founded on the first stage dike and partially founded on the tailings in the Test Cell. The staged construction resulted in the formation of a bench on the Reservoir side of the dike.
Excess water from the Surface Cell is transferred to the Reservoir by pumping or a siphon system that controls water levels. The Reservoir and a final Polishing Pond are separated by a causeway and stop log structure, which controls the water level in the polishing pond. Water from the polishing pond is then discharged to Twin Lakes Creek through the West Twin Outlet Structure, a 3 to 5 m high earth fill dam with a valve controlled, concrete lined spillway. Excess water from the WTDA is discharged to the environment via the West Twin Outlet Structure between July and September of each year.

A baffle dike is located immediately upstream of the Polishing Pond inlet, constructed of end-dumped rock fill. The baffle dike was constructed to act as a flow-through structure that would enhance retention and improve water quality. This was constructed prior to 1990 to address marginal water quality issues, but became redundant after the construction of the Surface Cell and was breached. The crest of the baffle is approximately 372 m asl.

3.2 Historical Tailings Deposition Practices

Tailings were initially deposited sub-aqueously into West Twin Lake beginning in 1977. Based on the known mine reserves at the time, West Twin Lake had sufficient tailings storage capacity for the life of the mine. Mine reserves, however, continued to expand each year and by the mid 1980's, it was apparent that continued production would exceed the storage capacity of West Twin Lake. In 1988, an approval was received from the NWT Water Board to begin surface deposition of tailings at Nanisivik. To accommodate this, West Twin Lake was divided into two sections using an earthen dike. The dike was constructed using a north/south trending causeway that was developed by beaching of tailings in the lake as a foundation. The eastern portion of the lake, the Reservoir, retained its original lake level and was used as a stand-by when surface disposal was not practical (i.e. during annual dike construction periods). The western part of the lake, the Surface Cell, became the main deposition area for the tailings and accommodated sub-aerial tailings.

On-land deposition of tailings in the Surface Cell commenced on August 27, 1990. The tailings were mainly discharged from the north-west corner of the Surface Cell. The full capacity level of the Surface Cell was raised to an elevation of 374 m with the construction of the initial lift of the West Twin Dike in 1991. Tailings discharge in the Surface Cell continued throughout the 1990's with annual (except for 1994) raises of the West Twin Dike in 2 m increments. Tailings continued to be discharged mainly from the north-west corner of the Surface Cell with a deeper section of the pond in the southeast corner for water reclamation and mineral processing purposes.

Tailings discharge practices were amended during the mid-1990's to promote stratification of sediments by discharging from the perimeter of the Surface Cell. Excess supernatant pond water continued to be collected in a depression situated upstream from the south end of the dike. This water was siphoned to the Reservoir. The ultimate raise of the dike, to a nominal elevation of 388 m, was completed in 1999 and tailings continued to be placed in the Surface Cell until the mine closed in September 2002.

Figure 6 illustrates how the tailings level in the Surface Cell evolved over time, with the original lake bottom elevations shown, based on bathymetry maps produced by the mine. As can be seen, an east/west causeway had become fully exposed in the Surface Cell by 1982. Although not shown on the section in Figure 6, a north/south tailings causeway had also developed within the lake at the same time. This north/south causeway was eventually used as the foundation for the West Twin Dike. Tailings continued to be deposited sub-aqueously into the Surface Cell until 1991, at which the first lift of the West Twin Dike was constructed. Construction of the initial lift and subsequent annual raises of the West Twin Dike allowed for sub-aerial and sub-aqueous deposition of tailings to continue throughout the 1990's. Tailings were generally discharged from an on-land deposition point near the north-west corner of the Surface Cell. Tailings discharge was also conducted along the upstream face of the West Twin Dike sealing the dike face and providing the foundation for the next raise of the dike. Surface water was generally directed to the south-east portion of the Surface Cell where a depression was located, referred to in the remainder of the report as the "deep water storage pond". In total, it is estimated that 6.5 million m^3 of tailings were deposited into the Surface Cell between 1978 and 2002.

Figure 7 illustrates the evolution of the tailings level in the Reservoir and Test Cell over time. Tailings were deposited sub-aqueously into the Reservoir beginning in 1976. The discharge of tailings generally took place near the current location of the West Twin Dike resulting in the aggradation of the tailings deposit in a south-easterly direction into the Reservoir. Tailings deposition along an east-west trending line from the centre of the West Twin Dike resulted in exposure of a tailings causeway in the Reservoir by 1988. This causeway eventually became the foundation for the east/west arm of the Test Cell Dike. Tailings deposition along a northwest-southeast trending line resulted in a second tailings causeway near the reclaim water pumphouse, which was exposed by 1992. This causeway eventually became the foundation for the north/south arm of the Test Cell Dike. The majority of the tailings discharge activities in the 1990's occurred in the Surface Cell. The Test Cell Dike was constructed in 2000 and 2001, increasing the storage capacity of the Test Cell, thereby allowing for the additional placement of tailings into the Test Cell. Deposition of tailings at the toe of the West Twin Dike in 2000 resulted in aerial exposure of tailings in the Reservoir and Test Cell. In total, it is estimated that 3.5 million m^3 of tailings have been deposited into the Reservoir and Test Cell since 1978.

4.0 CHARACTERIZATION OF WEST TWIN DISPOSAL AREA TAILINGS

The geotechnical, geothermal and geochemical properties of the WTDA tailings have been assessed during several studies completed for Nanisivik Mine throughout the operational history of the WTDA. The following sections summarize the results of those studies.

4.1 Geotechnical Characterization

4.1.1 Geotechnical Investigations

Several geotechnical investigations of the WTDA have been conducted over the operational history of the mine. Approximately 50 geothermal monitoring instruments were installed during investigations prior to 2002. In 2002 and 2003, a comprehensive investigation of the WTDA tailings was undertaken by BGC in which 36 geothermal monitoring instruments were installed. The following is a chronological history of the significant geotechnical investigations conducted at the WTDA:

- 1989/1990 – Geotechnical investigations of the causeways that had developed in West Twin Lake to assess permafrost aggradation. Thermocouples were installed in five boreholes.
- 1992 – Geotechnical investigations of WTDA including drilling and installation of thermocouples and frost gauges from the 376 m bench of the West Twin 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 West Twin Dike.
- 1997 – Geotechnical drilling and installation of thermocouples at various locations of the West Twin 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.
- 2002 and 2003 – Geotechnical drilling and installation of geothermal and piezometric monitoring instruments at the WTDA.

Although the results of the investigations prior to 2002 were considered in the overall characterization of the WTDA tailings deposit, the following sections focus on the results of the investigations undertaken in 2002 and 2003.

4.1.2 Ground Conditions

In 2002 and 2003, a total of 44 boreholes were drilled into the tailings at the Surface Cell, Test Cell Dike and at the toe of the West Twin Dike. Limited access due to water cover prevented the drilling of boreholes in the Test Cell area. The approximate location of each borehole is illustrated on Figure 8 and a summary of the borehole information is provided in Table 3. The drilling was completed utilizing the Atlas Copco 262 diamond drill available at the mine site. Drilling was conducted utilizing chilled brine and samples were recovered in a double tube core barrel. Instrumentation installed in the boreholes includes thermistors, thermocouples, vibrating wire piezometers and standpipe piezometers. For borehole logs and further discussion regarding the drilling method, types of instrumentation installed and installation procedures, refer to the Taliks Assessment Report (Water License Part G, Item 5).

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.

The geotechnical drilling completed in the Surface Cell in 2002 and 2003 can be divided into four distinct areas, as shown on Figure 8:

- **Area 1** – located near the historical location of the deep water storage pond 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 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.

Area 1

Area 1 was typically used as the historical location of the deep water 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

Area 2 is located between the historical location of the deep 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

Area 3 is located north of the historical location of the deep 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

Area 4 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.

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.

4.1.2.3 Test Cell Dike

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

The boreholes encountered frozen shale (dike construction material) 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.

4.1.3 Lab Testing

Various samples of tailings 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.

4.1.3.1 Grain Size Distribution

The grain size distribution of 120 samples of tailings from the WTDA was determined and the results are illustrated on Figure 9. Ten tailings samples were tested twice, with and without hydrometer testing, resulting in the 130 grain size distributions illustrated on Figure 9. The test results indicate the composition of the tailings varies between primarily sand (98.9%) and primarily silt (95.7%). 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.

4.1.3.2 Specific Gravity

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.

4.1.3.3 Frozen Bulk Density

The frozen bulk density of 33 samples of tailings from the WTDA was calculated and the results are illustrated on Figure 10. 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.

4.1.3.4 Moisture Content and Saturation

The moisture content of 114 samples of tailings from the WTDA was calculated and the results are illustrated on Figure 11. 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 12. This figure indicates that the moisture content increases with increasing fines 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.

4.1.3.5 Thermal Conductivity

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.

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.

4.1.4 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 Waterra 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 free 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 tank located near the Industrial Complex. The use of this brine likely had a significant impact on the water quality results obtained, as discussed in later sections.

4.1.4.1 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 not considered 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 discharged 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.

4.1.4.2 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 II.

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 2003 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 indicators in water and ice for all sample results from May and August 2003 are summarized in Table 6.

4.1.4.3 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 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 will be supplemented over time with additional sampling results. 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 did 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.

4.1.5 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 III. 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 III. Based on these tests, the calculated hydraulic conductivity of the tailings is in the range of 1×10^{-6} to 1×10^{-7} m/s.

4.1.6 Freezing Point Depression

The conductivity of the water samples was used to estimate the freezing point depression of the pore water within the tailings. This was done by using the conductivity values to estimate the amount of soluble salts present in the water sample. Using a conductivity of 6230 μS, and the approximate correlation of 1 part per thousand (ppt) salinity equating to approximately 1560 μS conductivity, the salinity was calculated to be approximately 4 ppt. The freezing point depression was determined to be approximately 0.2°C using the relationship between salinity and freezing point depression developed by Ono (1966).

Freezing point depression of talik pore water was further assessed by comparing ground conditions observed during drilling with measured ground temperatures from thermistors installed within the Surface Cell talik. This approach has been mentioned in McKay (1998). This method indicates that the freezing point depression of the talik pore water may be as much as -1.2°C. The remainder of this section discusses the information supporting this assessment of freezing point depression.

The supporting information is best examined by considering firstly the information collected proximal to the West Twin Dike and secondly, the information collected proximal to the Surface Cell pond.

<u>Proximal to the West Twin Dike</u>

The information from this area is derived from thermistor BGC03-13 and 03-09 installed into the Surface Cell talik and the thermistors incorporated into the vibrating wire piezometers at BGC03-12, 03-14, 03-31 and 03-32.

- The vibrating wire piezometers within the Surface Cell talik contain an internal thermistor to measure the temperature at the tip. Four vibrating wire piezometers are installed at locations proximal to the West Twin Dike (BGC03-12, 03-14, 03-31 and 03-32). These instruments indicate water temperatures of approximately -0.4° to -0.5°C in the areas where thawed conditions were observed in the Surface Cell talik.
- A thawed zone was encountered in borehole BGC03-13 between 11 and 14 m. Subsequent geothermal monitoring data collected from a thermistor installed in this zone indicates a ground temperature of approximately -0.4°C.
- A thawed zone was encountered in borehole BGC03-09 between 11 and 27 m. Subsequent geothermal monitoring data collected from a thermistor installed in this zone indicates ground temperatures between -0.1° and -0.2°C.

Proximal to the Retained Pond

- The vibrating wire piezometer installed in the Surface Cell talik proximal to the retained pond (BGC03-35) indicates water temperatures of approximately -1.2°C at the tip where thawed conditions had been encountered during drilling.
- A thawed zone and artesian pressures were encountered in borehole BGC03-11 between 11 and 18 m below ground surface. Subsequent geothermal monitoring data collected from thermistors installed in this zone indicates ground temperatures between -0.2° and -0.9°C.
- A thawed zone and artesian pressures were encountered in borehole BGC03-09 between 11 and 27 m below ground surface. Subsequent geothermal monitoring data collected from thermistors installed in this zone indicates ground temperatures between -0.1° and -0.7°C.

This information would suggest that the amount of freezing point depression increases with distance away from the West Twin Dike. Alternatively, the magnitude of freezing point depression increases in magnitude with distance from the freezing front. This is likely related to pore water expulsion, solute rejection and cryoconcentration at the freezing front.

4.2 Geothermal Characterization

Regular monitoring of the geothermal instruments, both pre- and post-2002/2003 geotechnical investigations, has been ongoing. The results of the monitoring are illustrated graphically on the plots included in Appendix IV. The following sections review the results of the monitoring data collected from geothermal instruments located in the Surface Cell, within the West Twin Dike, at the toe of the West Twin Dike and within the Test Cell Dike.

4.2.1 Surface Cell

The data collected from the geothermal monitoring instruments verifies the observations made during the 2002 and 2003 field investigations that many areas of the Surface Cell contain thawed tailings. As discussed in Section 4.1.2.1, the Surface Cell boreholes and instruments can be divided into four main areas. The following sections review the geothermal information collected from each area.

Area 1

Area 1 is located approximately where the historical location of the former Surface Cell deep water storage pond was located. The depression was infilled with tailings in the summer of 2002. The geothermal monitoring instruments located in Area 1 include:

- thermistors BGC02-01, 02-02, 02-03, 03-11; and,
- thermocouples 02-12 and 03-36.