CanZinco Ltd.
Nanisivik Mine
Closure and Reclamation Plan

Volume 2 of 2
Supporting Documents

A. 2001 Environmental Site Assessment and Proposal for Phase 2 ESA, Gartner Lee Limited, February 28, 2002.
B. Reclamation Cover Design for Nanisivik Mine West Twin Disposal Area Surface Cell, Gartner Lee Limited, March 08, 2002.
C. Pseudostatic Analysis for Seismic Stability of West Twin Lake Dyke, Closure Planning for Nanisivik Mine, NU, BGC Engineering Inc., February 5, 2002.
D. Report on Hydrological Study Nanisivik Spillway Design, Golder Associates Ltd., February 2002.
E. Preliminary Design of the West Twin Dike Spillway for Closure, Nanisivik Mine, NU, BGC Engineering Inc., February 28, 2002.

Prepared for:

CanZinco Ltd.

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REPORT ON

HYDROLOGICAL STUDY
NANISIVIK SPILLWAY DESIGN

Submitted to:

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EXECUTIVE SUMMARY

Nanisivik Mine is in the process of submission of the Closure and Restoration Plan to the Nunavut Water Board. As part of the plan preparation, Golder Associates has been retained by Nanisivik Mine to carry out a hydrological study of the proposed spillway from the Surface Cell in the West Twin Disposal Area (WTDA).

The main objective of the hydrological study was to determine peak water levels in the tailings basin corresponding to various input precipitation events and spillway configurations. The hydrological study involved a review of the background information, regulations, meteorological records, and hydrological modelling.

Study Conclusions

- The amount of rainfall and snowmelt at the Nanisivik Mine is small. Therefore, a comparatively small spillway is required at the Nanisivik Mine, even to convey extreme floods.

- According to the classification provided in the Dam Safety Guidelines of the Canadian Dam Association, the consequences of potential failure of Twin Lake Dyke are considered to be minimal. No loss of lives is anticipated and financial and environmental damages would be low. On that basis, it would be adequate to design the spillway for a 1:100 to 1:1000 year flood. It is recommended, however, that the spillway be designed to convey the PMP event. Such an approach should simplify the approval of the Closure and Restoration Plan by the agencies, but will not add to the cost of the spillway construction.

- The extreme daily rainfall and snowmelt amounts at Nanisivik are comparable. The daily rainfall PMP event is estimated to be approximately 140 mm. The daily snowmelt PMP event is estimated to be 155 mm. (For comparison, a daily PMP event in Northern Ontario is approximately 500 mm to 700 mm).

- The spillway is assumed to be a rectangular channel, 6 m wide, 1.5 m to 2 m deep, with a longitudinal slope of the sections ranging from 1% to 4%. The total length of the spillway will be approximately 450 m.

- The simulated peak water level in the tailings basin resulting from a PMP event is approximately 0.6 m.

- The spillway width affects the peak water level in the tailings basin. If the spillway width is 5 m rather than 6 m, then the simulated water level is approximately 0.1 m higher, (i.e. approximately 0.7 m).

- If the spillway slope is 1% or less, the flow over the spillway would be sub-critical most of the time. If the spillway slope is greater than 2%, the flow over the spillway would be super-critical most of the time. The range of spillway slopes between 1% and 2% corresponds to a transitional zone, where the flow could be either sub-critical or super-critical.

- When the flow is super-critical (spillway slope greater than 2%), the spillway would act as a weir. The flow control section would be at the inlet, and the peak water level in the tailings basin would be independent of the slope.

- In the transitional zone (spillway slopes between 1% and 2%), the spillway longitudinal slope has a marginal impact on the peak water level. The calculated difference in the simulated peak levels corresponding to a 1% slope and a 2% slope is 2 cm only, which is likely to be beyond the accuracy of the calculations. Generally, this conclusion was expected because from the flow in the channel is proportional to the square root of the longitudinal slope.

- Peak velocities on the spillway range from approximately 1.6 m/s to 3.3 m/s depending on the spillway slope of 1% to 4%, respectively. The corresponding flow depths range approximately from 0.3 m to 0.6 m. The spillway should be protected from erosion, especially in the potential locations of hydraulic jump (e.g., spillway outlet to Reservoir).

- There is no requirement for additional pond storage upstream of the Twin Lake Dam. From the hydrological perspective, such storage would not add any benefit. The spillway is adequate to convey the runoff without using pond storage to reduce peak flows. It is understood that any standing water could adversely affect the integrity of the frozen tailings.

Study Recommendations

- It is recommended that the Nanisivik Mine spillway be designed to convey the PMP event.

- It is recommended that the flow regime, hydraulic jump conditions, and the flow velocities be confirmed once the final spillway alignment has been selected.

- It is recommended that a hydrological study be carried out for the entire tailings water management system, which includes the Surface Cell, Reservoir, East Twin Lake, the Polishing Pond with the decant station, and the Twin Lakes Creek. The study should

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1.0 INTRODUCTION

1.1 Background

The Nanisivik Mine, located on the Borden Peninsula of Baffin Island in the Nunavut Territory, is a base metal mine that has been in production for over twenty years. The mine operates under the Nunavut Water Board License (NWB1NAN9702 dated July 31, 1997).

As per **Part H, Item 2** of the Water License, the Nunavut Water Board requested that an abandonment plan be submitted for the restoration of surface lands on the Nanisivik property. A Final Closure and Restoration Plan will be submitted as required to the Board, as the life of mine plan is developed and decisions made on the ultimate date of closure (September 2002).

The mine Closure and Restoration Plan should address the post-closure tailings water management. Therefore, the design of water control structures is a component of the plan. In October 2001, Golder Associates (Golder) was retained to assist in hydrological assessment and preliminary hydraulic design of the spillway at the tailings dam.

1.2 Surface Drainage Conditions

The existing system of the tailings water management at Nanisivik Mine consists of the following components (Figure 1):

- The Surface Cell – the main deposition area for the tailings solids.
- The West Twin Dyke – confines the Surface Cell and separates it from the a lower water retention pond, called the Reservoir.
- The Reservoir – receives siphoned tailings water from the Surface Cell.
- Stop Log Control structure – controls discharge from the Reservoir.
- Polishing Pond – receives outflow from the Reservoir and provides additional water clarification.
- Decant Station – control water effluent from the Polishing Pond to the environment.
- Twin Lakes Creek – receives discharge from the Polishing Pond. The creek drains in the north-westerly direction and eventually discharges to the Strathcona Sound.

After the mine closure, water will drain from the Surface Cell by gravity. Therefore, an overflow spillway needs to be constructed at the south abutment of the West Twin Dyke.

1.3 Objectives and Scope of Work

The objective of the study is to provide hydrological analysis and preliminary hydraulic design of an overflow spillway from the Surface Cell.

The scope of work for this hydrological assessment was defined in the Proposal dated October 11, 2001. The scope of work includes the following activities:

- Review of background information, previous studies, and available references concerning site hydrology.

- Identify and review relevant regulations and information to determine the appropriate flood design criterion for the mine closure. Golder will review the mine license, the downstream land uses, the Dam Safety Guidelines of the Canadian Dam Association (CDA) and other relevant information. (According to the CDA requirements, the inflow design flood may range from 1/100 year event to PMP event depending on the expected consequences of the dam failure.).

- Review and, if necessary, extend the extreme rainfall analysis conducted by Golder in 1998-99. The analysis will include statistical evaluation of rainfall events, snow accumulation and melt, combined effect of rain+snow events, and Probable Maximum Precipitation (PMP) analysis.

- Estimate the inflow hydrographs to the tailings pond area corresponding to various design scenarios. Selection of the critical storm duration will be essential for the selection of the appropriate event (extreme rainfall or snowmelt) and proper design of the spillway.

- Evaluate the impact of the tailings pond capacity on the dimensions of the spillway.

- Determine dimensions, configuration, and invert elevation of the spillway and downstream ditch as required to carry the peak outflows from the design event after routing through storage.

- Identify flow velocities and locations where the erosion protection is required.

2.0 SPILLWAY HYDROLOGICAL ANALYSIS

2.1 Background Information Review

Golder has reviewed the following sources of information:

- Golder, 1998. Report on 1998 Geotechnical Inspection of Waste Containment Dykes. Nanisivik Mine. Baffin Island. Report 982-2432-5100.
- BGC Engineering Inc., 2001. Nanisivik Mine. A Division of Canzinco Ltd. 2001 Geotechnical Inspection of Waste Containment Dikes. Project No. 0255-003
- Nanisivik Mine, 2000. Interim Abandonment and Restoration Plan 2000. NWB1NAN9702
- W.D. Hogg and Carr D.A, 1985. Rainfall Frequency Atlas of Canada. A Publication of Canadian Climate Program.
- Meteorological Survey of Canada, 2002. Rain+Snowmelt Intensity, Duration, Frequency Values for Nanisivik Airport Prepared by the Hydrometeorology Division, Canadian Climate Centre.

2.2 Regulations Review

2.2.1 Canadian Dam Association

Dam Safety Guidelines prepared by the Canadian Dam Association (CDA) provide direction on the selection of floods for the design of dams and discharge facilities (CDA, 1999). The requirement of the guidelines is that the dams should be designed to pass safely an Inflow Design Flood (IDF). The selection of the IDF shall be based on the consequences of failure.

The consequences of failure are categorized as follows:

- Very High, which involves large number of fatalities and extreme damages
- High, which involves some fatalities and large damages
- Low, which involves moderate damages and does not anticipate any fatalities.

The IDF is selected based on the above rating of the consequences of failure as follows:

- Very High Consequences – Probable Maximum Flood (PMF).
- High – Annual Exceedance Probability (AEP) between 1/1000 and the PMF.
- Low – AEP between 1/100 and 1/1000.

2.2.2 Northwest Territories Water Board

The Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories (Water Board, 1990) classify the abandoned tailings disposal areas based on potential environmental impact. We assume that these guidelines have been adopted by Nunavut.

Three levels of impact are distinguished: low, medium, and high. The design criteria for abandoned tailings impoundment structures are established as follows:

- Low Impact: Worst case of 1 in 50 year storm or seismic event
- Medium Impact: Worst case of 1 in 100 year storm or seismic event
- High Impact: Worst case of 1 in 200 year storm or seismic event

2.2.3 Nanisivik Mine License

It is our understanding that the mine license and the Interim Abandonment and Restoration Plan (Nanisivik Mine, 2000) do not contain specific requirements for the hydraulic design conditions at closure. Therefore, there are no specific hydraulic design commitments that the Nanisivik Mine has taken and must fulfil at closure.

2.2.4 Regulations Review - Conclusions

The hydraulics design criteria of the Dam Safety Guidelines are more stringent than those of the Northwest Territories Water Board guidelines. Consideration should be given to both guidelines as well as the Nanisivik meteorological conditions to select the most appropriate hydraulic design criteria.

2.3 Extreme Precipitation Analysis

Flooding in the northern environment could potentially be caused by different physical phenomena: rainfall or snowmelt. The design rainfall is derived from the statistical characteristics of rain, which is measured using automatic rain gauges. The snowmelt is calculated based on the air temperature, precipitation, and snow accumulation of the ground. The calculated snowmelt values in fact represent snow+rain intensities, i.e., they account for the combined effect of rainfall and snowmelt.

Often it is not obvious which phenomenon produces higher flooding. Typically, rainfall causes higher flooding at small watersheds and snowmelt causes higher flooding at large watersheds, but there is no single rule that tells whether snowmelt or rainfall causes the extreme flood. Therefore, it is necessary to compare the floods generated from rainfall and from snowmelt and use the more extreme events for the spillway design.

The extreme rainfall and snowmelt data are discussed in the following sections.

2.3.1 Rainfall Analysis

Golder contacted Meteorological Service of Canada and confirmed that the intensity-duration-frequency relationship for the Nanisivik Airport Climate Station was not available. The closest station to the Nanisivik Mine for which Meteorological Service of Canada could provide the rainfall IDF values was Pond Inlet Airport. These values had been obtained earlier and presented in the 1998 Geotechnical Inspection Report (Golder, 1998).

The Pond Inlet Airport Climate Station is situated approximately 220 km east of the mine site. Considering the substantial distance between the mine and the climate station, it was felt important to confirm that representative extreme rainfall data are used for the analysis. Consequently, the rainfall IDF relationship for the Nanisivik Mine was developed using the Rainfall Frequency Atlas of Canada. The limitations of the rainfall maps from the atlas are noted: the maps were developed based on the scarce rainfall monitoring network, using interpolation between remote stations. Nevertheless, the derived IDF values from the maps helped confirm what extreme rainfall is representative for the Nanisivik Mine. This rainfall IDF relationship is listed in Table 1.

The rainfall IDF values derived for the Nanisivik Mine were compared with those for the Pond Inlet Airport (Table 2). As can be seen from Table 2, the IDF values at the two locations are consistent, though the rainfall volumes derived for the Nanisivik Mine appear to be marginally higher (e.g., daily 100-year storm of 41 mm at the Nanisivik Mine and 36 mm at the Pond Inlet Airport). Consequently, the rainfall IDF values derived for the Nanisivik Mine from the Rainfall Atlas of Canada were used in the hydrological calculations.

The daily PMP event based on the Nanisivik Mine rainfall data is estimated to be 140 mm, which is consistent with the previous estimates (Golder, 1998).

2.3.2 Snowmelt Analysis

As mentioned above, the snowmelt can not be measured directly. Therefore, numerical models are employed to calculate the snowmelt amounts corresponding to various durations and return periods. The snowmelt estimates are based on degree-day type equations. The input data used in the calculation of the snowmelt estimates are daily maximum and minimum temperatures, daily rainfall total and daily depth of fresh snow measurements by ruler.

Meteorological Service of Canada uses five variations of the snowmelt models for different regions of Canada (e.g., Eastern Canada, Western Canada, Southern Ontario). There is no snowmelt model specifically developed for the Northwest Territories or Nunavut. Therefore, the results of all five models were reviewed and interpreted for the Nanisivik Mine.

The snowmelt models provide annual extreme values for durations from 1 to 30 days and estimated amounts for return periods up to 100 years. The calculated 100-year return, daily snowmelt amounts range from 27 mm/day to 49 mm/day; the average value between the five models is 35 mm/day.

The daily PMP due to the snowmelt is estimated to be 155 mm/day. This is a conservative estimate.

2.3.3 Comments on Extreme Precipitation

Generally, the extreme rainfall amounts at the Nanisivik Airport are fairly low. As a comparison, the daily PMP events in Northern Ontario range from 400 mm to 700 mm. A typical daily 100-year rainfall is approximately 100 mm. Therefore, Nanisivik Mine is likely to require comparatively small spillway.

The snowmelt volumes generated at Nanisivik are comparable to the rainfall for the duration of interest (daily and shorter).

Low precipitation allows the mine to design the outflow structure capable of handling the extreme events with high return period at a reasonable cost.

2.4 Design Storm Selection

The selection of the precipitation input for hydrological design involves definition of the following parameters:

- Type of event (rainfall or snowmelt).
- Design storm duration.
- Design storm temporal distribution.
- Return period (frequency) of the event.

2.4.1 Type of Event (Rainfall or Snowmelt)

The comparison of daily snowmelt and rainfall demonstrated that the two phenomena produce approximately equal amounts of water. For example, as discussed earlier, daily 100-year rainfall is estimated to be 41 mm and daily 100-year return snowmelt ranges from 27 mm to 49 mm, 35 mm being the average value. Similarly, the daily rainfall PMP is estimated to be approximately

140 mm and the daily snowmelt PMP is estimated to be 155 mm. Both PMP estimates fall within the range of 140 mm to 210 mm reported for the site previously (Golder, 1998).

The extreme snowmelt estimates appear to be marginally higher than the extreme rainfall estimates, but the differences are small. Given that the uncertainty and extrapolation errors associated with the estimate of extreme precipitation events (especially PMP), it can be concluded that the snowmelt (estimated 155 mm) and the rainfall (estimated 140 mm) are comparable.

2.4.2 Design Storm Duration

The design storm duration is selected based on the watershed size and properties. Typically, when the peak runoff from the watershed is of interest, the storm duration should be equal to the time of concentration of the watershed. When the reservoir routing is involved, however, the critical storm duration (the duration of the storm that results in he highest water level in the reservoir) may be longer because of the reservoir attenuation.

The West Twin Lake watershed area is approximately 127 ha; the watershed length is approximately 1300 m. The time of concentration in this watershed is likely to be a few hours. Consequently, the design calculations for the West Twin Dyke spillway were carried out using daily (24 hours) and 12-hour rainfall events and daily snowmelt event.

2.4.3 Design Storm Temporal Distribution

Temporal distribution of a precipitation event affects how the event passes through the tailings basin, though its impact is typically less pronounced than that of the event volume and duration. Three types of storm distribution were utilised in the hydrological analysis:

- Chicago Storm distribution (Keifer and Chu, 1957) for rainfall events.
- Atmospheric Environment Service (AES) storm distribution (NRCC, 1989) for rainfall events.
- Uniform distribution for snowmelt events

The “Chicago storm” represents the method of design storm derivation from the rainfall IDF values rather than the storm pattern typical for Chicago (which is probably quite different from the storm pattern at Nanisivik). The IDF data for Nanisivik Mine were used to derive the storm pattern for the hydrological analysis.

The AES storm distribution from the Prairies was used to evaluate the sensitivity of the spillway hydraulic performance to the incoming rainfall pattern. The snowmelt was represented using the uniform distribution.

Generally, the impact of the precipitation pattern on the spillway hydraulic performance is much less than that of the return period of the event. In other words, the selection of a PMP event versus a 100-year event affects the hydraulic design more than the selection of the temporal distribution for either event. Numerical analysis confirmed this observation (discussed later in the text.).

2.4.4 Return Period of Design Event

The main considerations in selecting the return period of the design event are as follows:

- The consequences of failure, which include potential loss of life, financial and environmental damages.
- The cost of the structure, which includes, for example, considerations of practicality, such as construction methods, size of construction equipment, maintenance requirements.

Consequences of Failure – Loss of Life

Nanisivik Mine is situated in a remote area. There are currently no people living “downstream” of the potential dyke failure impact area and we assume that this situation will continue after the mine closure. Therefore, the fatalities in case of the West Twin Dyke failure are not anticipated.

Consequences of Failure – Financial and Environmental

It is our understanding that the property damage resulting from the potential dyke failure would also be minimal. If the dyke fails, some of the frozen tailings will erode and move downstream. The extent of erosion will be limited because of the permafrost conditions. The monetary damage, therefore, would likely to be limited to the cost of collection the escaped tailings, placement them back to the tailings basin, and restoration of the dyke. It is understood, however, that in the event of a significant dike failure the cost of restoration could prove to be very expensive if heavy equipment would have to be shipped to the site.

The environmental damage would be associated with an increase in concentrations of suspended sediments, lead and zinc sulphides in the receiving stream.

Consequences of Failure - Summary

Based on the review of potential consequences of the West Twin Dyke failure, we believe that the resulting damages could be classified as low to moderate. Therefore, according to the Dam Safety Guidelines, the spillway should be designed for a 100-year to a 1000-year flood.

Cost Considerations

There are certain limitations on the dimensions of the structure that could be constructed. Because the amount of precipitation at Nanisivik is low, the required spillway may be small, but due to the construction techniques (e.g., blasting) and equipment (e.g., size of the excavator bucket), the spillway may have to be larger than hydraulically necessary.

It is our understanding that the depth of the spillway channel can not be less than 1.5 m to 2 m because blasting of the permafrost and rock will be employed. It is also understood that the width of the spillway will not be less than 5 m due to the size of the construction equipment. Therefore, the hydraulic performance of the smallest structure that could be practically constructed was assessed for various design events.

2.4.5 Recommended Design Storm

Based on the considerations of the consequences of failure and cost of structure, it is recommended that the PMP event be used for the spillway design. This recommendation is conservative. It should simplify the approval of the Closure and Restoration Plan by the agencies, but should not add to the cost of the spillway construction.

Planning the tailings basin closure for a PMP event should simplify the approval process. At the same time, the selection of the PMP event for the design does not add to the cost of the spillway structure.

2.5 Hydrological Modelling

Hydrological models mimic physical processes in the watershed and simulate the response of the watershed to the rainfall and snowmelt input. The GAWSER model (Guelph All-Weather Sequential Event Runoff model) was used for the hydrological simulation of the Nanisivik Mine tailings basin. This model is widely used in Canada for various types of hydrological analyses.

The objective of the hydrological modelling was to simulate peak water levels in the tailings basin and to evaluate their sensitivity to various scenarios of the spillway configuration. The sum of the peak water level and the desired freeboard indicates the required vertical distance between the spillway invert and the dam crest. The optimal combination of the spillway configuration, invert elevation, dam crest, and upstream storage could be determined from the analysis.

2.5.1 Modelling Approach

West Twin Dyke Watershed

The West Twin Dyke drainage area is approximately 127 ha. The area was measured using a planimeter from the topographic map provided in digital form by BGC Engineering.

It was assumed that the ground in the watershed has low permeability. Therefore, the soil properties were selected to represent small losses of precipitation and high runoff.

Tailings Basin

The shape of the tailings basin defines the storage upstream of the dyke and affects the flood routing through the basin. It was assumed that after the mine closure the tailings surface would slope at 1% from West to East, toward the West Twin Dyke. The deep reservoir hole that serves at present for the tailings disposal will be filled. The upstream slope of the West Twin Dyke was assumed to be 1.5H:1V. The dyke length was assumed to be 900 m. The elevation-storage relationship for the basin formed by the dyke and the tailings was calculated accordingly.

Spillway

The conceptual plan for the spillway and potential scenarios for the spillway alignment were provided to Golder by BGC Engineering. It was assumed in the analysis that the spillway would be a channel of the following geometry:

- Approximate width: 5 m to 6 m.
- Longitudinal slope: from 1% to 4%.
- Side slopes: vertical side walls were assumed
- Hydraulic roughness (Manning's) coefficient: 0.035
- Invert: at the lowest point in the tailings basin (point of contact of the tailings surface and the dyke).

The elevation-discharge relationship for the tailings basin was developed from the hydraulic calculations of flow in the spillway channel.

Design Precipitation Events

As discussed earlier, the analysis was carried out for a 24-hour rainfall PMP (140 mm), 12-hour rainfall PMP (94 mm), and daily snowmelt PMP (155 mm).

Simulated Scenarios

The “base case” of the spillway was assumed to be a channel 6 m wide, 1.5 m deep, with vertical side walls (rectangular cross-section), and a longitudinal slope of 1%. This is a conservative case from the perspective of overestimating the water levels in the tailings basin. For example, if the side walls of the channel are not vertical (the cross-section is trapezoidal), its hydraulic capacity will be higher and the water level in the tailings basin will be lower. Similarly, the longitudinal slope of the channel is likely to be greater than 1%. Therefore, its hydraulic capacity will be higher and the water level in the tailings basin will be lower.

The effect of the channel width and slope on the peak water level in the tailings basin was considered.

Backwater Effect

The flow in the spillway was simulated assuming normal flow conditions. It is understood that the Reservoir, which receives the effluent from the Surface Cell, is located approximately 14 m lower than the Surface Cell. It is unlikely that the water level in the West Twin Lake could rise sufficiently high to create a backwater in the spillway.

Outflow Conditions

The flow regime at the spillway could be either sub-critical or super-critical (critical flow being the boundary conditions between the two). Understanding of the flow regime helps determine what affects the outflow rate from the Surface Cell.

If the flow in over the spillway is super-critical, then the flow rate is fully governed by the spillway inlet and does not depend on its slope and geometry. In other words, the hydraulic capacity of the spillway invert controls the discharge over the spillway, and the discharge is the same whether the spillway slope is 3% or 10%. Similarly, modifications to the spillway geometry would have no effect on the outflow rate.

If the flow regime at the spillway is sub-critical, the discharge depends on the slope, channel shape, and roughness. Then modifications to these parameters of the spillway would affect the outflow rate from the Surface Cell.

Hydraulic calculations demonstrated that for the spillway longitudinal slope of 1% or less, the flow regime is primarily sub-critical. For the spillway longitudinal slope of greater than 2% the flow regime is primarily super-critical. At 2% longitudinal slope, normal depths are close to the critical depths, so either sub-critical or super-critical flow regime could occur.

It is understood that the spillway is likely to be steep (more than 2% slope) because of the substantial elevation drop between the proposed spillway inlet and outlet. Therefore, super-critical flow conditions would prevail.

Super-critical flow in the channel is typically associated with a hydraulic jump. The hydraulic jump involves a rapid increase in the flow depth, reduction in the flow velocity, and extensive channel erosion. Potential locations of the hydraulic jump should be evaluated, and erosion protection measures implemented at those locations. For example, it is likely that the hydraulic jump would take place at the at the point of effluent from the spillway to West Twin Lake.

Flow Velocities

The flow velocities depend on the spillway slope. For the maximum design discharges (corresponding to the PMP events), the flow velocities range from approximately 1.6 m/s (longitudinal slope of 1%) to 3.3 m/s (longitudinal slope of 4%). The corresponding flow depths range approximately from 0.3 m to 0.6 m. There are various design monographs for the selection of the rip-rap size for erosion protection. For example, for the velocity of 3.3 m/s, the recommended rip-rap size ranges from approximately 30 kg (equivalent spherical diameter of 0.25 m) to approximately 200 kg (equivalent spherical diameter of 0.5 m). Please note that the rip-rap sizes are provided here for illustration purposes only. Proper geotechnical design of the erosion protection measures should be carried out.

2.5.2 Modelling Results

The results of the hydraulic analysis are summarized in Table 3. The following observations could be made from Table 3:

- The peak simulated water level in the tailings basin resulting from a PMP event is approximately 0.6 m.
- The peak water level in the tailings basin resulting from a 500-year event is approximately 0.3 m, from a 100-year event – approximately 0.25 m.
- If the spillway slope is 1% or less, the flow over the spillway would be sub-critical most of the time. If the spillway slope is greater than 2%, the flow over the spillway would be super-critical most of the time. The range of spillway slopes between 1% and 2% corresponds to a transitional zone, where the flow could be either sub-critical or super-critical.
- When the flow is super-critical (spillway slope greater than approximately 2%), the spillway would act as a weir. The flow control section would be at the inlet, and the peak water level in the tailings basin would be independent of the slope.
- In the transitional zone (spillway slopes between 1% and 2%), the spillway longitudinal slope has a marginal impact on the peak water level. The calculated difference in the

simulated peak levels corresponding to a 1% slope and a 2% slope is 2 cm only, which is likely to be beyond the accuracy of the calculations. Generally, this conclusion was expected because from the flow in the channel is proportional to the square root of the longitudinal slope.

- Peak velocities on the spillway range from approximately 1.6 m/s to 3.3 m/s depending on the spillway slope. The corresponding flow depths range approximately from 0.3 m to 0.6 m. The spillway should be protected from erosion, especially in the potential locations of hydraulic jump (e.g., spillway outlet to the Reservoir).

- The spillway width affects the peak water level in the tailings basin. If the spillway width is 5 m rather than 6 m, then the simulated water level is approximately 0.1 m higher, i.e. approximately 0.7 m.

- The peak water level simulated from a 12-hour rainfall PMP is approximately 0.5 m, which is marginally lower than that corresponding to a 24-hour event (approximately 0.6 m).

- The simulated peak water level from the snowmelt PMP event is approximately 0.4 m. The snowmelt PMP water level appears to be lower than the rainfall PMP water level because of the different temporal distributions assumed for rain and snow events: uniform distribution for snowmelt and non-uniform distributions for rainfall.

- There is no requirement for additional pond storage upstream of the West Twin Dike. From the hydrological perspective, such storage would not add any benefit. The spillway is adequate to convey the runoff without using pond storage to reduce peak flows. It is understood that any standing water could adversely affect the integrity of the permafrost.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

- The amount of rainfall and snowmelt at the Nanisivik Mine is small. Therefore, a comparatively small spillway is required at the Nanisivik Mine, even to convey extreme floods.

- According to the classification provided in the Dam Safety Guidelines of the Canadian Dam Association, the consequences of potential failure of Twin Lake Dyke are considered to be minimal. No loss of lives is anticipated and financial and environmental damages would be low. On that basis, it would be adequate to design the spillway for a 1:100 to 1:500 year flood. It is recommended, however, that the spillway be designed to convey the PMP event. Such an approach should simplify the approval of the Closure and Restoration Plan by the agencies, but will not add to the cost of the spillway construction.

- The extreme daily rainfall and snowmelt amounts at Nanisivik are comparable. The daily rainfall PMP event is estimated to be approximately 140 mm. The daily snowmelt PMP event is estimated to be 155 mm. (For comparison, a daily PMP event in Northern Ontario is approximately 500 mm to 700 mm).

- The spillway is assumed to be a rectangular channel, 6 m wide, 1.5 m to 2 m deep, with a longitudinal slope of the sections ranging from 1% to 4%. The total length of the spillway will be approximately 450 m.

- The simulated peak water level in the tailings basin resulting from a PMP event is approximately 0.6 m.

- The spillway width affects the peak water level in the tailings basin. If the spillway width is 5 m rather than 6 m, then the simulated water level is approximately 0.1 m higher, (i.e. approximately 0.7 m).

- If the spillway slope is 1% or less, the flow over the spillway would be sub-critical most of the time. If the spillway slope is greater than 2%, the flow over the spillway would be super-critical most of the time. The range of spillway slopes between 1% and 2% corresponds to a transitional zone, where the flow could be either sub-critical or super-critical.

- When the flow is super-critical (spillway slope greater than 2%), the spillway would act as a weir. The flow control section would be at the inlet, and the peak water level in the tailings basin would be independent of the slope.

- In the transitional zone (spillway slopes between 1% and 2%), the spillway longitudinal slope has a marginal impact on the peak water level. The calculated difference in the simulated peak levels corresponding to a 1% slope and a 2% slope is 2 cm only, which is likely to be beyond the accuracy of the calculations. Generally, this conclusion was expected because from the flow in the channel is proportional to the square root of the longitudinal slope.

- Peak velocities on the spillway range from approximately 1.6 m/s to 3.3 m/s depending on the spillway slope of 1% to 4%, respectively. The corresponding flow depths range approximately from 0.3 m to 0.6 m. The spillway should be protected from erosion, especially in the potential locations of hydraulic jump (e.g., spillway outlet to the Reservoir).

- There is no requirement for additional pond storage upstream of the West Twin Dike. From the hydrological perspective, such storage would not add any benefit. The spillway is adequate to convey the runoff without using pond storage to reduce peak flows. It is understood that any standing water could adversely affect the integrity of the frozen tailings.

3.2 Recommendations

- It is recommended that the Nanisivik Mine spillway be designed to convey the PMP event.

- It is recommended that a hydrological study be carried out for the entire tailings water management system, which includes the Surface Cell, Reservoir, East Twin Lake, the Polishing Pond with the decant station, and the Twin Lakes Creek. The key issues to be addressed in the study include the following:
  - Characterisation of the post-closure water management system, including documentation of the flow control structures that will be removed, upgraded, and left unchanged.
  - Flood routing through Reservoir.
  - Assessment of hydraulic capacity of the decant station.

- It is recommended that the flow regime, hydraulic jump conditions, and the flow velocities be confirmed once the final spillway alignment has been selected.

- It is recommended that the erosion protection be designed to withstand the expected flow velocities.

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Table 1
Rainfall Intensity-Duration-Frequency Values. Nanisivik Mine

Storm Duration (min)	5	10	15	30	60	120	360	720	1440
Mean, mm	0.7	1.1	1.4	2.0	4.1	6.0	8.5	11.0	15.8
ST Dev, mm	0.5	0.7	0.6	0.7	1.2	1.5	3.3	5.5	8
Return Period	Rainfall Volumes (mm)								
T =2 Yr	0.6	1.0	1.3	1.9	3.9	5.8	8	10	14
T = 5 Yr	1.1	1.6	1.8	2.5	4.9	7.1	11	15	22
T = 10 Yr	1.4	2.0	2.2	2.9	5.6	8.0	13	18	26
T=20 Yr	1.6	2.4	2.5	3.3	6.2	8.8	15	21	31
T = 50 Yr	2.0	2.9	3.0	3.9	7.1	9.9	17	25	37
T = 100 Yr	2.3	3.3	3.3	4.3	7.7	10.7	19	28	41
T = 200 Yr	2.5	3.7	3.6	4.6	8.3	11.5	21	31	45
T = 500 Yr	2.9	4.2	4.0	5.2	9.2	12.6	23	35	51
PMP	8.2	11.6	10.4	12.8	21.4	29	58	94	136

Storm Duration (min)	5	10	15	30	60	120	360	720	1440
Return Period	Rainfall Intensities (mm/hr)								
T =2 Yr	7.4	5.9	5.2	3.8	3.9	2.9	1.3	0.8	0.6
T = 5 Yr	12.7	9.6	7.3	5.0	4.9	3.5	1.8	1.2	0.9
T = 10 Yr	16.2	12.1	8.7	5.9	5.6	4.0	2.1	1.5	1.1
T=20 Yr	19.6	14.4	10.1	6.7	6.2	4.4	2.4	1.8	1.3
T = 50 Yr	24.0	17.5	11.8	7.7	7.1	4.9	2.8	2.1	1.5
T = 100 Yr	27.2	19.8	13.1	8.5	7.7	5.4	3.1	2.4	1.7
T = 200 Yr	30.5	22.1	14.4	9.3	8.3	5.8	3.4	2.6	1.9
T = 500 Yr	35	25.1	16.1	10.3	9.2	6.3	3.8	2.9	2.1
PMP	98	70	42	25.6	21.4	14	9.7	7.8	5.7

Note: the IDF values developed using the Rainfall Frequency Atlas of Canada

Table 2

Comparison of 100-year Return Rainfall at Nanisivik Mine and Pond Inlet Airport

Rainfall Duration, hours	Rainfall Volume, mm	
	Nanisivik Mine	Pond Inlet Airport
1	7.7	7.5
12	28	28
24	41	36

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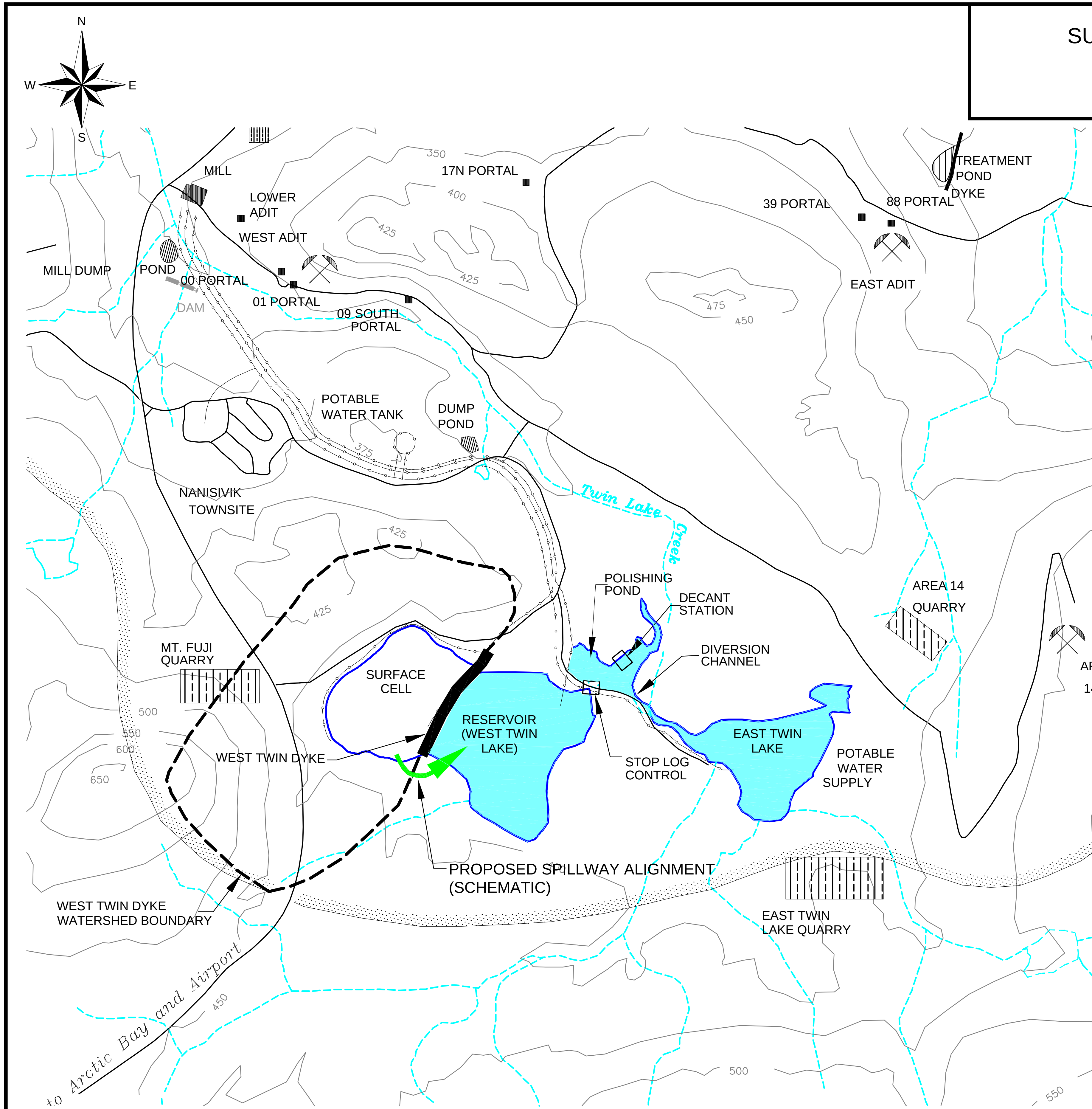
Table 3
Summary of Spillway Hydrological Analysis
West Twin Dyke, Nanisivik Mine

Precipitation Event				Spillway Dimensions			Peak Water Depth	Comments
Temporal Distribution	Return Period	Duration	Volume	Longitudinal slope	Width	Side Slope		
	yrs	hours	mm	%	m		m	
Chicago	**PMP**	**24**	**136**	**1%**	**6**	**vertical walls**	**0.6**	**Base case**
Chicago	100	24	41	1%	6	vertical walls	0.3	effect of return period
Chicago	500	24	51	1%	6	vertical walls	0.3	effect of return period
Chicago	PMP	24	136	**>2%**	6	vertical walls	0.6	effect of slope
Chicago	PMP	24	136	1%	**5**	vertical walls	0.7	effect of width
Unhiform	PMP	24	155	1%	6	vertical walls	0.4	effect of snow
AES	PMP	24	136	1%	6	vertical walls	0.7	effect of storm distribution
AES	PMP	**12**	94	1%	6	vertical walls	0.5	effect of storm duration
AES	PMP	24	136	1%	**5**	vertical walls	0.8	effect of width

SURFACE WATER MANAGEMENT PLAN
NANISIVIK MINE TAILINGS AREA

FIGURE 1



SOURCE: DIGITAL MAP PROVDED BY BGC ENGINEERING

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Date FEBRUARY 2001

Project 011-1838

Golder Associates

Drawn TDR

Chkd AG

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