Environment Canada 1998. Climate change impacts on permafrost engineering design. Published by the Environmental Adaptation Research Group, AES, Environment Canada. Funded by the Panel on Energy Research and Development (PERD). March 1998, 42 pages.

Fell, R., MacGregor, P. and Stapeldon, D. 1992. Geotechnical Engineering of Embankment Dams. Rotterdam, Netherlands: A.A. Balkema.

Fetter, C.W. 1994. Applied Hydrogeology, Third Edition. Englewood Cliffs, N.J.: Prentice-Hall.

Gartner Lee Ltd. 2001. Polaris Mine – Polaris Landfill Closure Report. Submitted to Cominco Ltd., March 2001.

Gartner Lee Ltd. 2002. Nanisivik Mine Closure and Reclamation Plan. Submitted to Nunavut Water Board, February 2002.

Golder Associates 1998. 1998 Geotechnical Inspection of Waste Containment Dikes, Nanisivik Mine, Baffin Island, N.W.T. Report No. 982-2432.5100. Submitted to Nanisivik Mine, a division of CanZinco Ltd., October, 1998.

Golder Associates 1999. Geotechnical Assessment of Cover Materials for West Twin Disposal Area, Nanisivik Mine, Baffin Island, N.W.T. Report No. 982-2432.5200. Submitted to Nanisivik Mine, a division of CanZinco Ltd. February, 1999.

Golder Associates 2002. Preliminary Hydrological Study of Nanisivik Spillway Design. Report No. 011-1838. Submitted to Breakwater Resources Ltd. February 2002.

Grozic Ed M., Horne, William M. and Merkosky, Roland. 2003. Permafrost Containment Landfills at Arctic Dew Line Sites. Proceedings of The 56th Canadian Geotechnical Conference, Winnipeg, September 2003.

Holubec, Igor and Hohnstein, David. 2003. Partially Saturated Granular Cover for Reactive Tailings in Permafrost – Lupin Mine Experience, Nunavut, Canada. Proceedings of the 7th International Symposium on Mining in the Arctic, Iqaluit, Nunavut. April 2003.

Huschke, R.E. (editor) 1959. *Glossary of Meteorology*. American Meteorological Society, Boston, Mass.

IPCC 1995. Climate change 1995: the science of climate change – technical summary. Cambridge University Press, Cambridge, UK.

Johnson, G.H. 1981. Permafrost – Engineering Design and Construction. John Wiley & Sons, New York, 540 pages.

Kersten, M.S., 1949. Thermal Properties of Soils. University of Minnesota, Engineering Experiment Station, Bulletin No. 28, 227 pages.

Lorax Environmental 1999. Nanisivik Mine – Acid Generation Potential of Tailings and Shale Cover Material: Kinetic Testing Final Report. Prepared for Nanisivik Mine, September 1999.

Lorax Environmental 2001. Nanisivik Mine – Acid Generation Potential of Soil, Waste Rock and Shale – Acid Base Accounting Report. Prepared for Nanisivik Mine, April 2001.

Mackay, J. Ross, 1983. Downward water movement into frozen ground, western Arctic coast, Canada. Canadian Journal of Earth Sciences, Vol. 20, p. 120-134.

Mackay, J. Ross, 1997. A full-scale field experiment (1978-1995) on the growth of permafrost by means of lake drainage, western arctic coast: a discussion of the method and some results. Candian Journal of Earth Sciences, Vol 34, p. 17-33.

Nanisivik Mines Ltd. 1991. Area 14 permafrost study Letter Report submitted to Mr. Peter Bannon, Controller of Water Rights, April 19, 1991, 2 pages plus attachments.

Nanisivik Mines Ltd. 2000. Part G, Item 15: Test Cell Evaluation Study. Submitted to Nunavut Water Board. February, 2000.

Natural Resources Canada. 1995. Canada – Permafrost 1995. The National Atlas of Canada, 5th Edition. Published by the National Atlas Information Service, Canada Centre for Mapping, Geomatics Canada and the Terrain Sciences Division, Geological Survey of Canada, Natural Resources Canada 1995.

Nixon, J.F., 1992. 1-D Geothermal Program (THERM1). Description and User's Manual, Version 92-2. Dated September 1992, retailed by Nixon Geotech Ltd.

Patterson, K.M. and Powis, K. 2002. Structural and Stratigraphic controls on Zn-Pb-Ag mineralization of the Nanisivik Mississippi Valley-type deposit, northern Baffin Island, Nunavut; Geological Survey of Canada, Current Research 2002-C22, 12 p.

Patterson, K.M., Powis, K., Sutherland, R.A., and Turner, E.C. 2003. Stratigraphy and structural geology, Nanisivik area, northern Baffin Island, Nunavut; Geological Survey of Canada Open File 1552, scale 1:100,000.

Reid, Bob 1996. Evaporation Studies at Mine Tailings Ponds in the Northwest Territories, Canada. Proceedings of the Hydro-Ecology Workshop on the Arctic Environmental Strategy, Canadian Geophysical Union, May 5-10,1996, Banff, Alberta, pp. 115-134.

Savigny, W., Logue, C. and MacInnes, K. 1995. Forest Fire Effects on Slopes Formed in Ice-Rich Permafrost Soils, Mackenzie River Valley, Northwest Territories. Proceedings of: 48th Canadian Geotechnical Society Conference, September 1995, pp. 989-998.

Terratech 1990. Geotechnical Investigation, Permafrost Aggradation, Nanisivik Mine, NWT Report No. 1434-1, submitted to Nanisivik Mines Ltd. November 14, 1990.

Terratech 1993a. Construction Surveillance, West Twin Lake Containment Dike. Submitted to Nanisivik Mine, January 1993.

Terratech 1993b. Geotechnical Test Program, West Twin Lake Test Cells. Submitted to Nanisivik Mine, January 1993.

Tordon, Frank. 1997. Memo to Nanisivik Mine Re: Hydraulic Confinement of West Twin Lake. October 26, 1997.

Tordon, Frank. 1998. Geotechnical Visit of Nanisivik Mine April 15-30, 1998. Letter report to Nanisivik Mine, April 30, 1998.

TABLES

Table 1: Summary of Component Closure Plan Reports

Water License Reference	Report
Part G, Item 3	Final Closure and Reclamation Plan
Part G, Item 4	Reclamation Cover Designs
Part G, Item 5	West Twin Disposal Area Talik Investigation
Part G, Item 6	Borrow Areas Development and Closure Plan
Part G, Item 7	West Twin Disposal Area Surface Cell Spillway Design
Part G, Item 8	Waste Rock and Open Pit Closure Plan
Part G, Item 9	Reclamation and Closure Monitoring Plan
Part G, Item 12	Annual Review of Reports G3 to G9 and Submission, for Approval, of Proposed Modifications
Part G, Item 13	Report on Environmental Site Assessment (ESA) Program
Part G, Item 14	Human Health and Ecological Risk Assessment (HHERA)
Part G, Item 15	West Twin Disposal Area Closure Plan
Part G, Item 16	Underground Mine Solid Waste Disposal Plan
Part G, Item 17	Landfill Closure Plan
Part G, Item 20	Annual Review of Reports G15 to G17 and Submission, for Approval, of Proposed Modifications
Part G, Item 21	Annual Reclamation Liability Cost Update
Part G, Item 22	2007 Terms of Reference for Comprehensive Assessment of Mine Site Remediation

Table 2: Weather Stations Proximal to West Twin Disposal Area

Station Name	AES Station Number	Station Location		Elevation (m)	Available Period of Record	Approx. Distance to WTDA (km)
		Latitude	Longitude			
Arctic Bay	2400400	73° 2' N	85° 9' W	11	1937-1976	25
Arctic Bay CS	2400404	73° 0' N	85° 1' W	10	1999-2003	25
Nanisivik Airport AES	2402730	72° 58' N	84° 37' W	642	1976-2003	10
Nanisivik WTDA	N/A	73° 02'N	84° 31' W	372	1993-2001	0
Pond Inlet	2403200	72° 41' N	77° 59' W	4	1922-1965	220
Pond Inlet A	2403201	72° 40' N	77° 58' W	55	1975-2003	220
Resolute CARS	2403500	74° 43' N	94° 58' W	67	1947-2003	350

Table 3: Mean Monthly Air Temperatures at Nanisivik Airport Station

(Period of Record: 1977 to 2000)

Month	Monthly Air Temperatures (°C)		
	Minimum Mean	Mean	Maximum Mean
January	-32.1	-29.2	-26.5
February	-33.1	-30.3	-27.3
March	-30.8	-27.8	-24.7
April	-23.4	-20.0	-16.6
May	-13.5	-10.6	-7.8
June	-2.8	-0.4	1.9
July	2.5	4.9	7.4
August	-0.8	1.5	3.7
September	-7.6	-5.6	-3.8
October	-17.2	-14.9	-12.6
November	-25.4	-22.7	-19.9
December	-29.4	-26.6	-22.0
Annual	-17.8	-15.1	-10.1

Table 4: Monthly Precipitation Values at Nanisivik Station

(Period of Record: 1977 to 2000)

Month	Total Precipitation[1]			Mean Monthly Rainfall (mm)[2]	Mean Monthly Snowfall (cm)[2]
	Historical Monthly Low (mm/year of occurrence)	Monthly Mean (mm)	Historical Monthly High (mm/year of occurrence)		
January	Trace/1978	7.6	70.0/1977	0	4.4
February	Trace/1978	3.9	16.8/1986	0	3.8
March	0.2/1982	6.6	19.6/1986	0	6.4
April	Trace/1992	9.8	31.0/1989	0	9.8
May	1.2/1998	17.2	68.6/1991	1	16.9
June	1.0/2000	23.5	47.5/1985	6.7	15.7
July	6.2/1999	35.3	71.2/1983	27.5	7.2
August	6.4/1990	40.9	71.7/1996	22.5	17.3
September	10.2/1992	43.5	88.0/1977	4.2	36.9
October	4.0/1997	30.9	98.6/1985	1	31.2
November	1.6/1992	16.0	62.7/1981	0	15.8
December	Trace/1988	7.3	19.9/1976	0	7.3
Annual		242.5		62.9	172.7

(1) Precipitation data at the Nanisivik climate station have not been corrected for snowfall under-catch.

(2) Mean rainfall and snowfall data is missing significant amounts of data and are therefore approximate.

Table 5: Derived Extreme Annual Precipitation Values at Nanisivik Station (after Golder 1998)

(Period of Record: 1977 to 1997)

Return Period (Years)	Annual Precipitation[1] (mm)
2	232
5	275
10	302
20	327
50	357
100	380
200	402
500	431

(1) Precipitation data at the Nanisivik climate station are not corrected for snowfall under-catch.

Table 6: Frequencies of Extreme Rainfall at Pond Inlet Airport Climate Station (after Golder 1998)

Return Period (Year)	Extreme Rainfall Intensity for Various Durations (mm/hr)						
	5-Minute	10-Minute	30-Minute	1-Hour	2-Hour	12-Hour	24-Hour
2	8.5	6.6	4.4	3.5	2.8	1.2	0.8
5	11.3	8.7	5.9	4.6	3.6	1.5	1.0
10	13.2	10.1	6.9	5.3	4.1	1.7	1.1
20	15.5	11.8	8.1	6.2	4.8	2.0	1.3
50	17.2	13.1	9.0	6.8	5.3	2.2	1.4
100	18.9	14.4	9.9	7.5	5.8	2.4	1.5

Table 7: Estimated Mean Monthly and Annual Lake Evaporations (after Reid, 1996)

Month (1)	Lake Evaporation (mm)
January	0
February	0
March	0
April	0
May	0
June	51
July	101
August	31
September	20
October	0
November	0
December	0
Total	**203**

(1) Distribution of monthly lake evaporation were derived based on mean monthly air temperatures.

Table 8: Global Warming Estimates for Nanisivik Based on Best Estimate Case

	70°N Latitude					80°N Latitude					73°N Latitude
Year	**DJF**	**MAM**	**JJA**	**SON**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**	**Annual**	**Annual**
2000	0.5	0.4	0.1	0.1	0.3	1.3	0.7	0.1	0.5	0.7	0.4
2100	6.0	4.2	1.0	1.1	3.1	7.0	3.5	0.5	2.4	3.4	3.2
Difference					2.8					2.7	**2.8**

Table 9: Global Warming Estimates for Nanisivik Based on High Sensitivity Case

	70°N Latitude					80°N Latitude					73°N Latitude
Year	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	Annual
2000	1.0	0.7	0.2	0.2	0.5	1.1	0.6	0.1	0.4	0.6	0.5
2100	10.5	7.2	1.8	2.0	5.4	12.3	6.2	0.9	4.2	5.9	5.5
Difference					4.9					5.4	**5.0**

Table 10: Design Values of MAAT for Selected Northern Projects

	FOX-M DEW[1] Line Site	Nanisivik	Polaris Mine[2]
Approximate Latitude	69° N	73° N	76° N
Long-term Mean Annual Air Temperature	-14.1° C	-15.1° C	-16.5° C
1 in 100 Year Warm Year	-11.1° C	-13.3° C	-13.5° C
Best Estimate Global Warming in 2100	-10.7° C	-12.3° C	-13.5° C
High Sensitivity Global Warming in 2100	-8.2° C	-10.1° C	-11.4° C

(1) Values derived from Grozic et al. (2003).
(2) Values derived from EBA (2001).

Table 11: Moisture Content Required for Saturation of Shale

Dry Density (kg/m^3)	% of SPMDD	Specific Gravity (G_s)	Void Ratio (e)	Saturated Moisture Content (%)
2000	100	2.6	0.30	12
		2.65	0.33	12
1900	95	2.6	0.37	14
		2.65	0.39	15
1800	90	2.6	0.44	17
		2.65	0.47	18

Table 12: Cover Material Geotechnical Testing Results (from Golder, 1999)

PARAMETERS	SAMPLE A (Mt. Fuji Shale)	SAMPLE B (East Twin Lake Shale)	SAMPLE C (Twin Lakes Sand and gravel)	Typically Acceptable Rip Rap[1]	Typically Acceptable Rip Rap[2]
Absorption – maximum (%)	2.19	2.58	1.18	<2	2 – 6
Bulk Specific Gravity (saturated surface dry) Mg/m^3	2.651	2.616	2.651	>2.6	2.24 – 2.64
Los Angeles Abrasion (% loss)	34.0	32.5	29.5	<10	40-60
Slake Durability Index (% loss)	98.8 (Type I)	98.3 (Type I)	n/a	not provided	>90
Freeze Thaw (% loss) at 25 cycles	19.7 (6.1)[4]	2.3	0.1	<25 @ 25 Cycles	10 - 14 (16-25 Cycles)

Notes : 1) The typical acceptable values from Farar 1993.
2) The typical acceptable values from Lutton and Wong 1993.
3) n/a means not applicable.
4) Sample broke in half

Table 13: Summary of Metals Analysis on Shale

		West Twin Dike	ETL Quarry	WTL Quarry		Shale Hill Quarry	WTL Quarry
		Shale	Shale	Shale	Shale	Shale	Shale
Ag	ppm	0.2	0.5	0.3	0.7	0.3	0.5
Al	%	3.34	2.12	0.81	0.85	2.93	0.99
As	ppm	9	5	3	8	3	11
B	ppm	N/A	50	40	40	80	50
Ba	ppm	149	30	10	20	20	20
Be	ppm	N/A	0.5	<0.5	<0.5	0.8	0.5
Bi	ppm	N/A	<2	<2	<2	<2	2
Ca	%	8.75	11.15	12.55	11.2	8.24	11.65
Cd	ppm	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Co	ppm	11	8	9	9	10	9
Cr	ppm	69	19	14	19	29	22
Cu	ppm	19	19	21	43	22	44
Fe	%	2.48	1.56	1.51	1.5	2.11	1.66
Ga	ppm	N/A	<10	<10	<10	10	<10
Hg	ppm	N/A	<1	<1	<1	<1	<1
K	%	1.85	0.87	0.46	0.47	0.89	0.5
La	ppm	N/A	10	10	10	10	10
Mg	%	6.56	7.86	7.78	7.09	7.68	7.36
Mn	ppm	N/A	496	380	464	383	427
Mo	ppm	N/A	<1	1	5	<1	7
Na	%	0.08	0.04	0.04	0.03	0.03	0.03
Ni	ppm	23	14	14	24	19	26
P	ppm	N/A	280	270	320	290	350
Pb	ppm	48	6	17	27	<2	29
S	%	N/A	0.38	1.36	1.5	0.27	1.46
Sb	ppm	0.6	<2	<2	<2	<2	<2
Sc	ppm	N/A	4	3	4	6	4
Sr	ppm	N/A	114	122	86	69	64
Ti	%	N/A	0.01	<0.01	<0.01	0.02	<0.01
Tl	ppm	N/A	<10	<10	<10	<10	<10
U	ppm	N/A	<10	<10	<10	<10	<10
V	ppm	N/A	22	12	40	36	52
W	ppm	N/A	<10	<10	<10	<10	<10
Zn	ppm	150	24	14	11	33	34

Table 14: Maximum Thaw in Frost Gauge Network

Frost Gauge #	Location	1997	1996	1995	1994	1993
F1	West Twin Dike	-102	-105.5	-111	-118	-142.5
F2	West Twin Dike	-119	-118.0	-129	-126	-142
F3	TC#1	-72.5	-73.0	-73	-82	-99
F4	TC#1	-95	-90.0	-93	-109	-126
F5	TC#1	-105	-124.0	-138	-185.5	-209
F6	TC#1	-97	-103.0	-108	-128.5	-165.5
F7	TC#2	-87	-98.0	-94	-90	-94.5
F8*	TC#3	-124	-127.0		-102	-100
F9	TC#4	-133	-135.0	-146	-145	-155
F10	TC#5	-140	-150.0	-159	-162.5	-163

Notes:
F1 Frost Gauge in North end of Dike structure at the 376 metre elevation.
F2 Frost Gauge in South end of Dike structure at the 376 metre elevation.
F8 - construction on this pad in 1995.
All depths are measured in centimetres.

Table 15: Summary of Climate Data Used for Geothermal Model of Cover

Month	Temperature[1] (°C)	Wind Speed[2] (km/hr)	Snow Cover[3] (cm)	Daily Solar Radiation[4] (W/m^2)
January	-29.0	23.1	18.4	0.0
February	-30.3	23.1	19.1	7.7
March	-27.5	22.0	20.6	63.6
April	-20.2	22.0	22.1	178.9
May	-10.5	23.1	22.5	280.1
June	-0.3	23.1	12.8	302.7
July	5.0	22.0	1.5	227.1
August	1.5	23.1	0.4	134.1
September	-5.5	26.4	4.1	63.4
October	-14.7	25.3	11.3	15.5
November	-22.7	24.2	15.4	0.8
December	-26.1	23.1	16.9	0.0

Note [1]: from Nanisivik Airport AES over the period 1976 to 2001.
Note [2]: from Resolute Airport AES station.
Note [3]: modified from Resolute Airport AES Station.
Note [4]: modified from Resolute Airport AES Station plus 5% increase.

Table 16: Summary of Soil / Rock Parameters used in Geothermal Model of Cover

Unit Description	Thermal Conductivity (W/m°C)		A	B	Gravimetric Water Content (%)	Dry Density (Mg/m^3)
	Thawed	Frozen				
Sand & Gravel	2.19	2.38	0.05	-0.5	9	1.8
Shale Cover	2.46	2.89	0.05	-0.4	20 (10)	1.8
Tailings	1.9*	3.2*	0.04	-0.2	16*	2.5
Shale Bedrock	1.72	1.98	0.05	-0.3	5	2.7

*Based on EBA lab results, 2003.

Table 17: Testing Frequencies for Cover Materials

Item	Minimum Test Frequency	
	Shale	Twin Lakes sand and gravel
Grain Size Distribution	Every 10,000 m^3	Every 10,000 m^3
Moisture Content	Every 5,000 m^3	Not Required

Table 18: Performance Monitoring of Surface Reclamation Covers

Monitoring Method	Monitoring Component	Issues	Determinations
Visual monitoring	**Armour Layer**	Erosion	Erosion of underlying shale
		Settlement	Standing water on surface
		Frost effects	Displaced surface fragments
		Break down of particles	More erosion of underlying shale
Visual monitoring	**Shale Layer**	Erosion	Exposure of underlying tailings Reduction of insulating thickness
Visual monitoring and survey monuments		Settlement	Interrupts surface drainage and may results in standing water Reduction of insulating thickness
Thermistors and frost gauges		Insulation for permafrost aggradation	Thaw into tailings may result in poor quality of runoff water, or initiate oxidation of tailings
Drilling, sampling and testing for bulk density and moisture content of shale and underlying tailings		Moisture content retained in void space (controls oxygen entry)	Must check that moisture retention is being achieved to verify limiting of oxygen entry into underlying tailings
Shallow monitoring wells		Poor water quality from surface drainage	May have negative impact on water quality in Reservoir
Visual monitoring Shallow monitoring wells		Tailings displaced into shale	May result in poor quality surface drainage
Visual monitoring	**Drainage Swales**	Erosion	Exposure of underlying tailings Reduction of insulating thickness
Visual monitoring and survey of swale grades		Settlement/ heave of the swale	Standing water

Table 19: Reclamation Period Monitoring of Surface Covers

Monitoring Method	Year of Reclamation Activities	
	1	2
Thermistors	Monthly	Monthly
Frost Gauges	Every two weeks (June - September)	Every two weeks (June - September)
Monitoring Wells (Water Quality Samples)	Twice in Summer Period	Twice in Summer Period
Geotechnical Inspections	Twice/year (Spring/ Fall)	Twice/year (Spring/ Fall)
Topographic Survey	Twice/year (of selected points)	Twice/year (of selected points)

Table 20: Closure Period Performance Monitoring Schedule

Monitoring Method	Year Following Completion of Reclamation Activities				
	1	2	3	4	5
Thermistors	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
Frost Gauges	Every Two Weeks (June – September)	Every Two Weeks (June – September)	Every Two Weeks (June – September)	Only if Required	Only if Required
Water Quality	Once per Summer	Once per Summer	Once per Summer	Once per Summer	Once per Summer
Geotechnical Inspections	Twice/ year (Spring/ Fall)	Once/year Pending suitable performance	Once/year Pending suitable performance	Once/year Pending suitable performance	Once/year Pending suitable performance
Survey	Once/year	Once/year	Once/year	None	None

Table 21: Contingency Plans for Surface Reclamation Covers

Issues	Consequences	Mitigation Approach
Erosion of armouring layer	• Reduction in Twin Lakes sand and gravel and shale thickness • Reduction in insulation thickness • Potential poor quality run-off	• Enlarge the surface particle size. • Flatten surface grades. • Supplement layer with additional armour.
Settlement of cover interrupts surface drainage	• Allows for standing water that may leave thermal impacts	• Localized repair of settled area to correct surface grade.
Excessive depth of active layer thaw	• Sub-surface thawed tailings may cause poor surface water quality runoff	• Need to determine if cause is climatic conditions (warm) and/or thermal properties of the cover shale and/or sand and gravel armour. • If excessive thaw depth occurs in localized areas need to determine if surface water quality impacts are significant and/or if oxidation may be initiated. • If impacts are significant, determine if cover layer can be thickened, if moisture content can be increased or if grade can be reduced to enhance moisture retention in the cover.
Surface water runoff quality becomes poor	• Potential impacts on Reservoir water quality	• Assess and attempt to mitigate root causes with-respect-to the cover and the underlying tailings. • Potential treatment of water in the Reservoir prior to discharge to the environment
Heaving of cover results in open cracking	• Infiltration of water/oxygen • Oxidation of tailings • Production of leachate	• Localize repair of cracked areas by contouring or supplement with additional material.