APPENDIX VII
WATER QUALITY PROJECTIONS

Part A – Lorax 2004a
Part B – Nanisivik Mine Water Quality Listing
Part C – Estimate of Porewater Expulsion
Part D – Lorax 2004b
Part E – Results of the Water Quality Projection

PART A

Lorax Technical Memorandum
Geochemical Stability of Subaqueous Mine Tailings

LORAX
ENVIRONMENTAL

February 5, 2004

Gartner Lee
4912-49th Street
Yellowknife, NWT
X1A 2N1

Attention: Eric Denholm

Re: The Geochemical Stability of Subaqueous Mine Talings

The storage of sulphidic mine tailings under water cover (subaqueous storage) has been practiced for many decades. Prior to the 1980's this mode of deposition was adopted more for reasons of convenience than environmental stewardship. However, in the ensuing years, myriad scientific studies have been conducted on the *in situ* reactivity of such materials and have concluded that subaqueous disposal is the most environmentally sound manner in which to store potentially acid-generating tailings in perpetuity (Pedersen, 1985; MEND, 1994; MEND, 1996; Pedersen et al., 1993; Pedersen et al., 1997 and others). This letter is designed to offer an overview of the salient findings of the previous 20 years research in this field and in doing so, characterize the potential for reactivity of sulphide tailings under water at the Nanisivik mine site.

The susceptibility of sulphide minerals to oxidation and acid and metal generation relates to their genesis; they are formed in highly reducing environments devoid of oxygen and host elements (most notably sulphur) in their lowest oxidation states (*i.e.,* S^{2-}). Consequently, metal sulphides are thermodynamically unstable in the comparatively oxygenated environment of the earth's surface. Indeed, the key ingredients in the production of ARD include: sulphide mineral surfaces, air (oxygen) and water (Evangelou and Zhang, 1995; Moses and Herman, 1991); these ingredients are in abundance on the earth's surface; thus, the acid-generating oxidation process is continuous where sulphide minerals are exposed (Nicholson et al., 1988; Wunderly et al., 1996).

The kinetics of pyrite oxidation in the subaqueous environment is markedly slower than under subaerial conditions. Several factors contribute to the observed difference, all of which ultimately stem from the availability of molecular oxygen. Pyrite in mining wastes exposed to the atmosphere, for example, is initially oxidized by atmospheric O_2 which liberates acidity, sulphate and ferrous iron into solution. Following the oxidation of Fe^{2+} to Fe^{3+}, acid is generated via the subsequent hydrolysis of Fe^{3+} to $Fe(OH)_{3(s)}$. Fe^{3+} is a much more effective at oxidizing pyrite than is molecular oxygen (Luther, 1987; Moses and

Herman, 1991) but its concentration is exceeding low at neutral pH (Stumm and Morgan, 1983). The oxidation of Fe^{2+} to Fe^{3+} in the subaerial setting is not limited by the availability of molecular oxygen; consequently the hydrolysis of Fe^{3+} and the generation of acid will progressively lower the pH in the absence of readily available neutralizing minerals. The development of low pH conditions further enhances sulphide oxidation due to increased bacterial activity and increased activity of free Fe^{3+}(Luther, 1987). The high dissolved metal loads characteristic of ARD can be largely attributed to increased solubility of pyrite and other metal sulphides at low pH.

Rates of sulphide oxidation in subaqueous settings are limited by the much lower availability of dissolved oxygen and the fact that bacterial oxidation of pyrite in such environments is minimal. Oxygen limitation stems from two fundamental properties of water. First, the maximum concentration of dissolved oxygen found in natural waters is approximately 30-fold lower than that found in the atmosphere. Second, once the small inventory of dissolved oxygen in water is consumed, it is replaced to the reaction site very slowly by the process of molecular diffusion (Li and Gregory, 1974; Gunderson and Jorgensen, 1990); diffusion of oxygen in water is nearly 10,000 times slower than in air (Weast, 1986). Thus, the oxidation of submerged pyrite cannot generate acid at the rates common to subaerial environments. The minimal rate of oxidation which occurs at the sediment-water interface is too low to cause the decrease in pH required to accelerate pyrite oxidation; the inhibition of oxygen resupply ultimately limits the rate at which sulphides can oxidize (Davison, 1991).

Because metal solubility is intrinsically linked to the rate of pyrite oxidation and the pH of the tailings porewaters (*i.e.,* low pH porewaters solublize greater concentrations of metals; Stumm and Morgan, 1981); metal release from subaqueous tailings is low by default. Furthermore, the transport mechanism of metals from the reaction site (*i.e.,* porewater) is molecular diffusion, a process which is effective only over very short distances (Lerman and Brunskill, 1971; Gunderson and Jorgensen, 1990). Thus, only a thin veneer of tailings at the sediment-water interface is subject to potential oxidation. Indeed, dissolved oxygen profiles in tailings ponds typically penetrate only a few mm into the subaqueous deposit (Lorax, unpublished data).

In some studies, metal release to the water column has been observed; however, it has never been attributed to the oxidation of sulphide minerals. Rather, metals such as Zn and Cu are known to associate with both organic matter and metal oxyhydroxides; these species are subject to release through reductive dissolution. This mechanism is only an issue in tailings ponds which host neutralization sludges or host active biological cycles (Balistrieri and Murray, 1992; Hamilton-Taylor and Davison, 1995; Hamilton-Taylor et.

al., 1996; MEND 1994; MEND, 1996 and others). Indeed, many of the deposits studies under the MEND program demonstrated the capacity for subaqueous tailings to consume metals from the water column (*e.g.,* Anderson Lake and Mandy Lake; Pedersen et al., 1991; 1993; 1994; 1997).

The implications to the Nanisivik tailings pond are that for all practical purposes, the permanently submerged tailings within the tailings pond can likely be considered chemically benign. Metal releases from porewater are not anticipated to occur, and, even under conditions of maximum non-oxidative release rates observed in the literature (MEND, 1995; Westerlund et al., 1986) in concert with the residence time of the tailings pond, Zn additions to the water column would likely be undetectable.

Please feel free to contact me if you have any questions.

Sincerely,

J. Jay McNee, Ph.D.
Senior Environmental Geochemist

References

Balistrieri, L. S. and Murray, J. W. (1992). "The cycling of iron and manganese in the water column of Lake Sammamish, Washington." Limnol. Oceanogr. *37*: *510-528.*

Davison, W. (1991). "The solubility of iron sulphides in synthetic and natural waters at ambient temperature." Aquat. Sci. *53*: *309-329.*

Evangelou, V. P. and Zhang, Y. L. (1995). "A review: Pyrite oxidation mechanisms and acid mine drainage prevention." Crit. Rev. Environ. Sci. Technol. *25*(2): *141-199.*

Gundersen, J. K. and Jorgensen, B. B. (1990). "Microstructure of diffusive boundary layers and the oxygen uptake of the sea floor." Nature *345*: *604-607.*

Hamilton-Taylor, J. and Davison, W. (1995). Redox-driven cycling of trace elements in lakes. Physics and Chemistry of Lakes. A. Lerman, J. A. Gat and D. M. Imboden. Heidelberg, Springer-Verlag: 217-263.

Hamilton-Taylor, J., Davison, W. and Morfett, K. (1996). "The biogeochemical cycling of Zn, Cu, Fe, Mn and dissolved organic C in a seasonally anoxic lake." Limnol. Oceanogr. *41*(3): *408 - 418.*

Lerman, A. and Brunskill, G. J. (1971). "Migration of major constituents from lake sediments into lake water and its bearing on lake water composition." Limnol. Oceanogr. *16*: *880-890.*

Li, Y.-H. and Gregory, S. (1974). "Diffusion of ions in sea water and in deep-sea sediments." Geochim. Cosmochim. Acta *38*: *703-714*.

Luther III, G. W. (1987). "Pyrite oxidation and reduction: molecular orbital theory considerations." Geochim. Cosmochim. Acta *51*: *3193-3199*.

MEND (1994). Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba.

MEND (1995). Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia.

MEND (1996). Geochemical Assessment of the Equity Silver Tailings Pond, MEND.

Moses, C. O. and Herman, J. S. (1991). "Pyrite oxidation at circumneutral pH." Geochim. Cosmochim. Acta *55*: *471-482*.

Nicholson, R. V., Gillham, R. W. and Reardon, E. J. (1988). "Pyrite oxidation in carbonate-buffered solution: 1. Experimental kinetics." Geochim. Cosmochim. Acta *52*: *1077-1085*.

Pedersen, T. F. (1985). "Early diagenesis of copper and molybdenum in mine tailings and natural sediments in Rupert and Holberg Inlets, British Columbia." Can. J. Earth. Sci. *22*: *1474-1484*.

Pedersen, T. F., McNee, J. J., Flather, D. F., Mueller, B., Sahami, A. and Pelletier, C. A. (1997). Geochemistry of submerged tailings in Buttle Lake and the Equity Silver Tailings Pond, British Columia and Anderson Lake, Manitoba: What have we learned? Fouth International Conference on Acid Rock Drainage, Vancouver.

Pedersen, T. F., McNee, J. J., Mueller, B., Flather, D. H. and Pelletier, C. A. (1994). Geochemistry of Submerged Tailings in Anderson Lake, Manitoba: Recent Results. International Land Reclamation and Mine Drainage Conference

Pedersen, T. F., Mueller, B. and McNee, J. J. (1991). Diagenetic reactivity of mine tailings in mesotrophic and oligotrophic lakes in Manitoba and British Columbia. 2nd International Conference on the Abatement of Acidic Drainage, Montreal.

Pedersen, T. F., Mueller, B., McNee, J. J. and Pelletier, C. A. (1993). "The early diagenesis of submerged sulphide-rich mine tailings in Anderson Lake, Manitoba." Can. J. Earth Sci. *30*: *1099-1109*.

Stumm, W. and Morgan, J. J. (1981). Aquatic Chemistry. New York, John Wiley & Sons.

Weast, R. C. (1986). CRC Handbook of Chemistry and Physics. Florida, CRC Press.

Westerlund, S. F. G., Aderson, L. G., Hall, P. O. J. and Iverfeldt, A. (1986). "Benthic fluxes of cadmium, copper, nickel, zinc and lead in the coastal environment." Geochim. Cosmochim. Acta *50*: *1289-1296*.

Wunderly, M. D., Blowes, D. W., Frind, E. O. and Ptacek, C. J. (1996). "Sulfide mineral oxidation and subsequent reactive transport of oxidation in mine tailings impoundments: a numerical model." Wat. Resour. Res. *32*(10): *3173-3187*.

Part B

Nanisivik Mine Water Quality Listing for Total Zinc for Stations NML-23 and NML-24

Nanisivik Mine Water Quality Record, Total Zinc at Stations NML-23 and NML-24

Location	Station	Date	Temperature	pH	Total Zn (mg/L)
				Average:	*0.056*
East Lk	NML 23	13-Jun-96		7.53	0.045
East Lk	NML 23	17-Jul-96	2.8	7.55	0.018
East Lk	NML 23	08-Aug-96	2.3	7.45	0.031
East Lk	NML 23	24-Mar-98	3.7	7.67	0.107
East Lk	NML 23	16-Apr-98	11.5	10.07	0.134
East Lk	NML 23	25-May-98	1.5	8.57	0.294
East Lk	NML 23	18-Jun-98	7.3	8.56	0.060
East Lk	NML 23	08-Jul-98		8.23	0.005
East Lk	NML 23	17-Jul-98		6.40	0.006
East Lk	NML 23	25-Aug-98		2.48	0.070
East Lk	NML 23	14-Dec-98		7.00	0
East Lk	NML 23	17-Feb-99	2.0	8.01	0.046
East Lk	NML 23	23-Mar-99	0.6	6.73	0.018
East Lk	NML 23	29-Apr-99	2.0	6.15	0.099
East Lk	NML 23	15-Mar-00	1.5	6.71	0.015
East Lk	NML 23	12-Apr-00	2.0	6.50	0.031
East Lk	NML 23	15-Jun-00	3.8	7.34	0.045
East Lk	NML 23	21-Jun-00	2.7	7.06	0.045
East Lk	NML 23	28-Jun-00	6.5	7.07	0.217
East Lk	NML 23	19-Jul-00	6.9	6.79	0.077
East Lk	NML 23	21-Jul-00	7.7	8.34	0.153
East Lk	NML 23	13-Sep-00	2.1	6.80	0.188
East Lk	NML 23	11-Oct-00	1.8	6.90	0
East Lk	NML 23	28-Nov-00	1.5	8.03	0.022
East Lk	NML 23	13-Dec-00	0.1	7.13	0
East Lk	NML 23	07-Dec-01	1.9	8.83	0.011
East Lk	NML 23	07-Jun-01	1.4	9.61	0
East Lk	NML 23	08-May-01	2.2	8.10	0.044
East Lk	NML 23	09-Jul-01	8.2	8.38	0.013
East Lk	NML 23	12-Sep-01	5.3	8.02	0.003
East Lk	NML 23	13-Aug-01	11.4	9.18	0.002
East Lk	NML 23	17-Jan-01	4.6	7.60	0.032
East Lk	NML 23	20-Apr-01		7.00	0.032
East Lk	NML 23	21-Mar-01	1.2	7.24	0.019
East Lk	NML 23	25-Jul-01	15.0	7.62	0.057
East Lk	NML 23	26-Nov-01	1.1	7.01	0
East Lk	NML 23	28-Feb-01	0.9	8.44	0.065
East Lk	NML 23	31-Oct-01	1.0	7.90	0.054
East Lk	NML 23	AUG 8	2.3	7.45	0.031
trib to East Lk	NML 24	17-Jul-96	2.9	7.15	0.061
trib to East Lk	NML 24	08-Aug-96	2.0	7.16	0.018
trib to East Lk	NML 24	16-Jul-98	4.4	6.25	0.065
trib to East Lk	NML 24	25-Aug-98	3.4	4.10	0.124
trib to East Lk	NML 24	25-Jun-99	2.3	8.03	0.014
trib to East Lk	NML 24	27-Jun-00	4.2	7.82	0.093
trib to East Lk	NML 24	21-Jul-00	6.6	7.80	0.195
trib to East Lk	NML 24	12-Jul-01	7.2	7.60	0
trib to East Lk	NML 24	AUG 8	2.0	7.16	0.018

Part C

Estimate of Porewater Volume Expelled During Freezing of the Surface Cell and Test Cell Taliks

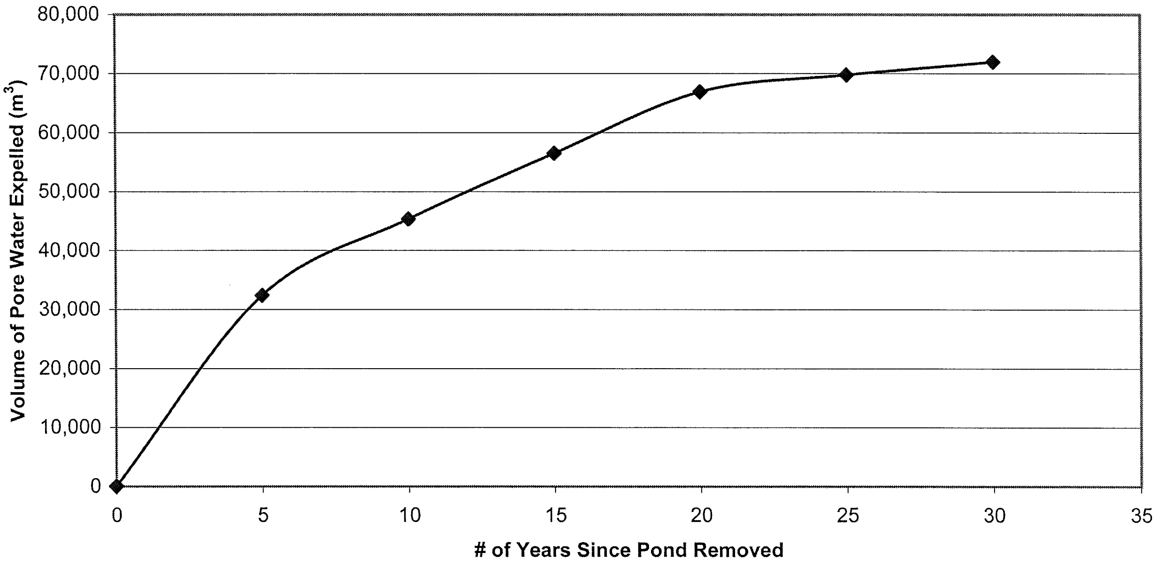
Estimate of Water Expelled During Freezing of the Surface Cell Talik

			Vol of Water Expelled***	
Year	Vol Thawed Tailings*	Vol of Unfrozen Water**	per 5 year period	Cumulative
	m^3	m^3	m^3	m^3
0	2000000	800000	0	0
5	1100000	440000	32400	32400
10	740000	296000	12960	45360
15	430000	172000	11160	56520
20	140000	56000	10440	66960
25	61000	24400	2844	69804
30	0	0	2196	72000

* Based on geotechnical investigation results and geothermal modelling of freezeback.

** Based on average volumetric water content of 40%.

*** Assumes 9% of water expelled in response to freezing.



Volume of Expelled Pore Water from Surface Cell v Time

Estimate of Water Expelled During Freezing of the Test Cell Talik

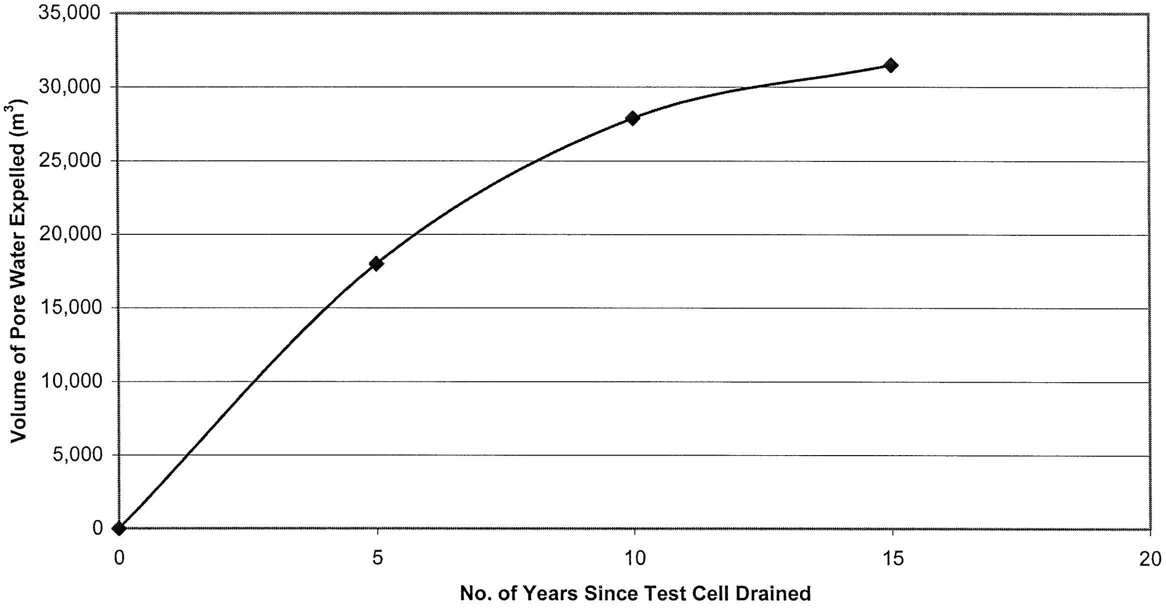
			Vol of Water Expelled***	
Year	Vol Thawed Tailings*	Vol of Unfrozen Water**	per 5 year period	Cumulative
	m^3	m^3	m^3	m^3
0	1,000,000	400,000	0	0
5	500,000	200,000	18,000	18,000
10	225,000	110,000	9,900	27,900
15	125,000	40,000	3,600	31,500

* Based on geotechnical investigation results and geothermal modelling of freezeback.

** Based on average volumetric water content of 40%.

*** Assumes 9% of water expelled in response to freezing.

Pore Water Expulsion from Test Cell Talik



Part D

Lorax Technical Memorandum
Nanisivik Water Quality Predictions

LORAX
ENVIRONMENTAL

Memorandum

To: Eric Denholm

From: Jay McNee
Andrew Rollo

CC:

Date: 1/23/2004

Re: Nanisivik Water Quality Predictions

Introduction

In support of a tailings closure water quality model, Gartner-Lee (Whitehorse) requested that Lorax Environmental Services (Lorax) estimate drainage chemistry from both the Nanisivik Tailings (resulting from the flow of surface water through the active layer at the perimeter of the pond), and the shale material used in dyke and cover construction. This memo reports the details of this investigation and includes a discussion of the available data, the methods used in the estimation of concentration ranges, as well as the results of these calculations. It should be noted that the estimates generated in this memo are based on limited data and, thus, must be viewed with caution. More defensible predictions could only be based on field-scale leach studies and/or monitoring data from site.

Method

While field-scale experiments were not conducted, several sources of data do exist for the Nanisivik Mine site. The primary sources of data available to estimate drainage chemistry for the Nanisivik tailings and shale included: a kinetic testing study conducted by Lorax Environmental on Nanisivik tailings and tailings dyke shale material (Lorax 1999), and a study conducted on the effects of climate and temperature on the oxygen uptake of tailings deposited at the Nanisivik mine (Elberling 2000). The Lorax (1999) report contained leachate data from humidity cell testing on both pH-neutral tailings and shale dyke material while the Elberling (2000) study offered porewater data collected directly from pH-neutral and acidic tailings at the Nanisivik site; there were no field-based data available for the shale material.

The purpose of this investigation is to provide estimates of water chemistry anticipated from the interaction of each of the rock types with infiltrating water. Both field and laboratory data were available for the tailings under pH-neutral conditions, while only laboratory data were available for the shale. Therefore, the pH-neutral tailings data (common to both studies) were used to approximate a relation between laboratory and field chemistry. The data were first subjected to geochemical speciation modelling (PHREEQC; Parkhurst and Appelo 1999) to determine whether or not secondary mineral controls on metal concentrations existed. Once it was deemed that no such controls existed, the ratios determined from this comparison were then applied to the shale to convert kinetic testing results into approximate field porewater concentrations. While it is recognized that this approach has several limitations as a proxy for extrapolation to field conditions, it was deemed the best approach available given the limited amount of field-based data. In order to best constrain estimates of drainage chemistry, the initial predictions were subjected to geochemical speciation modelling to correct for potential secondary mineral controls and finally compared with the limited field data where available.

The final data are presented as a range of values for the parameters of interest in which the low concentrations best represent higher flushing rates of water and the higher concentrations are more indicative of minimal flushing rates, recognizing that flow through both unsaturated tailings and shale cover material in the active layer will be highly seasonal and variable in nature.

It should be noted that the methods used to estimate water chemistry in this investigation assume that the differences between the field and lab based tailings data are not related to lithology. Rather, they relate primarily to differences in climate between the lab and the field, including temperature and precipitation. Thus, it should be noted that due to the differences in lithologies between the tailings and shale material, including sulphide and carbonate content, the field-based concentrations approximated for the shale using this method will likely serve as an upper limit for those encountered in the field.

Results

Tailings

Average pH-neutral and acidic porewater data from Elberling (2001), kinetic test effluent data from the pH-neutral tailings, and the ratio between these two concentrations are listed in Table 1-1.

PHREEQC model runs on the humidity cell data for the pH-neutral tailings confirmed that there were no secondary mineral controls on metal concentrations. Thus, the tailings porewater and kinetic test leachate data offer reasonable maximum (porewater) and minimum (kinetic test effluent) concentrations that are estimated to occur within the pH-neutral tailings. The field/lab ratio listed in Table 1 represents the factors by which the kinetic test data are scaled to emulate the porewater data.

Table 1:
Average values of Nanisivik tailings pore water data (Elberling 2000), kinetic test effluent data, and field/lab ratios. Note that all concentrations are given in mg/L.

	*Porewater (pH-neutral)	*Porewater (acidic)	*Porewater (acidic, well flushed)	Kinetic test leachate	field:lab ratio (pH neutral)
pH	7-8	2-3	6.5	7.6	-
Cd	0.026	0.36	0.1	0.0017	15.3
Ca	100	100	400	108	4.3
HCO_3	100	100	400	23.2	41.4
K	4	60	20	0.133	30.1
Mg	500	7000	2500	45.1	11.1
Pb	0.044	0.13	0.05	0.0012	36.7
SO_4	1900	25000	10000	430.6	4.4
Zn	48	2350	70	0.339	141.6

***Data from Elberling (2001)**

The range of concentrations anticipated for acidic tailings are derived from the Elberling 2000 data from the upper horizons of the oxidized tailings column (Table 1). Concentrations during spring melt are low and pH is relatively high as flushing rates are high; however, as the summer progresses and the tailings are rinsed more slowly, the pH drops and metal concentrations increase towards the concentrations described in Table 1.

Shale

The only water chemistry data available for the shale material, which is used as the cover material in the tailings management area at Nanisivik, is from laboratory-based kinetic test leachate data (Lorax 1999). Humidity cell leachate by itself is a poor proxy for field chemistry due largely to the different water/rock ratios between the field and the laboratory. Therefore, in order to better estimate field-based porewater conditions for the shale material, the field/laboratory ratios calculated from the pH-neutral tailings data have been applied to the kinetic test effluent data for the shale. Table 2 contains the average kinetic test effluent data (Lorax 1999), as well as the pore-water data estimates for the shale.

The high bicarbonate and low sulphate concentrations calculated in the above table are consistent with the fact that this shale is a light brown micritic carbonate rock with less than 0.5% sulphide minerals (Lorax 1999). It should be noted that pH in the estimated shale pore-water is assumed to be the same as was observed in the shale kinetic test results. This assumption is presumed valid due to the similarity in field and lab pH values observed in the tailings, discussed previously.

The concentration of Zn predicted for the shale porewater appears to be erroneously high using the ratio approach. It is likely that the predicted value of 1.7 mg/L is an overestimate particularly in light of the fact that the elevated release of Zn from the tailings is due to the presence of sphalerite, which does not exist in the shale. Sphalerite is known to oxidize more rapidly than pyrite and likely accounts for much of the elevated release rates of Zn from the tailings even though it comprises only a small fraction of the sulphide inventory. The suggestion that Zn is overestimated for the shale is indirectly supported by the solid-phase data which indicate that it exists in the shale at little more than crustal abundance. Indeed, the humidity cell data indicate that the release of Zn is similar to that of Cu (for which there are no field data) and perhaps an order of magnitude greater than that for Pb. Accordingly, a more realistic upper estimate of concentration might be on the order of 0.5 mg/L and actual concentrations observed in the field could be considerably lower.

Table 2:
Average kinetic test effluent data (Lorax 1999) and calculated pore-water chemistry estimates for the Nanisivik tailings dyke shale.

	Kinetic test effluent	**Estimated porewater**
pH	8.5	8.5
Cd	0.000056	0.00086
Ca	9.95	43
HCO_3	24.3	1006
K	2.1	63
Mg	4.1	46
Pb	0.0014	0.05
SO_4	6.6	29
Zn	0.012	*1.7

***Over estimate given the absence of sphalerite**

The purpose of this study was to estimate potential drainage chemistry from the Nanisivik tailings and shale comprising the tailings cover material. The methods used in these calculations thus far involved the application of ratios derived from the comparison of independent field and laboratory data. However, this method involved no consideration of chemical limitations on pore-water chemistry, such as mineral solubility. Saturation indices calculated using PHREEQC suggest that calcite is near saturation in the relatively dilute kinetic test samples. As the solute concentration in these waters increases, it would be expected that calcite and potentially other minerals would become saturated and exert control on the concentration of Ca, HCO_3, pH and possibly other parameters. Therefore, the estimated concentrations presented in Tables 1 and 2 have been adjusted to account for supersaturation of authigenic minerals, and the final results of the estimation calculations are listed in Table 3:

Table 3:
Predicted Ranges of Concentrations of Parameters in the Porewaters of unsaturated Tailings and Shale Materials (concentrations in mg/L unless otherwise noted)

	Tailings				Shale	
	pH-neutral		Acidic			
	Min	Max	Min	Max	Min	Max
pH	7-8		2-6.5		7-8	
Cd	0.002	0.03	0.1	0.4	0.00006	0.0009
Ca	100	100	100	500	10	43
HCO_3	23	100	0	100	24	100
K	0.1	4	20	60	2	63
Mg	45	500	2500	7000	4	46
Pb	0.001	0.04	0.05	1	0.001	0.05
SO_4	430	1900	10000	25000	10	30
Zn	0.3	48	70	2350	0.01	0.5

The range of predicted concentrations arises from the difference of "flushing rates" between the laboratory and field but appear to represent the natural range observed in the field, both in the natural tailings (Elberling, 2000) and in the unimpacted surface water quality samples seen from the site (Nanisivik data, unpublished). Accordingly, the minimum values from the above table would best represent periods of high rain fall, when the water/rock ratio is elevated and residence times are short. In such cases, dilute drainage chemistry would be expected. Maximum values are more representative of periods with relatively little precipitation, when water/rock ratios are low and concentrated drainage chemistry arises through longer residence times and potential evaporative concentration. Indeed, this is best seen in the acidic tailings data (Elberling, 2000) in which the heavily oxidized upper horizons of tailings were seen to host near neutral pH and lower metal concentrations during the high flushing rate of spring melt. Porewater concentrations for Zn and other metals increased by more than one order of magnitude as the flushing rate decreased while pH dropped to values between 2 and 3. Thus, while relatively fresh tailings are expected to be neutral to slightly basic in pH, older tailings will become acidic as sulphide oxidation progresses, removing all neutralization potential. The acidic tailings chemistry in Table 3 is intended to bracket both fresh and oxidized scenarios.

In general, the ranges of parameter concentration for each material type in Table 3 appear to be reasonable estimates of leachate chemistry given the limitations in the data. They are consistent in concentration and range with data observed in the field from both surface and porewater.

References

Elberling, B., 2001. Environmental controls on the seasonal variation in oxygen uptake in sulfidic tailings deposited in a permafrost-affected area. Water Resources Research, 37(1): 99-107

Lorax, 1999. Acid generation potential of tailings and shale cover material: Kinetic testing final report. Prepared for Nanisivik Mine.

Parkhurst, D.L. and Appelo, C.A.J., 1999. User's guide to PHREEQC (version 2) - a computer program for speciation, batch reaction, one-dimensional transport, and inverse geochemical calculations. Report # 99-4259, Submitted to US Geological Survey, Denver, CO. 312 pp.

Part E

Results of the Water Quality Projection

Nanisivik Mine, WTDA Polishing Pond Zinc Projections, Normal Climate Conditions, Closure Years 1 to 5

Variables:	WT Dyke toe area	2	ha @	0.15	contact	
	TC Dyke toe area	2	ha @	0.15	contact	
	Surface Cell talik	32,400	m^3 (5-years) @	0.025	mg/L	
	Test Cell talik	18,000	m^3 (5-years) @	0.025	mg/L	

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	6-mos.	Year	% of loading
avg rain (m)	0	0	0	0	0.001	0.013	0.032	0.032	0.015	0.002	0	0	0.095	0.095	
avg melt (m)	0	0	0	0	0.007	0.109	0.029	0	0.001	0.001	0	0	0.147	0.147	
% of annual melt	0%	0%	0%	0%	5%	74%	20%	0%	1%	1%	0%	0%	100%	100%	
Outflow from Surface Cell (m3/s)	included directly into "Runoff into Reservoir"														
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	included directly into "Runoff into Reservoir"														
Runoff over WT Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff over TC Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff/Precip into Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.005	0	0	0.030	0.015	
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	0	0	0	0	1.5	15.0	6.0	3.0	1.5	0.7	0	0	27.7	27.7	79%
Porewater Expelled SC (m3/s)	0	0	0	0	0.0003	0.001	0.0004	0.0002	0.0002	0.0002	0	0	0.0002	0.0001	
Zinc Concentration (mg/L)					0.025	0.025	0.025	0.025	0.025	0.025					
Zinc Loading (kg)	0	0	0	0	0.02	0.1	0.03	0.01	0.01	0.01	0	0	0.2	0.2	0.5%
Porewater Expelled TC (m3/s)	0	0	0	0	0.0001	0.001	0.0002	0.0001	0.0001	0.0001	0	0	0.0001	0.0001	
Zinc Concentration (mg/L)					0.025	0.025	0.025	0.025	0.025	0.025					
Zinc Loading (kg)	0	0	0	0	0.01	0.04	0.02	0.01	0.01	0.01	0	0	0.1	0.1	0.3%
Total: Outflow from Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.01	0	0	0.03	0.015	
Flow (m3)					27912	264509	109336	54600	26890	14284			497532	497532	
Total: Zinc Loading (kg)	0	0	0	0	1.5	15.3	8.2	5.3	3.3	1.2	0.0	0.0	35.0	35.0	100%
Calc: Zinc Concentration (mg/L)					0.055	0.056	0.075	0.098	0.119	0.084			0.072	0.073	

Nanisivik Mine, WTDA Polishing Pond Zinc Projections, Normal Climate Conditions, Closure Years 5 to 10

Variables: WT Dyke toe area 2 ha @ 0.15 contact
TC Dyke toe area 2 ha @ 0.15 contact
Surface Cell talik 12,960 m^3 (5-years) @ 0.033 mg/L
Test Cell talik 9,900 m^3 (5-years) @ 0.041 mg/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	6-mos.	Year	% of loading
avg rain (m)	0	0	0	0	0.001	0.013	0.032	0.032	0.015	0.002	0	0	0.095	0.095	
avg melt (m)	0	0	0	0	0.007	0.109	0.029	0	0.001	0.001	0	0	0.147	0.147	
% of annual melt	0%	0%	0%	0%	5%	74%	20%	0%	1%	1%	0%	0%	100%	100%	
Outflow from Surface Cell (m3/s)	included directly into "Runoff into Reservoir"														
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	included directly into "Runoff into Reservoir"														
Runoff over WT Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff over TC Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff/Precip into Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.005	0	0	0.030	0.015	
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	0	0	0	0	1.5	15.0	6.0	3.0	1.5	0.7	0	0	27.7	27.7	80%
Porewater Expelled SC (m3/s)	0	0	0	0	0.0001	0.000	0.0002	0.0001	0.0001	0.0001	0	0	0.0001	0.0000	
Zinc Concentration (mg/L)					0.033	0.033	0.033	0.033	0.033	0.033					
Zinc Loading (kg)	0	0	0	0	0.01	0.0	0.02	0.01	0.01	0.01	0	0	0.1	0.1	0.2%
Porewater Expelled TC (m3/s)	0	0	0	0	0.0001	0.000	0.0001	0.0001	0.0001	0.0001	0	0	0.0001	0.0000	
Zinc Concentration (mg/L)					0.041	0.041	0.041	0.041	0.041	0.041					
Zinc Loading (kg)	0	0	0	0	0.01	0.04	0.01	0.01	0.01	0.01	0	0	0.1	0.1	0.2%
Total: Outflow from Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.01	0	0	0.03	0.015	
Flow (m3)					27322	262008	108334	54141	26413	13807			492024	492024	
Total: Zinc Loading (kg)	0	0	0	0	1.5	15.3	8.2	5.3	3.3	1.2	0.0	0.0	34.9	34.9	100%
Calc: Zinc Concentration (mg/L)					0.056	0.057	0.076	0.098	0.121	0.087			0.073	0.073	

Nanisivik Mine, WTDA Polishing Pond Zinc Projections, Normal Climate Conditions, Closure Years 10 to 15

Variables:	WT Dyke toe area	2	ha @	0.15	contact
	TC Dyke toe area	2	ha @	0.15	contact
	Surface Cell talik	11,160	m^3 (5-years) @	0.051	mg/L
	Test Cell talik	3,600	m^3 (5-years) @	0.101	mg/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	6-mos.	Year	% of loading
avg rain (m)	0	0	0	0	0.001	0.013	0.032	0.032	0.015	0.002	0	0	0.095	0.095	
avg melt (m)	0	0	0	0	0.007	0.109	0.029	0	0.001	0.001	0	0	0.147	0.147	
% of annual melt	0%	0%	0%	0%	5%	74%	20%	0%	1%	1%	0%	0%	100%	100%	
Outflow from Surface Cell (m3/s)	included directly into "Runoff into Reservoir"														
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	included directly into "Runoff into Reservoir"														
Runoff over WT Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff over TC Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff/Precip into Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.005	0	0	0.030	0.015	
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	0	0	0	0	1.5	15.0	6.0	3.0	1.5	0.7	0	0	27.7	27.7	80%
Porewater Expelled SC (m3/s)	0	0	0	0	0.0001	0.000	0.0002	0.0001	0.0001	0.0001	0	0	0.0001	0.0000	
Zinc Concentration (mg/L)					0.051	0.051	0.051	0.051	0.051	0.051					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	0.02	0.01	0.01	0.01	0	0	0.1	0.1	0.3%
Porewater Expelled TC (m3/s)	0	0	0	0	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0	0	0.0000	0.0000	
Zinc Concentration (mg/L)					0.101	0.101	0.101	0.101	0.101	0.101					
Zinc Loading (kg)	0	0	0	0	0.01	0.03	0.01	0.01	0.01	0.01	0	0	0.1	0.1	0.2%
Total: Outflow from Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.01	0	0	0.03	0.015	
Flow (m3)					27148	261272	108039	54006	26272	13666			490404	490404	
Total: Zinc Loading (kg)	0	0	0	0	1.5	15.3	8.2	5.3	3.3	1.2	0.0	0.0	34.9	34.9	100%
Calc: Zinc Concentration (mg/L)					0.057	0.057	0.076	0.098	0.122	0.088			0.073	0.073	

Nanisivik Mine, WTDA Polishing Pond Zinc Projections, Normal Climate Conditions, Closure Years 15 to 20

Variables: WT Dyke toe area 2 ha @ 0.15 contact
TC Dyke toe area 2 ha @ 0.15 contact
Surface Cell talik 10,440 m^3 (5-years) @ 0.141 mg/L
Test Cell talik 0 m^3 (5-years) @ mg/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	6-mos.	Year	% of loading
avg rain (m)	0	0	0	0	0.001	0.013	0.032	0.032	0.015	0.002	0	0	0.095	0.095	
avg melt (m)	0	0	0	0	0.007	0.109	0.029	0	0.001	0.001	0	0	0.147	0.147	
% of annual melt	0%	0%	0%	0%	5%	74%	20%	0%	1%	1%	0%	0%	100%	100%	
Outflow from Surface Cell (m3/s)	included directly into "Runoff into Reservoir"														
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	included directly into "Runoff into Reservoir"														
Runoff over WT Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff over TC Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff/Precip into Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.005	0	0	0.030	0.015	
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	0	0	0	0	1.5	15.0	6.0	3.0	1.5	0.7	0	0	27.7	27.7	79%
Porewater Expelled SC (m3/s)	0	0	0	0	0.0001	0.000	0.0001	0.0001	0.0001	0.0001	0	0	0.0001	0.0000	
Zinc Concentration (mg/L)					0.141	0.141	0.141	0.141	0.141	0.141					
Zinc Loading (kg)	0	0	0	0	0.03	0.1	0.05	0.02	0.03	0.03	0	0	0.3	0.3	0.9%
Porewater Expelled TC (m3/s)	0	0	0	0	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0	0	0.0000	0.0000	
Zinc Concentration (mg/L)					0.000	0.000	0.000	0.000	0.000	0.000					
Zinc Loading (kg)	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.0	0.0	0.0%
Total: Outflow from Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.01	0	0	0.03	0.015	
Flow (m3)					27056	260880	107882	53934	26197	13591			489540	489540	
Total: Zinc Loading (kg)	0	0	0	0	1.5	15.4	8.2	5.3	3.3	1.2	0.0	0.0	35.0	35.0	100%
Calc: Zinc Concentration (mg/L)					0.057	0.057	0.076	0.099	0.122	0.089			0.073	0.074	

Nanisivik Mine, WTDA Polishing Pond Zinc Projections, Normal Climate Conditions, Closure Years 20 to 25

Variables:						
WT Dyke toe area	2	ha	@	0.15	contact	
TC Dyke toe area	2	ha	@	0.15	contact	
Surface Cell talik	2,844	m^3 (5-years)	@	0.291		mg/L
Test Cell talik	0	m^3 (5-years)	@			mg/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	6-mos.	Year	% of loading
avg rain (m)	0	0	0	0	0.001	0.013	0.032	0.032	0.015	0.002	0	0	0.095	0.095	
avg melt (m)	0	0	0	0	0.007	0.109	0.029	0	0.001	0.001	0	0	0.147	0.147	
% of annual melt	0%	0%	0%	0%	5%	74%	20%	0%	1%	1%	0%	0%	100%	100%	
Outflow from Surface Cell (m3/s)	included directly into "Runoff into Reservoir"														
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	included directly into "Runoff into Reservoir"														
Runoff over WT Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff over TC Dyke toe area (m3/s)	0	0	0	0	0.00001	0.0001	0.0001	0.00004	0.00002	0.000003	0	0	0.00005	0.00002	
Zinc Concentration (mg/L)					0.3	0.3	6	12	18	24					
Zinc Loading (kg)	0	0	0	0	0.01	0.1	1.1	1.2	0.9	0.2	0	0	3.5	3.5	10%
Runoff/Precip into Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.005	0	0	0.030	0.015	
Zinc Concentration (mg/L)					0.056	0.056	0.056	0.056	0.056	0.056					
Zinc Loading (kg)	0	0	0	0	1.5	15.0	6.0	3.0	1.5	0.7	0	0	27.7	27.7	80%
Porewater Expelled SC (m3/s)	0	0	0	0	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0	0	0.0000	0.0000	
Zinc Concentration (mg/L)					0.291	0.291	0.291	0.291	0.291	0.291					
Zinc Loading (kg)	0	0	0	0	0.02	0.1	0.03	0.01	0.01	0.01	0	0	0.2	0.2	0.5%
Porewater Expelled TC (m3/s)	0	0	0	0	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0	0	0.0000	0.0000	
Zinc Concentration (mg/L)					0.000	0.000	0.000	0.000	0.000	0.000					
Zinc Loading (kg)	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.0	0.0	0.0%
Total: Outflow from Reservoir (m3/s)	0	0	0	0	0.01	0.10	0.04	0.02	0.01	0.01	0	0	0.03	0.015	
Flow (m3)					26893	260190	107606	53807	26065	13459			488021	488021	
Total: Zinc Loading (kg)	0	0	0	0	1.5	15.3	8.2	5.3	3.3	1.2	0.0	0.0	34.9	34.9	100%
Calc: Zinc Concentration (mg/L)					0.057	0.057	0.076	0.099	0.123	0.089			0.073	0.073	