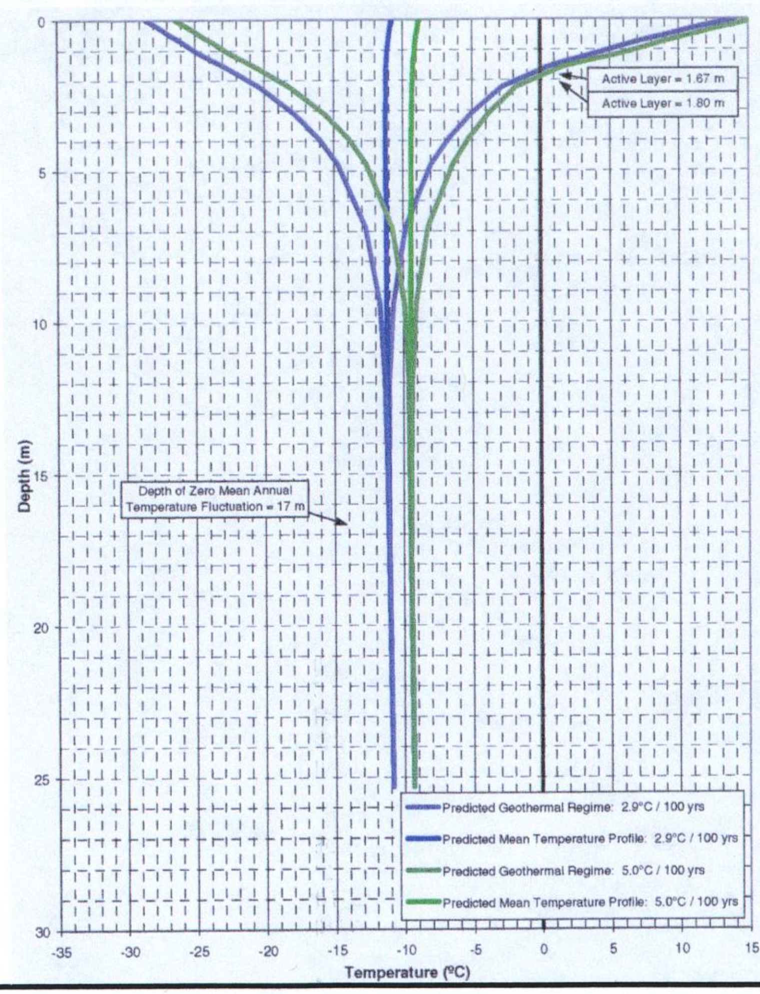


FIGURE C
PREDICTED FUTURE GEOTHERMAL REGIME FOR THIN SNOW COVER CONDITIONS (2100 AD)

FOR BEST ESTIMATE GLOBAL WARMING (2.9°C/100yr) AND HIGH ESTIMATE GLOBAL WARMING (5.0°C/100yr)

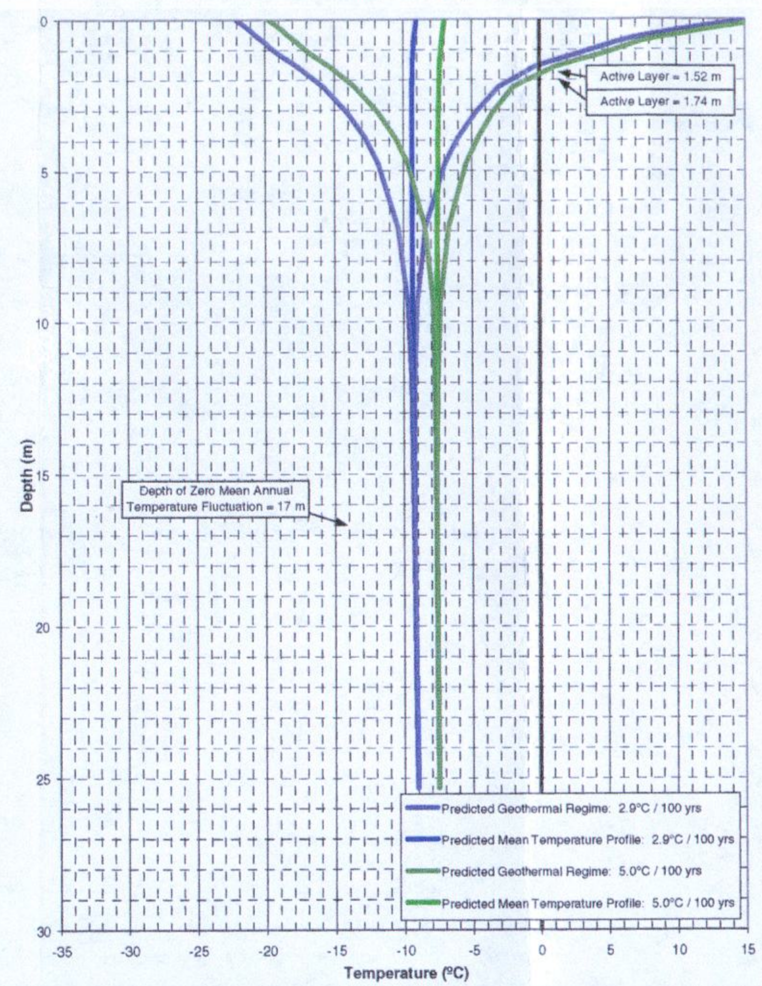


FIGURE D
PREDICTED FUTURE GEOTHERMAL REGIME FOR THICK SNOW COVER CONDITIONS (2100 AD)

FOR BEST ESTIMATE GLOBAL WARMING (2.9°C/100yr) AND HIGH ESTIMATE GLOBAL WARMING (5.0°C/100yr)

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REVIEWED BY:	PJM, HC, AJK
DRAWN BY:	BB/CPW
DATE ISSUED:	MARCH 2, 2001
PROJECT NUMBER:	20–935
FILE NAME:	20935–F2–LF04.DWG
REVISION:	0

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Existing and Predicted Geothermal Regime (Gravel and Fractured Shale Cover)

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Figure No. APPENDIX 4

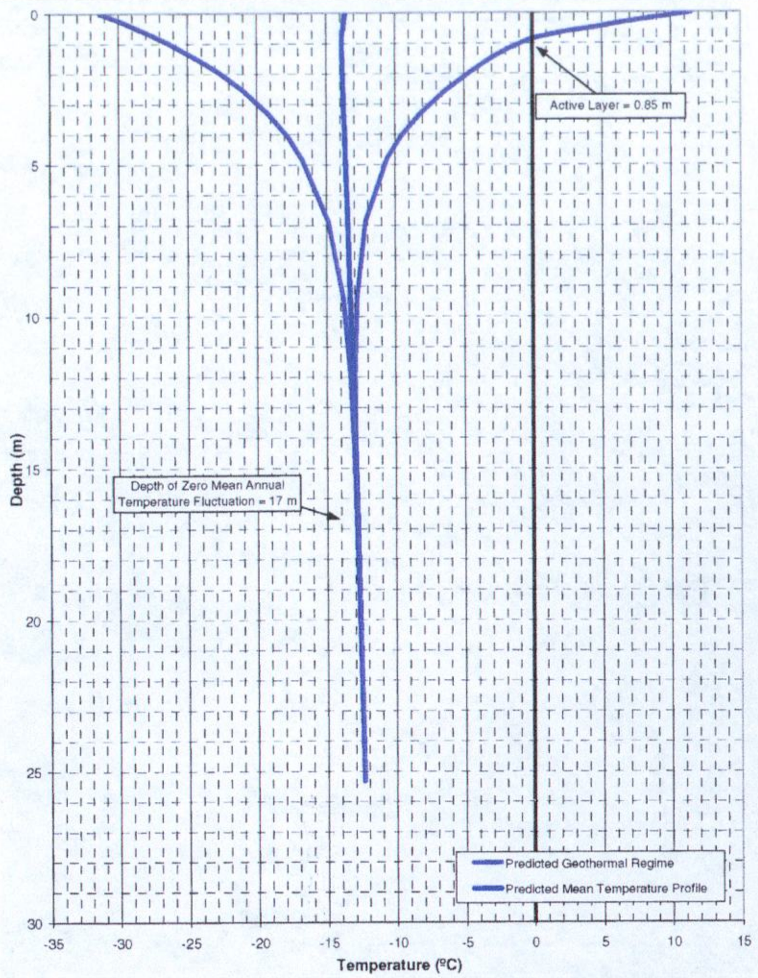


FIGURE A
PREDICTED BASELINE GEOTHERMAL REGIME (THIN SNOW COVER CONDITIONS)

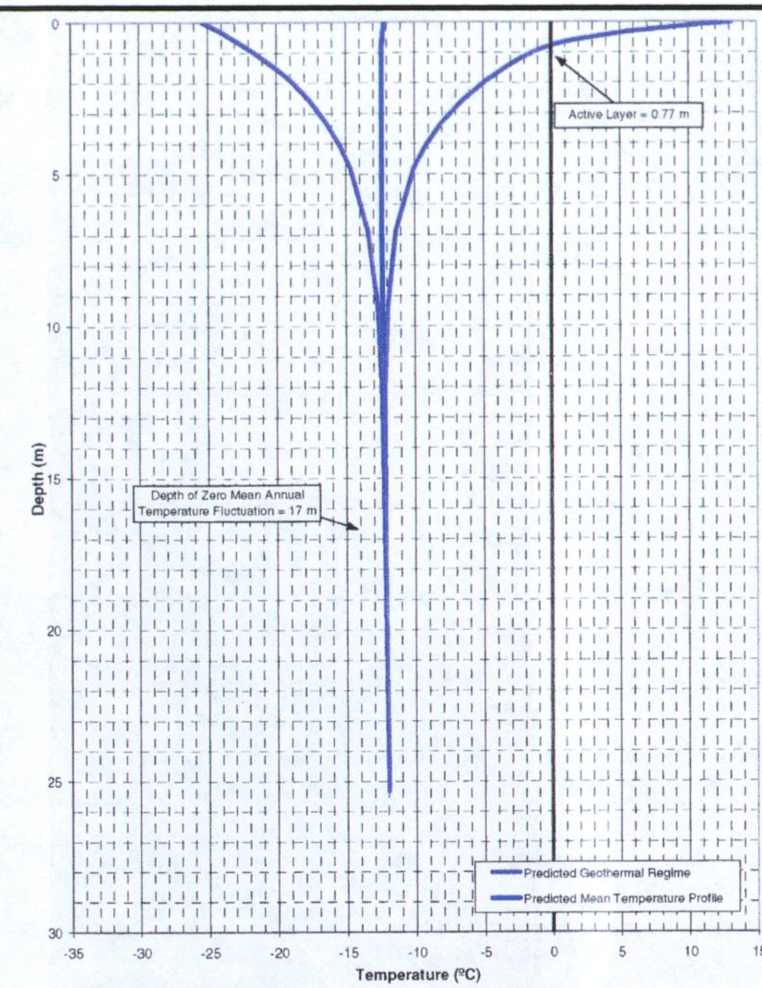


FIGURE B
PREDICTED BASELINE GEOTHERMAL REGIME (THICK SNOW COVER CONDITIONS)

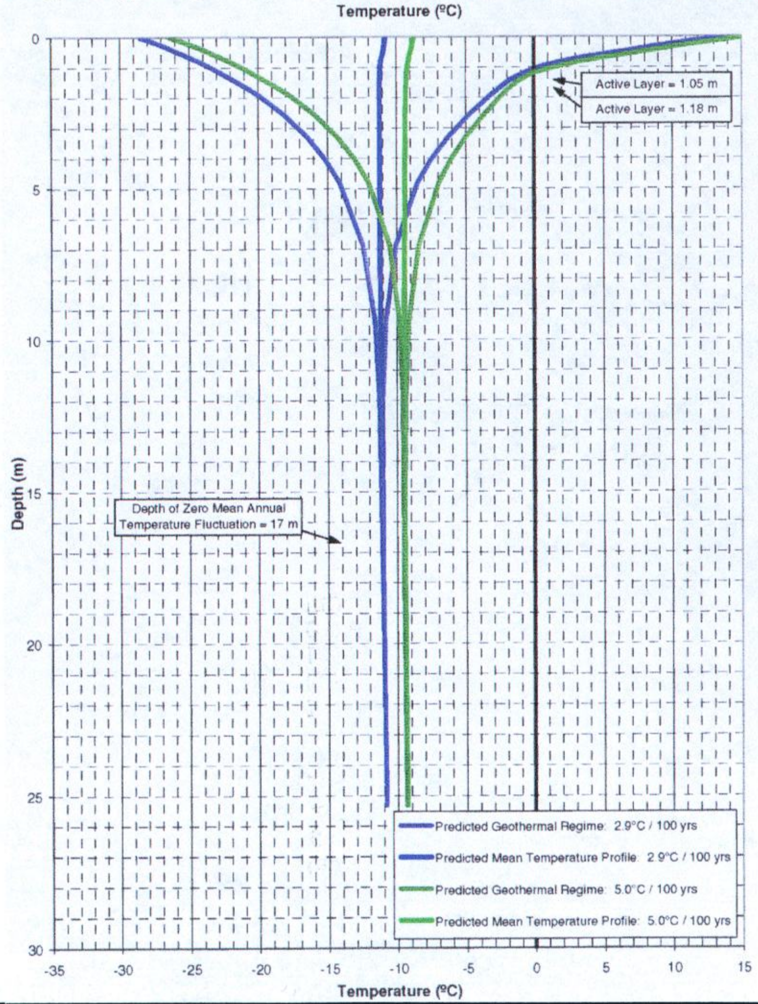


FIGURE C
PREDICTED FUTURE GEOTHERMAL REGIME FOR THIN SNOW COVER CONDITIONS (2100 AD)

FOR BEST ESTIMATE GLOBAL WARMING (2.9°C/100yr) AND HIGH ESTIMATE GLOBAL WARMING (5.0°C/100yr)

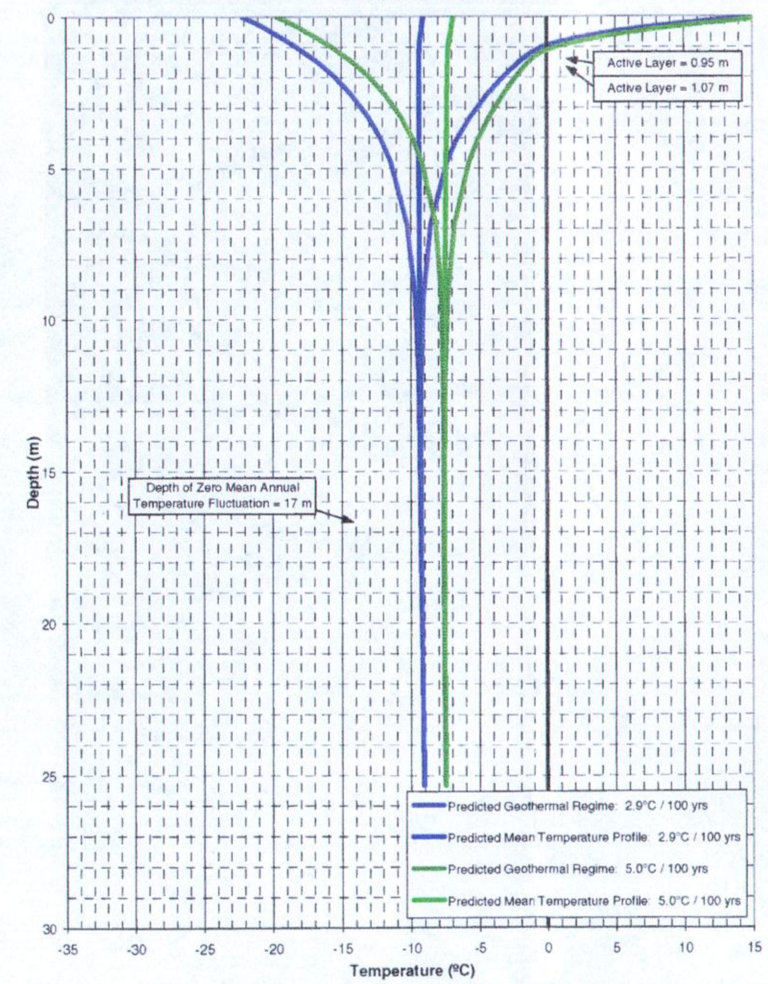
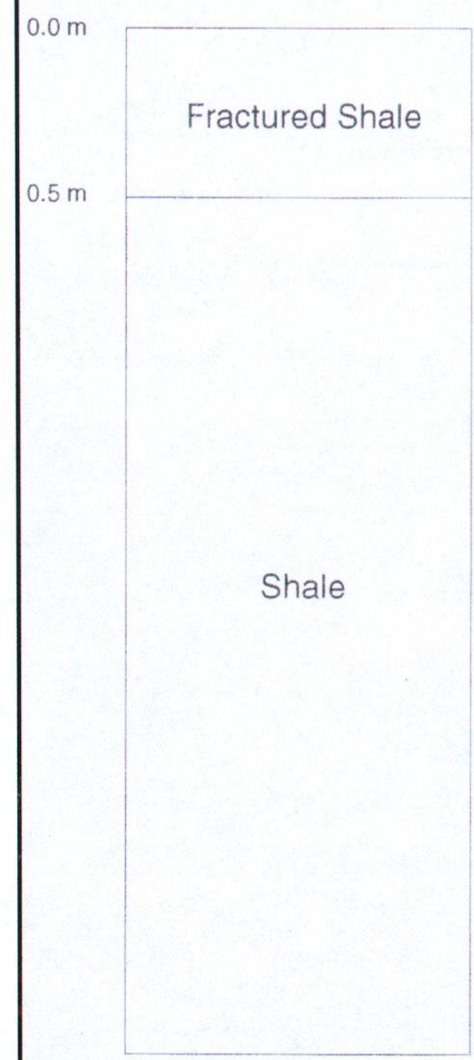


FIGURE D
PREDICTED FUTURE GEOTHERMAL REGIME FOR THICK SNOW COVER CONDITIONS (2100 AD)

FOR BEST ESTIMATE GLOBAL WARMING (2.9°C/100yr) AND HIGH ESTIMATE GLOBAL WARMING (5.0°C/100yr)

LEGEND

Model Stratigraphy



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REVIEWED BY:	PJM, HC, AJK
DRAWN BY:	BB/CPW
DATE ISSUED:	MARCH 2, 2001
PROJECT NUMBER:	20–935
FILE NAME:	20935–F2–LF05.DWG
REVISION:	0

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Existing and Predicted Geothermal Regime (Fractured Shale Cover)

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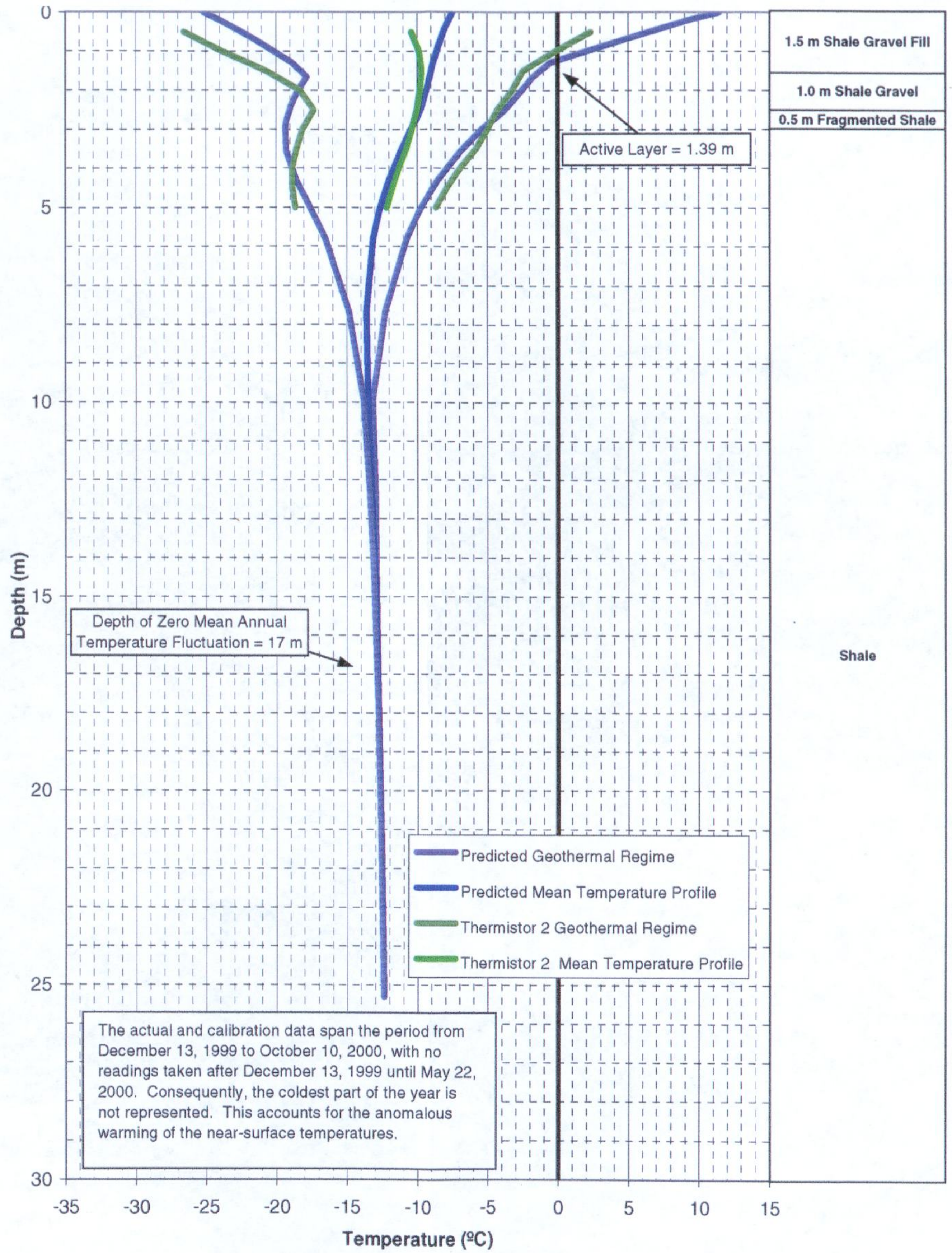
Figure No. APPENDIX 5



PREDICTED GEOTHERMAL REGIME AND MEAN TEMPERATURE PROFILE CALIBRATED TO THE THERMISTOR 2 TEMPERATURE READINGS AND GROUND PROFILE

LEGEND

SOURCE OF DRAWING:
BGC ENGINEERING INC. MEMORANDUM: "POLARIS LANDFILL CLOSURE REPORT" DATED FEBRUARY 9, 2001, BY CLINT LOGUE/WAYNE SAVIGNY. PROJ. NO. 0168–006

REVIEWED BY:	PJM, HC, AJK
DRAWN BY:	BB/CPW
DATE ISSUED:	MARCH 2, 2001
PROJECT NUMBER:	20–935
FILE NAME:	20935–F2–LF06.DWG
REVISION:	0

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Geothermal Model Calibrated to the Thermistor 2 Temperature Readings

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Figure No. APPENDIX 6

LEGEND

CONTOUR, INDEX

CONTOUR, INTERMEDIATE

REFERENCE GRID LINE

CROSS SECTION

AREAL EXTENT OF FINAL COVER
AREA=64409 sq.m.

SCALE 1:2000
metres

0 10 20 30 40 50 100

Contour interval one metre

DRAWING INFORMATION
DESIGNED BY:
REVIEWED BY: PJM, HC
DRAWN BY: BB/CPW
DATE ISSUED: MARCH 2, 2001
PROJECT NUMBER: 20-935
FILE NAME: 20935-F2-LF07.DWG
REVISION:

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Operational and Construction
Landfill Proposed Final Contours

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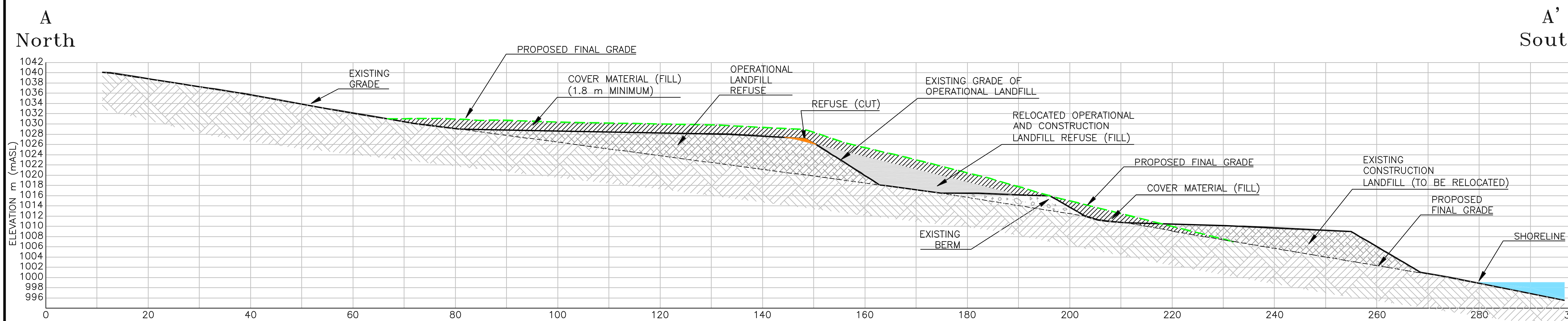
Figure No. APPENDIX
7



REFUSE

RELOCATED CONSTRUCTION REFUSE

OPERATIONAL LANDFILL CUT AREA

FINAL COVER (MINIMUM 1.8 m THICK)

NATIVE MATERIAL

BERM (FILL)

PROPOSED FINAL GRADE

EXISTING GRADE

ASSUMED NATIVE GROUND SURFACE

DRAWING INFORMATION
DESIGNED BY: PJM
REVIEWED BY: PJM, HC
DRAWN BY: BB/CPW
DATE ISSUED: MARCH 21, 2001
PROJECT NUMBER: 20-935
FILE NAME: 20935-F2-LF08.DWG
REVISION: 1

Scale

Horizontal 1:750
Vertical 1:750
Vertical Exaggeration x1
All units in metres

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Cross Section A-A'

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Figure No. APPENDIX 8