Golder (1998) conducted a frequency analysis on the annual precipitation series at the Nanisivik Airport climate station to derive extreme annual precipitation rates for the project site. The results for selected return periods are presented in Table 5, which shows that the derived extreme annual precipitation for a 1 in 100 year return period is 380 mm.

Golder (1998) also estimated short duration extreme rainfall events for Nanisivik. Available short duration extreme rainfall data from the AES station at Pond Inlet was used in their analysis due to the lack of available site specific data for Nanisivik. The resulting extreme rainfall depths for various durations and frequencies ranging from 2 to 100 year return periods are summarised in Table 6. The results indicate that a 24 hour 1:100 year precipitation event would amount to 36 mm of precipitation.

Golder (1998) also provided an assessment of Probable Maximum Precipitation (PMP). Huschke (1959) defines the PMP as "the greatest depth of precipitation, for a given duration, meteorologically possible for given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends". CDSA (1995) notes that the PMP is a description of the upper physical bound to precipitation that the atmosphere can produce. Hence, a PMP value is considered an upper bound parameter available for design of the tailings ponds and other drainage facilities.

Golder (2002) estimated the daily rainfall PMP for Nanisivik to be approximately 140 mm. It was recognized that very limited short duration rainfall data is available in the Baffin region and that the PMP value is only an estimate based on readily available data.

3.2.4 Lake Evaporation

Site specific evaporation data for the WTDA were collected by Mr. Bob Reid (DIAND - Yellowknife) between 1993 and 2001. The results of the study are summarized in Table 7. The lake evaporation rates provided by Mr. Reid were reviewed to provide a basis for estimating the monthly and annual lake evaporation rates. The results indicate that the mean annual evaporation at the WTDA is approximately 200 mm/year. Based on mean climatic conditions, precipitation exceeds lake evaporation by approximately 40 mm per year.

3.2.5 Global Warming

Climate change, and more specifically, global warming, is an on-going phenomena in the world today and its effects appear to be magnified at northern latitudes. Environment Canada (1995) notes that mean annual temperatures within the Mackenzie Valley have increased by 1.7°C over the last century. Burn (2002) notes that near surface permafrost in the Mackenzie Delta has warmed rapidly in response to regional climate warming; he also notes though, that warm permafrost in southern and central Yukon has showed little response to climate warming. Beilman et al. (2000) indicates that the southern limit of permafrost in Western Canada has moved northward by 39 km on average. Alternatively though, some reports for the eastern Arctic and northern Quebec (Allard et al. 1995) show cooling occurring over the same time period in which Mackenzie Valley warming has been documented. That observation has recently been superseded by Allard et al. (2002) that notes that permafrost warming is now occurring in northern Quebec, beginning with summer temperatures in 1993 and winter temperatures in 1995.

There is still much debate in both the scientific and the public circles on whether climate change is a natural phenomena or caused by anthropogenic ("man-made) inputs to the atmosphere, or some combination of the two. Anthropogenic climate warming is caused by "greenhouse gases" such as carbon dioxide (CO_2), methane (CH_4) and water vapour. These gases trap the Earth's outgoing radiation, and hence, warm the planet. Both carbon dioxide and methane are generated by industrial activity and the use of fossil fuels. Natural phenomena such as sun spots and solar activity are also potential causes for global warming.

Regardless of the causes, air temperature warming in the western Canadian Arctic has occurred. Figure 9 shows almost 60 years of recorded air temperatures at Yellowknife (62°27'N), along with a linear regression line fitted to the data points. Based on the coefficient of determination of only 0.16 (for context, a value of 1.0 would indicate perfect correlation while a value of 0 would indicate no correlation), a warming trend of approximately 0.3°C/decade is indicated. The data for Inuvik, in the Mackenzie Delta at 69°18'N, was also plotted and Figure 10 displays the results. Based on 40 years of records, and a coefficient of determination of 0.36 (i.e. 36% of the data correlates with one another), a warming trend of 0.77°C/decade is indicated by the air temperature history. This correlation value is quite low for the regression but warming in the permafrost has been measured, as noted earlier in Burn (2002).

For the eastern Arctic, warming indications are not clear. As reviewed in Section 3.2.2, linear regression of 20 annual data points from the Nanisivik Station provided a warming trend of 0.6°C/decade with a coefficient of determination of only 0.22 (i.e. only 22% of the data is correlated with each other). For the Resolute Station, with 52 annual data points and hence a much larger sample population for statistical assessment, a warming of only 0.1°C/decade was indicated but the coefficient of determination was only 0.04, indicating almost no correlation. Hence, the Nanisivik and Resolute weather stations do not indicate any statistically significant warming within the data sets analysed (up to 2000). It is possible that eastern Arctic warming may be positively indicated at other Nunavut or northern Quebec locations or in more recent data (after 2000).

Environment Canada (1998) has published temperature guidelines as a consistent basis for planning and impact assessment for long-term projects in the North. Based on increasing concentrations of greenhouse gases, and using complex General Circulation Models (GCM's), the IPCC (1995) estimates a range of estimates for global warming values. Often quoted scenarios are the "Best Estimate" and the "High Sensitivity" values of 2.0°C and 3.5°C for the global temperature warming between 1990 and 2100. These global increases are then converted into regional warming values, based on the use of GCM's.

Environment Canada (1998 – Tables 8 and 9) provides values for the expected temperature increases by season, latitude and decade. The following limitation is noted though with the temperature increase values provided:

> "...they can be considered nominal temperature change scenarios for northern North America to the north and west of Hudson's Bay (emphasis by BGC). There is still considerable uncertainty on both the direction and magnitude of impact of global warming in the northeastern part of North America."

As a result, the values are provided but Environment Canada notes that they are likely not appropriate for the eastern Arctic. Unfortunately, there are no other guidelines for temperature increases in the eastern Arctic at the current time. Tables 8 and 9 therefore provide the interpolated temperature increase values proposed for Nanisivik, based on the Environment Canada guidelines. As a result, mean annual air temperatures increases of 2.8°C and 5.0°C for the Best Estimate and the High Sensitivity cases respectively, would be applied to the "current" MAAT value of –15.1°C. As a result, the Best Estimate MAAT for 2100 would be equivalent to –12.3°C and the High Sensitivity MAAT for 2100 would be –10.1°C.

For context with these values, and by means of a nearby and recent example, EBA (2001) provided an assessment of global warming values for the closure design relative to Polaris Mine, located at 76°N, just north of the Nanisivik latitude. Within that assessment, the Best Estimate and High Sensitivity values were 3.0°C/100 years and 5.1°C/100 years, respectively. As a result, the interpolated values in Tables 8 and 9 are just slightly less than the values used by EBA, as would be expected due to the slightly lower latitude of Nanisivik.

In addition to Polaris, Table 10 provides a summary of global warming estimates (and the 1 in 100 year warm year values) used on other northern projects. As a result, the design values proposed for Nanisivik are intermediate between the noted values for FOX-M (to the south) and Polaris (to the north).

3.3 Geology

3.3.1 Bedrock

The bedrock geology of the area has been mapped in detail by Patterson and Powis (2002). The local bedrock geology map of the area is shown in Figure 11 and the regional bedrock stratigraphy is illustrated on Figure 12. The Nanisivik region is underlain by carbonate and terrigenous clastic strata of the Mesoproterozoic Bylot Supergroup. The Bylot Supergroup is comprised of two terrigenous formations (Adam's Sound and Arctic Bay formations) and two carbonate formations (Society Cliffs and Victor Bay formations) and a mixed carbonate and terrigenous clastic formation (Strathcona Sound Formation). Quartz arenite of the Gallery Formation uncomfortably overlies the Proterozoic strata.

The Adams Sound Formation is a beige to light orange-brown, well cemented, medium to coarse-grained quartz arenite. It is over 100 m thick and is exposed in the Nanisivik Area as shown on Figure 11.

The Arctic Bay Formation is a medium grey to brown, micaceous, fine sandy siltstone interbedded with dark grey micaceous, silty shale. This formation outcrops southeast and southwest of Nanisivik and is approximately 200 m thick.

The Society Cliffs Formation is over 500 m thick and is exposed in the Nanisivik Area as shown on Figure 11. This formation has been subdivided into three units:

- Microbial dolostone (lower);
- Intraclastic dolostone (middle); and,
- Laminated dolomudstone (upper).

All components of the formation exhibit dolomite mineralization. Known sulphide deposits in the Nanisivik area are hosted within the middle and upper subdivisions of this formation.

The Victor Bay Formation is characterized by a gradual upward change from organic rich pyritic shale, to dolomitic mudstone, to more intraclastic and dolomitic facies. It is exposed throughout the Nanisivik area as shown on Figure 11. The formation has been subdivided into three units:

- Shale and dolomitic mudstone unit (lower);
- Dolomitic mudstone and intraclast floatstone (middle); and,
- Silty dolomitic mudstone and intraclast rudstone (upper).

The lower unit is approximately 180 m thick and consists of interbedded, organic rich, fissile shale and light-grey, planar-bedded dolomitic mudstone.

The middle unit is approximately 80 m thick and is marked by the appearance of intraclast rudstone and floatstone. Occasional occurrences of light-grey dolomudstone and black shale similar to those found in the lower unit are observed within the middle unit.

The upper unit is approximately 70 m thick and is characterized by the absence of shale and the prevalence of dolomitic intraclastic carbonate and the presence of terrigenous material within clastic carbonate rocks. This unit forms a transitional unit into the terrigenous Strathcona Sound Formation.

The Strathcona Sound Formation contains two mappable units. A light brown to orange coloured carbonate pebble to boulder conglomerate, with 1 to 50 cm diameter dolomitic mudstone clasts. Its thickness ranges from several metres to approximately 50 m. This unit is overlain by a green to dark grey, planar bedded, interbedded quartz wacke and shale unit forming a thick (>130 m), monotonous succession. The quartz wacke and shale are interbedded at scales ranging from 1 to 200 cm.

The Phanerozoic rocks of the Gallery Formation overlie the Mesoproterozoic strata and are exposed predominantly west of Nanisivik. The Gallery Formation forms a thick (>300 m) succession of interbedded red and white, poorly cemented, medium- to fine-grained quartz arenite. The Gallery Formation is easily identified by its deep red hematite-stained colour, and friable texture.

3.3.2 Overburden

Overlying the bedrock, specifically in the area of West Twin Lake, is a combined unit of lakebed sediments (silt and sand, trace to some clay) and glacial till (silty sand with gravel fragments). The lakebed sediments are identified by their red colour, a product of hematite oxidation staining. The till is generally very granular in nature, frozen below the depth of active layer thaw and may contain excess ice content. The thickness of the lakebed sediments/ till unit varies from 1 to 4 m. The lake bed sediments/ till upper surface generally follows the underlying bedrock topography. Additional discussion regarding the composition and location of local overburden deposits is included in Section 5.2.1.

3.4 Regional Permafrost

Nanisivik is located in the region of continuous permafrost. Permafrost has been observed to extend to a depth of at least 430 m, as observed in a borehole drilled from the underground workings. Ground conditions in the area have been characterized by NRC (1995) as having the potential for medium amounts of ground ice (as high as 20%) and mean annual ground temperatures colder than -10°C. This has been verified by ground temperature measurements at various locations around the mine site as cold as -13°C at depth. The depth of the active layer in natural ground has been observed to average between 1 to 2 m below ground surface.

4.0 MATERIALS AND LOCATIONS REQUIRING RECLAMATION COVER

One of the objectives of the mine closure plan is the isolation of reactive mine wastes and landfill materials to prevent the potential migration of contaminants and wastes to the environment. This section contains a brief description of the composition and location of mine wastes and landfill materials to be isolated. A summary of the geochemical characterization of tailings is included in the West Twin Disposal Area Comprehensive Closure Plan Report (Part G, Item 15). A detailed geochemical characterization of waste rock is included in the Rock Pile and Open Pit Closure Plan Report (Part G, Item 8).The Landfill Closure Plan (Water License Requirement Part G, Item 17) includes an assessment of the waste contained in that facility.

4.1 Reactive Mine Wastes

During mining operations, tailings were piped to the WTDA. The WTDA is illustrated on Figure 2. The tailings were deposited sub-aqueously into West Twin Lake until 1990, at which time the first lift of the West Twin Dike was constructed. Construction of the initial lift of the West Twin Dike divided West Twin Lake into two cells; the sub-aerial cell (Surface Cell), and the sub-aqueous cell (Reservoir). The presence of the West Twin Dike permitted the sub-aerial deposition of tailings in the Surface Cell. The Reservoir was further divided with the construction of the Test Cell Dike, which created a Test Cell devoted to studying reclamation cover options. Tailings are currently sub-aerially exposed in the Surface Cell and Test Cell. The Reservoir contains mostly sub-aqueously confined tailings, with a small area of sub-aerially exposed tailings at the toe of the West Twin Dike.

Based on previous work undertaken by Lorax (1999 and 2001), and more recently by BGC in 2003, the two following conclusions are provided with respect to the geochemistry of the tailings:

1. The tailings are potentially acid generating; and
2. Acid generation has not yet become established in the tailings.

The first conclusion is as expected, given that the Nanisivik Mine processed sulphidic ore. The confirmation that the tailings are acid generating creates the requirement for reclamation of the tailings with the objectives of preventing, controlling or mitigating acid generation and transport of oxidation products.

The second conclusion is reasonable for the Nanisivik site, given the relatively high inherent neutralization potential and high pH of the tailings and given that tailings were frozen and/or saturated in place shortly after deposition. This conclusion suggests that reclamation measures at this site should be focussed on the prevention of acid generation, rather than on control or mitigation strategies.

Waste rock generated by mining activity in the early years of operations was stored in several areas on the surface close to the underground mine entrances. Historic waste piles are located at: 02 South Portal, 09 South Portal, 39 North and South, Area 14, K-Baseline and Ocean View. Progressive reclamation of these piles has already been initiated and approximately 70% of the total volume of waste rock has been relocated into the underground mine or one of the open pits.

The rock types represented in the surface rock piles is a mixture of the various rock types encountered in the underground and open pit mines. This mixture would include a range of rock types from the host carbonaceous rock types to sulphidic waste containing predominantly pyrite mineralization.

Waste rock is generally composed of dolostone (up to 80% carbonate minerals), the host rock of the Nanisivik ore. Despite the fact that the waste rock is composed mainly of carbonate minerals, ABA testing completed by Lorax (2001) indicate that the some of the waste rock is PAG. This is due to the presence of sulphide minerals in the waste rock associated with the ore body.

There are four open pits on the Nanisivik Mine Property: Ocean view, East Open Pit, East Trench and West Open Pit. The open pits contain exposures of massive and disseminated sulphides (predominantly represented by pyrite mineralization) in the walls and floors. These exposures are largely discreet zones within the carbonaceous host rocks that generally form the bulk of the exposed rock.

4.2 Landfill Materials

The Nanisivik Landfill is located approximately 1 km west of the town site, as illustrated on Figure 1. The landfill has been historically used for disposal of waste materials from the Town of Nanisivik, the Nanisivik Airport and the mine. Industrial, institutional, residential and other miscellaneous waste streams were received at the Nanisivik landfill site. A description of the typical composition of each waste stream is as follows:

1. Industrial wastes include crushed drums, waste steel, scrap vehicles, and discarded mechanical equipment.
2. Institutional waste streams include wastes from food services, offices, day care, airport operations, and general housekeeping services.
3. Typical residential wastes include food waste, packaging materials, clothing and other household commodities.

Nanisivik Mine completed an internal Phase I/II site assessment for the landfill in 2000/2001, which included water and soil sampling downslope from the toe of the landfill. The report indicates that an average volume of 1,150 m^3 of solid waste (post burning) was added to the landfill with the majority of this volume originating from institutional sources.

Gartner Lee completed a Phase 2 and 3 Environmental Assessments of the landfill in 2002 and 2003. The results of testing completed on soil and seepage water samples indicated that no petroleum hydrocarbon contamination is present down gradient of the landfill.

5.0 DESIGN CONSIDERATIONS

5.1 Cover Type

The following section reviews the benefits and disadvantages of utilizing a wet or dry cover in the design of a reclamation cover for the tailings, waste rock, open pits and landfill material. A summary of each option is included in the following sections.

5.1.1 Wet Cover

In Canada, the use of water cover has been identified as a proven technology for isolating and minimizing the environmental impact from potentially acid generating mine wastes. Research published by Natural Resource Canada's MEND (Mine Environmental Neutral Drainage) Program shows that oxidation of sulphide materials can be inhibited by the presence of a water cover acting as an oxygen diffusion barrier. MEND also points out that while water covers have been applied at many sites, they are not universally applicable. Related issues such as the design and integrity of the containment structures, plus long term monitoring and maintenance costs, can negate the use of this technology.

5.1.2 Dry Cover

"Dry" cover systems as a closure management and decommissioning option for waste rock and tailings are a common ARD prevention and control technique used at numerous sites around the world. The objectives are to restrict/minimize the influx of water and provide an oxygen diffusion barrier. In many dry cover applications, the question of whether to select geo-synthetics over natural materials is a primary consideration.

5.1.2.1 Geosynthetics

Geosynthetic materials (geotextiles, geomembranes, geonets, and geocomposites) generally offer an economic advantage over natural materials due to their relative light weight and portability. This means that they can often be installed in a short construction period using light equipment and this can result in a lower unit cost. Geosynthetics also offer the advantage of exhibiting low permeability, limiting infiltration of water into underlying materials.

Some disadvantages of geosynthetics include the following:

- they are susceptible to tearing during installation;
- they may deteriorate over time due to prolonged exposure to harsh climatic elements;

- they offer minimal geothermal protection for underlying materials, unless overlain by an adequate thickness of native materials;
- the long term performance of geosynthetics has not yet been proven, especially in the harsh arctic climate; and,
- they are costly to transport to remote locations such as Baffin Island.

5.1.2.2 Natural Materials

Mine waste covers constructed of natural materials in cold regions generally incorporate granular material, sometimes in combination with a geosynthetic liner. The granular material, or a portion thereof, is saturated either during construction or over time as a result of infiltration of surface water into the cover. The saturated, frozen material provides a low permeable barrier to infiltration of water and oxygen.

5.1.3 Discussion on Cover Types

As discussed in Section 5.1.1, water cover can provide isolation of reactive mine wastes due to its ability to inhibit oxidation of sulphide minerals by acting as an oxygen diffusive barrier. Because of this capability, water cover is considered a viable option for the closure cover of the tailings currently contained within the Reservoir. Water cover is not considered a viable cover option for the sub-aerially exposed tailings in the Surface Cell or Test Cell. A water cover in these areas would provide a constant heat source in close proximity to the frozen containment dike and would have a negative effect on the long term stability of the dike.

With respect to the geosynthetic cover option, the poor thermal insulation properties and high mobilization costs, combined with the potential for tearing, shearing or otherwise compromising the integrity of the cover, introduces a performance risk that is not present for water cover or cover with natural materials. Therefore, this cover option is not considered appropriate as a singular element for any of the required cover designs. A geosynthetic material could be incorporated into a cover design, if used in combination with a cover of an adequate thickness of an appropriate natural material.

As discussed in Section 2.3, several successful case studies exist where natural material has been used as a mine waste cover in cold regions. This proven capability, in combination with favourable material availability, thermal, geochemical and cost characteristics, suggests that a reclamation cover composed of natural materials for the sub-aerially exposed mine wastes or landfill material is a preferred cover option.

It should be noted that the sub-aqueous cover for tailings in the Reservoir is only discussed briefly in this report on a conceptual level. Further discussion regarding the water cover for tailings in the Reservoir is included in the *Comprehensive Closure Plan for the West Twin Disposal Area* Report (Water license requirement Part G, Item 15).

5.2 Geotechnical Considerations

5.2.1 Cover Materials

5.2.1.1 Review of Available Natural Materials

A review of local natural materials by Terratech (1989) identified several potential cover materials with physical properties appropriate for use wholly, or in part, as a reclamation cover over the sub-aerially deposited tailings, waste rock, open pits and landfill material. The potential natural materials identified include the following:

Marine Silty Clay

A source for this material exists near the Nanisivik beach area (east and west of the dock). Access to the material and "workability" are restricted by the location and fine-grained nature of the material. This fine-grained material can not be worked/ripped in the freezing periods because of the high moisture content and resulting ice saturation. In the months of thaw, the active layer thawing restricts access to the area and subsequent significant surface scarring is caused by heavy equipment operations. The material can be collected in the spring when sublimation has taken place in the first few centimetres, and again in the fall after a frozen crust has developed on the ground surface to allow for traffic movement. This material was excluded from further consideration due to its limited availability relative to the volumes required and due to access logistics.

Airport Sand

This is local sand produced from surface decomposition of sandstone (Gallery Formation) bedrock. The deposit is located two kilometres south of the WTDA alongside the road to the airport. The Airport sand is not suitable for use as the main portion of the tailings cover due to availability limitations. Unlike the well graded sand and gravel, the Airport sand is predominantly fine grained in nature and, therefore, less attractive as a surface armouring material due to its susceptibility to wind erosion.

Till

Sources for this material are scattered as small deposits throughout the area. While the till can be worked over a somewhat longer seasonal period than the marine silty clay (i.e. the "melting season"), accumulating the volume required for the entire cover during the desired reclamation period would not be achievable. However, if significant volumes of glacial till become available as a result of stripping during borrow area development or spillway excavation, the till may be suitable for use as bulk fill.

Twin Lakes Sand and Gravel

The source for this material is a deposit located between the East and West Twin Lakes (Figure 11). This material is a reworked glacial diamicton deposited by local streams. Site experience in handling this material has shown it to be available during the "melting season" window of time.

Shale

The most readily available construction material at Nanisivik is derived from the local shale bedrock. The shale outcrops at several locations around the mine site as illustrated on Figure 11. The shale is part of the regional carbonate shelf sequence known as the Bylot Supergroup and is derived mainly from the Victor Bay Formation. Patterson et al. (2002) describe the shale of the Victor Bay Formation as "fissile". It is this friable nature that enables the material to be worked/ripped throughout much of the year. The shale is produced from the borrow areas as a relatively coarse grained material, consisting of mostly sand and gravel sized particles with trace amounts of silt and occasional cobbles and boulders. A further benefit of the shale material is its high carbonate content, which provides neutralizing potential against the possibility of acid generation in the tailings.

5.2.1.2 Selection of Preferred Cover Materials

The shale is selected for the main component of the cover for the following reasons:

- Availability – the shale is available in sufficient quantities at locations proximal to the areas requiring covering;
- Workability – the shale has been used for various purposes throughout the life of the mine and site staff have a valuable knowledge base of quarrying and handling the material;
- Carbonate Content – may provide buffering capacity should acidic leachate be produced by the underlying tailings;
- Grain Size Characteristics – the quarried grain size characteristics of the shale do not require additional mechanical break down to be used as a cover material.

It is recommended that an armouring material be placed above the shale to limit erosion (from both wind and water). The Twin Lakes sand and gravel is selected as an armouring material for the following reasons:

- Durability – the material is composed of re-crystallized quartzite which is characteristically highly durable and resistant to weathering;
- Availability – the material is available in sufficient quantity in an area proximal to the WTDA; and
- Light colour – the light colour of the material (tan to reddish) will reflect sunlight and provide less heat absorption than darker materials.

Till that is excavated as part of quarry development or spillway excavation activities may be used as a bulk fill material in cover construction. The fill could be placed in topographic lows provided boulders are removed prior to placement. The top 1.25 m of the cover would still be required to be composed of shale (1.0 m) and Twin Lakes sand and gravel (0.25 m).

5.2.1.3 Verification of Quantities

The available geotechnical information for the shale quarries and Twin Lakes sand and gravel deposit was reviewed to verify the materials are available in the required quantities.

Shale has been used for various purposes around the mine site throughout the mine history. It outcrops in several areas around the mine site and several borrow areas have been developed and used throughout the mine history. The verification of shale availability was conducted by the following techniques:

- Review of published geological maps to verify location of local outcroppings of shale and to verify geologic origin;
- Geological mapping to observe surficial stratigraphy;
- Geological drilling to observe sub-surface stratigraphy;
- Visual observation of existing quarry sites.

As noted before, the surface geology of the Nanisivik area was mapped by Patterson and Powis (2003). The information has been produced in map format by the Geological Survey of Canada. This map (GSC Open File 1552) was reviewed to verify location of local outcroppings of shale and to verify geological origin. The map confirms that shale is abundant in outcrop throughout the area. Figure 11 shows that the location of currently permitted borrow areas superimposed on the bedrock geology maps. The shale at each borrow area appears to be part of the lower unit of the Victor Bay Formation. Although the shale is part of the same geological unit at each location, some variability in lithology (and resultant characteristics) would be expected because of the depositional environment.

Geological inspection of the East Twin Lake (ETL), West Twin Lake (WTL), Mt. Fuji and Shale Hill quarries was conducted by BGC in 2003. The inspection confirmed that shale outcrops at surface at each location.

Geological drilling was conducted by BGC in 2003 at the ETL and WTL quarries. The borehole logs are included in Appendix I. The boreholes drilled at the ETL Quarry (BGC03-25 and 03-26) encountered shale bedrock. Borehole BGC03-25 encountered approximately 1 m of till overlying 2.5 m of shale overlying dolostone. The shale in this borehole had an RQD of 0%, Borehole BGC03-26 encountered approximately 2 m of till overlying shale. The borehole was terminated at 6.1 m in shale. The shale in this borehole had an RQD value of 0%. This borehole was terminated due to problems encountered with the shale caving into the borehole. The boreholes drilled at the WTL Quarry (BGC03-27 and 03-28) encountered varying amounts of shale. Borehole BGC03-27 encountered approximately 1 m of till overlying shale. The borehole was terminated at 5.8 m in shale. The rock quality of the shale in this borehole ranged between an RQD of 0% and 57%. Drilling was terminated in this borehole due to shale caving into the borehole. Borehole BGC03-28 encountered approximately 4.9 m of till and frost shattered bedrock overlying dolostone. The borehole was terminated at 5.2 m in dolostone. No shale was encountered in this borehole, with the exception of some fragments observed in the overburden. The dolostone encountered in boreholes BGC03-25 and 28 may be a stringer within the shale unit or it may be the lowermost portion of the formation, noted to be dolomitic mudstone (Patterson et al. 2003).

As a result of the review of available geological information, results of the geological drilling and visual inspection of the quarries, it appears that shale is available in sufficient quantities for use in the construction of reclamation covers. Further discussion on shale quantities and extraction methods is included in the Quarry Development and Reclamation Plan (Water License Requirement (Part G, Item 6).

The Twin Lakes sand and gravel deposit is located between ETL and WTL. The deposit is an alluvial fan deposited sub-aqueously at a time when ETL and WTL were part of one larger lake (Tordon 1997). Three boreholes were drilled into the deposit in 1998 as part of a study to assess the hydraulic connectivity of ETL and WTL. Tordon (1998) reports that the boreholes encountered sand and gravel to a depth of approximately 10 m. Shale bedrock was found in only one of the three boreholes (T/C 24) at a depth of 9.1 m, the other boreholes were terminated in the sand and gravel. Based on this information, there appears to be a sufficient volume of this material available for use in the reclamation covers. Further discussion on volumes and extraction methods is included in the Quarry Development and Reclamation Plan Report (Part G, Item 6).

5.2.2 Geotechnical Properties of Preferred Cover Materials

A review of the geotechnical characteristics of the shale and Twin Lakes sand and gravel was conducted by examining the results of various lab tests completed by BGC in 2003, Golder (1999) and Terratech (1993a and 1993b). The review was completed to assess the appropriateness of these materials for use in reclamation cover design.

The following geotechnical properties have been assessed in the aforementioned studies:

1. grain size distribution;
2. compacted density;
3. natural and saturated moisture content;
4. durability; and,
5. permeability.

The following sections review the results of these assessments and their relevance to the material being used in the reclamation cover design.

5.2.2.1 Grain Size Distribution

The grain size distributions of natural shale samples collected from the East Twin Lake and Mt. Fuji quarries by BGC in 2003, as well as in situ samples from Test Cell Test Cover #1, the Surface Cell Test Cover and the West Twin Dike are illustrated on Figure 13. The results confirm that the shale cover is granular in nature, consisting mainly of sand and gravel sized particles. The following is a list of principal conclusions derived from the results of the grain size distribution analyses:

- The composition of gravel and larger sized particles ranged between 62% and 94%;
- The composition of fines (percentage of sample smaller than 0.075 mm) ranged between 2% and 10%;
- The samples derived directly from the quarries were generally coarser that the samples derived from the West Twin Dike or the test covers.

But, to note again, the fines content of all noted samples only varied from 2 to 10%.

The grain size distributions of several samples collected from the Twin Lakes sand and gravel deposit are illustrated on Figure 14. The results indicate that the deposit is granular in nature consisting of mainly sand and gravel sized particles. Of course, larger particle sizes such as cobbles and boulders would not be represented within these samples. The following is a list of principal conclusions derived from the results of the grain size distribution analyses:

- The composition of gravel and larger sized particles ranged between 72 and 90%;
- The composition of fines ranged between 2 and 5%;

Figure 15 compares the grain size distributions of both the shale cover material and the Twin Lakes sand and gravel. From this figure, it is observed that the shale is generally finer and more variable in composition. The D_{50} grain size of the shale was observed to range between 4 and 25 mm, while the D_{50} grain size of the Twin Lakes sand and gravel was observed to range between 10 and 20 mm. Additionally, based on visual observations of the various deposits, the Twin Lakes sand and gravel is comprised of a larger percentage of rounded cobble and boulder sized particles compared to the shale cover, which consists of angular fragments.

Since the till material may be used as a bulk fill to fill in the topographic low spots in the Surface Cell, grain size analysis was completed on several till samples collected from the drilling investigation of the proposed spillway alignment. The results of the testing are illustrated on Figure 16. As can be seen, the grain size distribution of the till is highly variable but is generally a granular material composed of sand and gravel sized particles. The fines content of the till samples ranged between 7 and 29%, which indicates that the till generally contains more fine grained particles than the shale or Twin Lakes sand and gravel.

5.2.2.2 Compacted Density

A Standard Proctor density test was performed on the samples collected from the ETL and Mt. Fuji quarries in 2003. Prior to the density test, the particles larger than 20 mm diameter were removed from the sample, as per the ASTM test standard. A grain size analysis was then conducted on the shale used in the density test. The Standard Proctor Maximum Dry Density (SPMDD) values were determined to be 1870 and 2010 kg/m^3 for the ETL and Mt. Fuji samples, respectively. The optimum moisture contents were determined to be 6% and 7% for the ETL and Mt. Fuji samples, respectively.

Terratech (1993a) reports the results of a Standard Proctor density test completed on a sample from the stockpile of shale used to construct the West Twin Dike. The results of the test indicate a SPMDD of 2092 kg/m^3. The test indicated an optimum moisture content of approximately 9%.

Based on those three test values, the average SPMDD value for the shale is approximately 2000 kg/m^3. For the shale placed in the dike and the test covers, with only nominal compactive effort, in situ dry densities of 1800 kg/m^3 (90% SPMDD) to 1900 kg/m^3 (95% SPMDD) would be anticipated. Using measured specific gravity values of 2.60 to 2.65 (Golder 1999), the range of moisture values required for saturation were calculated and are summarized in Table 11. This table indicates that saturated moisture content values between 14 and 18% would be expected. Section 5.2.2.4 also provides additional discussion on this topic.