- 1992 – Geotechnical investigations of WTDA including drilling and installation of thermocouples and frost gauges from the 376 m bench of the WT Dike and each of the test covers in the Test Cell. Geotechnical drilling and installation of thermocouples were also completed at various other locations around the Nanisivik Mine site.
- 1994/1995 – Additional geotechnical drilling and thermocouple installation on the 376 m bench of the WT Dike.
- 1997 – Geotechnical drilling and installation of thermocouples at various locations of the WT Dike and at the toe of the dike in the Reservoir.
- 1998 – Geotechnical drilling in the delta fan between ETL and WTL to assess the hydraulic connectivity between the two lakes.
- 1999 – Geotechnical drilling at various locations on the West Twin Dike.
- 2001 – Geotechnical drilling and installation of thermocouples within the Surface Cell and Test Cell Dike.

Borehole logs, where available from these programs, are compiled in Appendix II.

In 2002 and 2003, a total of 44 boreholes were drilled in the Surface Cell, Test Cell Dike and at the toe of the West Twin Dike. Access difficulties prevented investigations in the Test Cell area. The approximate location of each borehole is illustrated on Figure 7. A summary of borehole information is provided in Table 3. Figure 7 also shows the location of 49 instruments (thermocouples and frost gauges) installed prior to the 2002/ 2003 geotechnical investigations.

The following sections summarize when each recent investigation program was undertaken, who conducted the investigation and the objectives and achievements of each stage of the geotechnical investigation of the Surface Cell and Test Cell taliks:

May 2002

In May 2002, Nanisivik Mine geological staff supervised the drilling of one borehole in the Surface Cell (BH10/TC #37). No detailed geotechnical log of the borehole was developed but the occurrence of thawed and frozen tailings was noted. A thermocouple was installed in this borehole.

September 2002

In September 2002, Mr. Geoff Claypool, E.I.T. of BGC Engineering Inc., supervised a geotechnical drilling program to observe the subsurface soil conditions within the WTDA. A total of 13 boreholes were drilled; BGC02-01 through 02-13. The purposes of these boreholes were to:

- observe ground conditions in the Surface Cell, toe of the West Twin Dike and foundation of the Test Cell Dike;
- install geothermal monitoring equipment to measure ground temperatures; and,

- if thawed ground conditions are encountered, install monitoring wells to assess water quality.

In total, five thermistors and six thermocouples were installed in the Surface Cell, and foundation of the Test Cell Dike to monitor ground temperatures. Two monitoring wells (BGC02-04 and 02-05) were installed in the Surface Cell to monitor water quality.

May 2003

In May 2003, Mr. Gerry Ferris, P.Eng. of BGC Engineering Inc., supervised a geotechnical drilling program to observe the subsurface soil conditions at various locations around Nanisivik Mine. A total of 17 boreholes were drilled in the WTDA. The purposes of these boreholes were to:

- further define the Surface Cell talik encountered during the September 2002 drilling investigation;
- install additional geothermal monitoring equipment (replacements for some 2002 instruments damaged) to measure ground temperatures; and,
- install monitoring wells to measure piezometric pressures and assess water quality.

In total, 11 thermistors and 1 thermocouple were installed in the Surface Cell, Test Cell Dike and at the toe of West Twin Dike to monitor ground temperatures. Two monitoring wells (BGC03-12 and 03-14) were installed in the Surface Cell to monitor piezometric pressures and water quality.

September 2003

In September 2003, Mr. Murray Markle, Nanisivik Mine Site Manager, supervised the drilling of nine boreholes in the Surface Cell (BGC03-31 through 03-39). The purposes of these boreholes were to:

- install additional geothermal monitoring equipment to further define the extent of the Surface Cell talik; and,
- install additional instrumentation capable of monitoring pore pressures within the Surface Cell talik.

In total, three thermistors and three thermocouples were installed in the Surface Cell to monitor ground temperatures. Three vibrating wire piezometers were installed to monitor pore pressures within the talik. Additionally, vibrating wire piezometers were placed within monitoring wells BGC03-12 and 03-14.

Also in September 2003, Sub-Arctic Surveys Ltd. (SAS) of Yellowknife, NT conducted a topographic survey of various locations of the Nanisivik Mine site including the WTDA. The location of many of the boreholes drilled during the 2002/2003 geotechnical investigations was also surveyed. The survey work conducted by SAS was completed in UTM NAD 83 coordinates.

4.1.1 Drilling Method and Instrumentation

The drilling was completed using an Atlas Copco 262 diamond drill. Chilled brine was used as drilling fluid and BQ-size (36.5 mm diameter) core was recovered when possible using a double-tube sample barrel. Recovered core was logged for ice content and grain size and stored for subsequent lab testing. Response of the drilling equipment was noted as each borehole was advanced through the subsurface. A detailed geotechnical log was created for each borehole and these borehole logs are included in Appendix II. Table 3 summarizes the instrumentation installed in the boreholes.

The following sections provide some commentary on the types of instrumentation installed in the various boreholes.

Thermistors

The thermistors that were installed were fabricated by M-Squared Instruments of Cochrane, AB. Each thermistor is type YSI44007 with a MS3106A20-29P termination. The accuracy of the thermistors, as noted by the manufacturer, is +/- 0.2°C. Each cable was ice-bath calibrated by the manufacturer prior to shipment to site. The calibration sheets for each of the thermistors are included in Appendix III. The switch-box required to monitor the instruments was manufactured by M-Squared Instruments and left at the mine for future monitoring requirements.

Thermocouples

The thermocouples installed were fabricated as needed on site by the BGC field representative. The thermocouples were constructed using type EXPP-T-20 (copper–nickel extension type) thermocouple wire produced by Omega Industries. The accuracy of this type of thermocouple wire is documented by the manufacturer to be +/-1°C.

Standpipe Piezometers

The standpipe piezometers were fabricated as needed on site using 3 m lengths of 25 mm (1 inch) diameter PVC pipe. Both slotted and riser (non-slotted) pipe sections were used in each installation. The pipe was threaded and fitted with end caps and top caps. Heat trace wire was installed in the centre of some of the standpipes to provide the ability to monitor the instrument during the winter months. It should be noted that the standpipes were also used to collect groundwater samples, and hence, they are also referred to in some instances as "monitoring wells".

Vibrating Wire Piezometers

Vibrating wire piezometers were fabricated by RST Instruments of Coquitlam, BC. Each instrument is a VW2100-type vibrating wire piezometer. Each instrument was calibrated by the manufacturer prior to shipment and the calibration sheets are included in Appendix III. The stated accuracy for these instruments is +/- 0.1% of the full scale reading. The instruments are monitored using the portable readout unit (VW2102), also manufactured by RST.

Installation Procedures

All thermistors and thermocouples were installed within a 25 mm diameter PVC riser pipe. The PVC pipe was installed through the drill string and was filled with vegetable oil to counteract buoyancy forces between the PVC pipe and drilling fluid contained within the drill string. The boreholes were backfilled with tailings slough and silica sand. The top 0.5 to 1.0 m of each borehole was backfilled with bentonite pellets to prevent direct infiltration of surface water into the borehole. The installations were enclosed within orange coloured, plywood boxes built at site or pre-fabricated metal surface casings for protection and identification. Detailed installation information is included on the borehole logs in Appendix II.

The standpipe piezometers were installed by threading several pieces of slotted and riser pipe together and installing the pipe through the drill string. The boreholes were backfilled using a combination of tailings cuttings and silica sand at selected intervals. The top 1.5 m of each borehole was backfilled with bentonite chips to prevent direct infiltration of surface water into the borehole. Heat trace was installed down the centre of the piezometers installed in 2003. Detailed installation information is included on the borehole logs in Appendix II.

Each vibrating wire piezometer was installed in a similar fashion to the standpipe piezometers. A borehole was drilled until thawed tailings were encountered. PVC pipe was placed into the borehole, with a slotted section being placed within the thawed interval. The vibrating wire piezometer was then placed inside the PVC pipe at an elevation within the thawed interval. Two of the vibrating wire piezometers were installed in wells that were previously standpipe piezometers (BGC03-12 and 03-14). Heat trace was installed in all vibrating wire piezometer installations. Detailed installation information is included on the borehole logs in Appendix II.

4.1.2 Ground Conditions

4.1.2.1 Surface Cell

Soil types encountered during drilling in the Surface Cell included shale fill, frozen and thawed tailings, lake bed sediments, till and shale and dolostone bedrock. Typically, frozen tailings were well bonded (N_{bn}) or friable with no visible ice (N_f), but occasional zones with visible ice contents up to 50% were observed. Occurrences of ground ice were encountered within the tailings in boreholes BGC03-07, 03-11, 03-12, 03-20, 03-21, 03-31, 03-38 and 03-39. Artesian pore pressures were observed in several boreholes, including the monitoring wells installed in boreholes BGC03-12 and 03-14. The ground conditions observed in each borehole are discussed in the remainder of this section and detailed on the borehole logs in Appendix II.

The geotechnical drilling completed in the Surface Cell in 2002 and 2003 can be divided into four separate areas, as shown on Figure 7:

- **Area 1** – located near the historical location of the deepest water storage on the Surface Cell.
- **Area 2** – located immediately upstream of the West Twin Dike between the dike and the deep water storage pond.
- **Area 3** – located along north of Areas 1 and 2 between the West Twin Dike and the retained pond.
- **Area 4** – located along the west side of the Surface Cell between the two retained ponds.

The following sections describe the ground conditions encountered during the geotechnical drilling in each of the four areas:

<u>Area 1</u>

The location of Area 1 is shown on Figure 7. This area was typically the historical location of the storage pond. A total of ten boreholes (BGC02-01, 02-02, 02-03, 02-04, 02–05, 02-07, 02-12, 03-11, 03-35 and 03-36) were drilled in this area. Prior to discussing the results of the drilling conducted in this area, it is important to review the following facts regarding the history of the tailings deposition at this location.

- The storage pond was filled with tailings in the summer of 2002 prior to the geotechnical drilling conducted in September 2002.
- Prior to 2002, tailings in this area generally had a water cover of at least 6 m.
- The southern portion of this area is located near the original shoreline of West Twin Lake.
- The original bathymetry indicated that the water depth increased to the northern portion of this area. Therefore, a thicker sequence of tailings would be expected in the northern portion of this area.

The following is a list of the principal observations made during the drilling completed in this area:

- In September 2002, the ground conditions in this area were generally thawed from surface to a depth ranging between 10.5 and 24.7 m, increasing in thickness to the north portion of the area.

- The boreholes drilled in September 2003 (03-11, 03-35 and 03-36) encountered frozen tailings from surface to a depth of between 4.5 and 4.9 m overlying thawed tailings. This indicates permafrost aggradation had occurred into the tailings.
- Boreholes 02-01, 02-02 and 02-03 encountered 1.5 to 4.0 m of frozen tailings overlying the bedrock or lake bed sediments at the bottom of each borehole. This indicates that some cooling of the tailings from underlying bedrock has occurred at this location. This is likely related to the fact the bedrock in this area was above the original shoreline of the lake.
- Borehole BGC03-11 encountered ice between 4.3 and 6.1 m.
- Flowing sands (lake bed sediments) were encountered in borehole BGC02-07 between a depth of 24.4 and 24.7 m. This indicates high pore pressures at depth.

Thermistors were installed in boreholes BGC02-01, 02-02, 02-03 and 03-11. The thermistors in boreholes BGC02-01 and 02-02 were damaged in late 2002 and are no longer operational. A thermocouple was installed in boreholes BGC02-12 and 03-36. Standpipe piezometers were installed in boreholes BGC02-04 and 02-05 and a vibrating wire piezometer was installed in borehole BGC03-35.

The flowing sands encountered in borehole BGC02-07 prevented instrumentation from being installed in the borehole. Borehole BGC02-07 was attempted two additional times in areas within 5 m of the original 02–07 location. Each attempt had similar results with no instrumentation being installed.

Area 2

The location of Area 2 is shown on Figure 7. This area is located between the historical location of the water storage pond and the West Twin Dike. A total of eight boreholes (BGC02-06, 02-11, 03-01, 03-02, 03-12, 03-13, 03-14, 03-15, 03-33, 03-34 and TC #35) were drilled in this area. Prior to discussing the results of the drilling conducted in this area, it is important to review the following facts regarding the history of the tailings deposition at this location.

- Prior to the construction of the West Twin Dike, tailings deposited in this area had a shallow water cover.
- After construction of the West Twin Dike, tailings deposited in this area generally had a shallow water cover or were aerially exposed due to its proximity to the West Twin Dike.

The following is a list of the principal observations made during the drilling completed in this area:

- Boreholes BGC02-06, 02-11, 03-01, 03-02, 03-13 and 03-14 encountered 8 to 11 m of frozen tailings overlying thawed tailings.
- Artesian pore pressures were observed in the thawed tailings encountered in boreholes 03-01 and 03-02.

- Borehole BGC03-15, the borehole closest to the dike, encountered frozen ground throughout most of borehole profile. A small zone between 13.4 and 14 m exhibited artesian pore pressures and thawed ground conditions.
- BGC03-34 was drilled to a depth of 13.7 m and was terminated in frozen tailings.
- BGC03-33 was drilled to a depth of 22.9 m and encountered thawed tailings at a depth of 18.3 m and lake bed sediments at a depth of 22.4 m.

Thermistors were installed in boreholes BGC02-06, 03-13, 03-15, 03-33 and 03-34. Thermocouples were installed in boreholes BGC02-11 and TC 35. The thermistor installed in borehole BGC02-06 was damaged in late 2002 and is no longer operational. A standpipe piezometer with heat trace tape was installed in borehole BGC03-14. A vibrating wire piezometer was installed in BGC03-12 and 03-14 during a subsequent investigation in September 2003 to provide piezometric monitoring capabilities during winter months. The artesian pore pressures encountered in boreholes BGC03-01 and 03-02, coupled with a malfunctioning water pump on the drill rig, resulted in difficult drilling and prevented installation of any instrumentation in these boreholes. Considering the proximity of thermistors BGC03-33 and 03-34 to each other, monitoring results from these instruments are thought to reflect a continuous geothermal profile between the ground surface and 22.9 m depth.

Area 3

The location of Area 3 is shown on Figure 7. This area is located north of the historical location of the water storage pond, between the West Twin Dike and the retained pond. A total of ten boreholes (02-13, 03-07, 03-08, 03-09, 03-10, 03-31, 03-32 and 03-37) were drilled in this area. This area was generally covered in shallow water cover or aerially exposed during tailings deposition after the construction of the West Twin Dike. This is due to its proximity to the dike and the on-land tailings discharge point in the northwest corner of the Surface Cell.

The following is a list of the principal observations made during the drilling completed in this area:

- Boreholes BGC02-13, 03-09 and 03-10 encountered frozen tailings from surface to a depth of approximately 11 m.
- Thawed tailings were generally encountered below 11 m.
- Occasional occurrences of artesian pore pressures in the thawed tailings below 11 m were observed.
- Boreholes BGC03-31 and 03-32 encountered frozen tailings and ice to a slightly deeper depth, between 13.7 and 17.7 m, and thawed tailings below. The boreholes were terminated in thawed tailings.
- Borehole BGC03-07 was drilled near the north end of the dike and encountered frozen tailings and ice lenses. A zone of tailings between 19.5 and 22.5 m was inferred to exhibit artesian pore pressures and thawed conditions based on response of the drilling equipment while advancing the borehole.

- Borehole BGC03-08 encountered 6.4 m of frozen tailings before encountering a piece of metal debris, at which point a decision was made to terminate the borehole.
- Borehole BGC03-37 was drilled into the shale pad located near the north abutment of the West Twin Dike to a depth of approximately 7.3 m. The borehole encountered approximately 2.7 m of shale fill overlying frozen tailings to a depth of 7.3 m.

Thermistors were installed in boreholes BGC03-07, 03-09, 03-10 and 03-37 and a thermocouple was installed in borehole BGC02-13. Vibrating wire piezometers have been installed in BGC03-31 and 03-32 to provide piezometric monitoring capabilities during winter months.

Area 4

The location of Area 4 is shown on Figure 7. This area is located on the west side of the Surface Cell between the two retained ponds. A total of five boreholes (BGC03-20, 03-21, 03-38, 03-39 and BH 10 (TC #37)) were drilled in this area. Prior to discussing the results of the drilling conducted in this area, the following facts are important:

- Tailings deposited in the northern portion of this area after construction of the West Twin Dike were generally covered in shallow water cover or aerially exposed. This is due to the proximity of this area to the on-land tailings discharge point in the northwest corner of the West Twin Dike.
- Tailings deposited in the southern portion of this area after construction of the West Twin Dike generally had a water cover.
- The north and south extremes of this area are located over the original shoreline of West Twin Lake.

The following is a list of the principal observations made during the drilling completed in this area:

- Borehole BGC03-20, located about 175 m west of the former water storage pond, encountered approximately 11.9 m of frozen tailings and ice layers from surface.
- Below the frozen tailings, thawed tailings were encountered to a depth of approximately 19 m. Artesian pore pressures were encountered in this borehole at a depth of approximately 14 m.
- Borehole BGC03-21 encountered frozen tailings and ice layers from surface to a depth of approximately 16 m at which point the shale surfacing layer of the original east/west causeway was encountered.
- Borehole BGC03-38 encountered frozen tailings and ice from surface to a depth of approximately 13.7 m where frozen till was encountered.
- Borehole BGC03-39 encountered approximately 1 m of shale at surface overlying frozen tailings and ice to a depth of 10.6 m where till was encountered.
- Borehole BH-10 (TC37) encountered tailings to a depth of 30 m. No core was recovered between 9 and 11 m and 24 and 27 m.

Thermistors were installed in boreholes BGC03-20 and 03-21 and thermocouples were installed in BGC03-38, 03-39 and BH-10 (TC37).

4.1.2.2 Toe of West Twin Dike

As discussed in Section 3.0, a tailings beach was formed at the toe of the West Twin Dike in the Test Cell and Reservoir during tailings deposition in 2001 and 2002. A total of four boreholes (BGC02-08, 02-09, 03-18 and 03-19) were drilled in this area.

In general, each borehole drilled at the toe of the West Twin Dike encountered frozen conditions throughout the entire depth of the borehole. A frozen layer of shale was encountered overlying frozen tailings and lake bed sediments. Frost shattered bedrock was encountered in two of the boreholes at a depth of approximately 7 m. Visible ice lenses were observed in the tailings in some of the boreholes.

Borehole BGC02-08 was drilled near the south end of the West Twin Dike. Frozen shale was encountered to a depth of 0.5 m. Frozen tailings were encountered between 0.5 and 4.0 m depth. The frozen tailings were not observed to contain visible ice. Lake bed sediments and frost shattered bedrock were encountered between 4.0 and 7.9 m.

Borehole BGC03-18 was drilled near the south end of the West Twin Dike. This borehole was drilled approximately 20 m closer to the Reservoir than borehole BGC02-08. Frozen shale was encountered to a depth of 0.5 m. Frozen tailings were encountered between 0.5 and 6.7 m depth. A layer of lake bed sediments was encountered between 6.7 and 7 m depth. Frost shattered rock was encountered below the lake bed sediments to a depth of 8.5 m. Visible ice was present in some of the tailings samples as lenses.

Borehole BGC03-19 was drilled near the middle of the West Twin Dike. Frozen shale was encountered to a depth of 0.8 m. Frozen tailings were encountered between 0.8 and 9.4 m. A layer of lake bed sediments was encountered between 9.4 and 9.8 m. No bedrock was encountered in this borehole. Visible ice was present in some of the tailings samples as lenses.

Borehole BGC02–10 was drilled near the north end of the West Twin Dike. Frozen shale was encountered to a depth of 0.5 m. Frozen tailings were encountered between 0.5 and 5.8 m. Ice was present in some of the tailings samples as lenses. Lake bed sediments and frost shattered bedrock were not observed in this borehole due to sampling difficulties. However, drill rod chatter was observed between 5.8 and 8.7 m possibly indicating the presence of gravel or frost shattered bedrock.

4.1.2.3 Test Cell Dike

As discussed in Section 3.0, a shale dike was constructed in the Reservoir in 2001 and 2002. The dike was constructed using two tailings causeways that had formed in the Reservoir. Two boreholes (BGC02-09 and 03-22) were drilled in this area.

In general, the boreholes encountered frozen shale (dike construction material) to a depth of between overlying frozen tailings overlying thawed tailings. Lake bed sediments were encountered only in borehole BGC02-09. No visible ice was observed in the frozen tailings samples.

Borehole BGC02-09 was drilled approximately 175 m from the toe of the West Twin Dike. The borehole encountered approximately 5 m of shale (dike construction material) overlying frozen tailings to a depth of 14.3 m. Below 14.3 m, thawed tailings were inferred, based on the response of the drill equipment while advancing the borehole, to a depth of 29.8 m. Lake bed sediments were encountered between 29.8 and 30.0 m. No bedrock was encountered in this borehole. No visible ice was observed in the frozen tailings samples collected from this borehole.

Borehole BGC03-22 was drilled approximately 75 m east of borehole BGC02-09. The borehole encountered approximately 4 m of shale (dike construction material) overlying frozen tailings to a depth of approximately 18 m. Below 18 m, thawed tailings were encountered to a depth of 27.4 m. Artesian pore pressures were observed at approximately 26 m. Neither lake bed sediments nor bedrock were encountered in this borehole. No visible ice was observed in the frozen tailings samples collected from this borehole.

4.2 Lab Testing

Various samples collected from the boreholes were selected for laboratory testing. Grain size, moisture content and bulk density testing were performed at the mine laboratory. Additional samples were then sent to Almor Testing Services Ltd. and EBA Engineering Consultants Ltd. for further testing. The test results were used to confirm the field classification of the soils. The laboratory testing results are summarized in Table 4 and included on the borehole logs in Appendix I. Data sheets obtained from the respective laboratories are included in Appendix III.

4.2.1 Soil Index Testing

Tailings

Approximately 128 samples of the tailings from the Surface Cell, Test Cell Dike and the toe of the West Twin Dike were selected for laboratory index testing.

The grain size distribution of 120 samples of tailings from the WTDA was calculated and the results are illustrated on Figure 8. Ten tailings samples were tested twice, with and without hydrometer testing, resulting in the 130 grain size distributions illustrated on Figure 8. The test results indicate the composition of the tailings varies between primarily (98.9%) sand and primarily (95.7%) silt. Clay size particles were observed in the tailings samples to a maximum of 3.0%. The range in observed particle size is likely related to segregation of particles as they settle out on the tailings beach and also under water.

The specific gravity (G_s) of 9 samples of tailings from the Surface Cell was derived according to ASTM Standard D422. Using this method, the specific gravity was observed to range between 3.89 and 4.46. The average specific gravity was calculated to be 4.08. This is lower than the previous estimate of the specific gravity ($G_s = 4.6$) of the tailings by Golder (1999) which was based on the specific gravity of the individual elements within the tailings.

The moisture content of 114 samples of tailings from the WTDA was calculated and the results are illustrated on Figure 9. This figure indicates that the moisture content ranges between 4.9 and 70%. The average moisture content of the samples not containing visible ice was calculated to be 16.5%. The relationship between moisture content and grain size distribution is illustrated on Figure 10. This figure indicates that the moisture content increases with increasing fines content.

The frozen bulk density of 33 samples of tailings from the WTDA was calculated and the results are illustrated on Figure 11. The frozen bulk density was observed to range between 2128 and 3526 kg/m^3 (average 2800 kg/m^3). The lowest frozen bulk densities correspond to the samples with the highest amount of ice content.

In order to evaluate the degree of saturation of the tailings, the specific gravity values derived from the grain size testing and the calculated frozen bulk densities were used to approximate the void ratio. Using the average moisture content of 16.5%, the average frozen bulk density of 2800 kg/m^3 and the maximum and minimum specific gravities, 3.89 and 4.46, the void ratio was calculated to range between 0.6 and 0.9. This is similar to the range of 0.6 to 1.0 noted for lead-zinc tailings by Vick (1983). The range of void ratios and specific gravities was then used to determine the water content required for saturation which was calculated to range between 16 and 19%. Considering that 58% of the moisture content values were greater that 16%, it is apparent that the majority of the tailings in the Surface Cell and Test Cell are saturated.
A composite sample of tailings from the Surface Cell was sent to EBA Engineering Consultants Ltd. in Edmonton, AB for thermal properties testing. The scope of work included the following tasks:

1. Determine the thermal conductivity in both frozen and unfrozen states;
2. Determine the relationship between unfrozen water content and freezing temperature; and,

3. Conduct index tests to measure the frozen bulk density, water content, particle size distribution and specific gravity of the composite sample.

A letter report from EBA, dated September 12, 2003, details the methodology and results of the testing. This letter is included in Appendix V.
The thermal conductivity was measured using the thermal needle probe method in accordance with the ASTM test procedure D5334-92. The unfrozen water content curve was determined using the Time Domain Reflectometry technique. The sample was blended and the resulting grain size distribution was observed to consist of 57% silt, 42% sand and 1% clay sized particles. The sample was moisture conditioned to a gravimetric water content of 15.5%. The results of the testing indicate that the thermal conductivity of the tailings is approximately 1.9 W/(m·°C) at room temperature and 3.2 W/(m·°C) at -15°C. The volumetric unfrozen water content of the sample ranged between 37.2% at 0°C to 4.9% at -11.9°C. The frozen bulk density was measured to be 2730 kg/m^3 and the specific gravity was measured to be 3.92.

Lake Bed Sediments

Approximately 13 samples of the lake bed sediments from the Surface Cell, Test Cell Dike and toe of the West Twin Dike were selected for laboratory testing.

The results of the grain size analyses of 10 samples of lake bed sediments (11 grain size distributions, one sample tested twice) indicate that the samples are composed of mainly sand and gravel (average composition of 87.5% coarse grained material). Hydrometer testing conducted on 2 samples of lake bed sediments indicates that the clay contents of 4.1 and 7.1%.

The results of the moisture content testing on 10 samples of lake bed sediments indicates a range between a low value of 9.0%, a high value of 50.8% and an average value of 22.5%.

Bedrock

Rock core was recovered from several of the boreholes drilled in the Surface Cell. The core was logged for lithology, Rock Quality Designation (RQD), degree of weathering and strength index. Overall, the bedrock was observed to be slightly weathered, strong to medium strong dolostone with RQD values ranging between 8% and 73%.

Five of the dolostone core samples were selected from those recovered during the September, 2002 drilling investigation for point load testing. The samples were sent to EBA Engineering Consultants Ltd. in Calgary, AB for testing. The samples were tested both axially and diametrally. The results of this testing indicates that the normalized point load index of the dolostone bedrock in the diametral direction ranged between 4.6 and 5.7 MPa, with an average of 5.2 MPa. When tested axially, the normalized point load index was observed to range between 8.6 and 10.4 MPa, with an average of 9.5 MPa. Using the conversion between point load index and unconfined compressive strength suggested by Hoek et al. (1981), the average diametral and axial unconfined compressive strength is calculated to be approximately 125 and 228 MPa, respectively. The laboratory point load test data is included in Appendix IV.

4.2.2 Water Quality Testing

In order to obtain groundwater samples from the talik, four monitoring wells were installed during the geotechnical investigation of the Surface Cell in 2002 and 2003. Boreholes BGC02-04, 02-05, 03-12 and 03-14 were drilled within the tailings and a standpipe piezometer, screened in the talik, was installed in each of the boreholes. Wells BGC02-04 and 02-05 were developed using a Watera pump system and a 1.9 cm diameter disposable bailer. Wells 03-12 and 03-14 displayed artesian conditions during drilling and were allowed to develop while flowing.

Prior to discussing the results of the sampling program, it should be noted that the drilling procedure required the use of chilled brine as a drilling fluid. The chilled brine provided a means of retrieving frozen core samples where possible, and helped maintain a stable borehole within the frozen zone. This approach was commonly used at the mine site while operating. The preparation of brine for the 2003 drill program generally followed these procedures. For the 2003 drill program, the brine was prepared by mixing water collected from the town water supply (i.e. East Twin Lake) with calcium chloride in an open agitation tank located near the Industrial Complex.

4.2.2.1 Field Parameters

Monitoring wells BGC02-04 and 02-05 were sampled soon after installation in September 2002. Monitoring wells BGC03-12 and 03-14 have been sampled twice since installation, once in May 2003 and once in August 2003. Conductivity and pH values were obtained from the samples collected in September 2002 and August 2003 using the pH/conductivity meter in the mine laboratory. The data obtained from the pH and conductivity testing is summarised in Table 5. The data collected in September 2002 is considered not representative of groundwater quality due to presence of chilled brine in the sample water. The data collected in August 2003 indicates that the pore water is basic and slightly conductive. Table 5 also contains the pH and conductivity values obtained from samples of the seepage water emitted from the dike in 1999 and the water samples collected from monitoring station 159-2 in 2001. Seepage water was collected from the dike face from two sources in 1999, one near TC #13 and one near TC #18. Water quality monitoring station 159-2 is located at the Reclaim Pump House in the Reservoir. The measured conductivities from all sources were observed to be similar. The measured pH levels of the pore water samples collected in 2003 were observed to be higher than the pH of the seepage water collected in 1999, but within the range of the pH levels recorded from samples collected at station 159-2 in 2001.

4.2.2.2 Water Quality Results

In May 2003, water samples collected from wells BGC03-12 and 03-14 and ice core samples recovered from boreholes BGC03-06, 03-20 and 03-21 were sent to Accutest Laboratories Ltd. in Ottawa, ON for analytical testing. Additional water samples collected from wells BGC03-12 and 03-14 in August 2003 were sent to Maxxam Analytics Inc. in Mississauga, ON for analytical testing. The lab data sheets are included in Appendix VI.

The following observations can be drawn from the groundwater quality results:

1. The initial (May 2003) samples from boreholes BGC03-12 and BGC03-14 contained elevated chloride concentration as compared to the August 203 samples (2820/10300 mg/L in May versus 413/1380 mg/L in August).
2. There is a general decrease in concentrations of many (total) parameters from May to August 2003 including SO_4,, Ca, Cu, Fe, Pb and Zn (Zn in BGC03-12 only).
3. Many parameter concentrations were substantially less in dissolved form than in total form in August 2003 including Cu, Fe, Pb and Zn.
4. Many parameter concentrations were substantially greater in ice than in water in May 2003 including Cu, Fe, Pb and Zn; SO_4 did not follow this trend and was substantially less in ice than in water.

The concentrations of several key ARD indicators in water and ice for all sample results from May and August 2003 are summarized in Table 6.

4.2.2.3 Summary of Water Quality Testing

In general, the initial sample results from any newly installed groundwater well should be evaluated in the context of possible residual effects of the drilling procedures, even in light of the purging of substantial well volumes during well development. In this case, it appears likely that the May 2003 samples were affected by the use of chilled brine in the drilling procedure as evidenced primarily by substantially elevated concentrations of chloride and calcium and also by elevated concentrations of some metals. The procedures for preparation of the brine would allow for the introduction not only of chloride and calcium but also metals (via possible contamination of the open agitation and transport tanks) into the groundwater. Therefore, the May 2003 results for boreholes BGC03-12 and 03-14 should be viewed as not representative of groundwater quality because of residual effects of the drilling procedure.

Concentrations of dissolved metals are typically lower than total metals in groundwater samples. This is because of the downhole agitation that typically occurs during purging and sampling of groundwater wells, which can mobilize suspended solids from the annulus around the screened well intake or within the bottom of the well. Therefore, the August 2003 results for boreholes BGC03-12 and 03-14 are as expected with regard to the difference between dissolved and total metal concentrations.

The generally higher metal concentrations observed in ice as compared to water could be suggestive of the effects of an unavoidable minor amount of tailings that were entrained into the ice sampled and, thereby, incorporated into the water sample. Therefore, the May 2003 results for ice should be viewed as not representative of groundwater or porewater quality because of the entrained tailings in the sample.

The groundwater quality data collected to date from the 2003 boreholes is preliminary and must be supplemented over time with additional sampling results before conclusions can be confidently drawn. Nonetheless, several overall preliminary conclusions can be drawn from the data that is available as follows:

1. Thawed groundwater is present within the tailings under artesian conditions in some locations.
2. Groundwater quality is neutral to alkaline due, presumably, to the residual effects of lime deposited with the tailings (i.e., tailings slurry would typically have pH of approximately 10 as a result of the need for alkaline pH for flotation of mineral concentrates).
3. Tailings groundwater quality shows no indications of the occurrence of acid rock drainage in the tailings (i.e., dissolved metal concentrations are generally low), which is attributed to the alkaline pH and rapid freezing and/or saturation of the tailings upon deposition.

4.3 Results of Piezometric Monitoring

The monitoring wells and vibrating wire piezometers installed in 2003, BGC03-12, 03-14, 03-31, 03-32 and 03-35 have been monitored to determine static water levels several times since installation. Graphical plots illustrating the results of the static water level monitoring have been included in Appendix VII. All piezometric monitoring instruments, with the exception of BGC03-35, indicate artesian piezometric conditions at depth. The pore pressures recorded from instruments 03-12, 03-12, 03-31 and 03-32 indicate a piezometric elevation approximately 0.5 to 2.0 m above ground surface. The pore pressures recorded from instrument 03-35, located approximately 175 m upstream of the crest of the dike, indicates a piezometric elevation of approximately 1.5 m below ground surface. Monitoring results recorded since May 2003 indicate that the piezometric levels fluctuate with time. Levels were initially highest during the spring. Reduced levels were recorded during summer months and increased levels have been observed during the winter months.

Recovery tests were performed in monitoring wells BGC03-12 and 03-14 in May, 2003. The tests measured the change in water level with time, following the removal of the heat trace wire. Graphical plots illustrating the results of the recovery tests have been included in Appendix VII. Based on these tests, the calculated hydraulic conductivity of the tailings is in the range of $1x10^{-6}$ to $1x10^{-7}$ m/s.