Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 5I:
Hydrology of Waste Rock Piles in Cold Climates

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Hydrology of Waste Rock Piles in Cold Climates - Volume 5I

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REPORT

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1.0 INTRODUCTION

This memorandum summarizes recent studies characterizing the hydrology of waste rock piles at mine sites located in cold climates. A set of climatic data are provided in a concurrent memorandum for inputs to predictive water and heat transport calculations for the Kiggavik waste rock piles.

This summary provides a background for predictions of seepage from proposed waste rock piles at the Kiggavik and Sissons Project (Kiggavik), operated by AREVA Resources Canada, Inc. (AREVA). Detailed hydrological assessment of a waste rock pile is required for estimates of mass loading to locations of regulatory compliance. Such assessment is also required for calculation of water balance at a mine site and for evaluation of the potential for collecting seepage from a waste rock pile for re-use in the processing of ore.

2.0 WASTE ROCK STUDY SITES

Many studies report geochemical conditions or seepage chemistry from waste rock piles in cold climates in Alaska, northern Canada, Greenland, Sweden, and Russia. Only a few of these studies, however, have included detailed hydrological analysis that has been reported publicly.

Comprehensive research studies have investigated the hydrology of waste rock piles in subarctic climates at the Faro site in the Yukon, the Cluff Lake and Key Lake sites in Saskatchewan, and at the Aitik site in northern Sweden. Studies conducted at the Red Dog site in northern Alaska, the Ekati site in the Northwest Territories, and the Svea site in northern Norway, each in a region of continuous permafrost, have reported some detail regarding waste rock hydrology. A research project at the Diavik site in the Northwest Territories has reported detailed hydrological results from waste rock piles that are the closest approximation to the proposed piles at Kiggavik.

Expected climatic and physical characteristics of the waste rock at Kiggavik are provided here for reference to the sites discussed below. Kiggavik is located 80 km west of Baker Lake, Nunavut, in a region of continuous permafrost with a mean annual temperature of approximately -12°C (1946 to 2008; Environment Canada). Mean annual precipitation at Baker Lake is 344 mm, of which 169 mm is rainfall. At Kiggavik, U deposits are hosted in granitic and meta-sedimentary rocks, and hydrothermal alteration zones may extend beyond the economically viable ore (AREVA 2010).

Table 1 provides climate indicators and waste rock types at four study sites located in the Arctic. The Diavik and Ekati sites have a very similar climate and a similar expected waste rock type as expected at Kiggavik, while the Red Dog and Svea sites are somewhat warmer and are likely to have finer-grained waste rock piles. These details and hydrological findings at each study site are discussed below. Several well-studied sites located in the Subarctic are also discussed below.

Table 1: Hydrologic Study Sites of Waste Rock Piles Located in the Arctic

Site	Location	Mean Annual Values				Waste Rock /Ore Type
		Ambient Temperature (°C)	Rainfall (mm)	Snowfall Water Equivalent (mm)	Potential Evaporation (mm)	
Diavik	NWT, Canada	-11 (1959-2006) -9 (1999-2006)	164	187	270	granitic and schist / kimberlite
Ekati	NWT, Canada	-11 (1959-2006) -9 (1999-2006)	164	187	270	granitic and schist / kimberlite
Red Dog	Alaska, USA	-6	170	300	580	shale / Pb-Zn
Svea	Svalbard, Norway	-6 (1975-2005)	93	93		sandstone and shale / coal

Sources of data listed in the table are provided below.

2.1 Diavik: Comprehensive Research Project

2.1.1 Description of Study Site

- Site Name: Diavik Diamond Mines (Rio Tinto, Harry Winston; 2001-present).
- Location: 310 km NE of Yellowknife, Northwest Territories, Canada.
- Waste Rock: full-scale stockpile (~90 ha by 50 m-high) of granitic and schist rocks with low S, low neutralizing potential (NP); three test piles (0.3 and 1.0 ha by 15 m-high) and six lysimeters (2 m-diameter by 2 m-high).

2.1.2 Description of Study

Three 15 m-high test piles and six 2 m-high upper lysimeters were constructed in 2006 at the Diavik diamond mine with additional funding from governmental and international organizations and partnership with four universities. A Type 3 test pile consists of potentially acid generating (PAG) rock, a Type 1 test pile consists of non-acid generating (NAG) rock, and a covered test pile consists of PAG rock that was re-sloped and covered with 1.5 m of glacial till below 3 m of NAG rock. The following instrumentation was installed during construction of the test piles:

- HDPE liner collects all seepage from the base of each test pile;
- discrete lysimeters (qty. 36) under the center of the piles;
- 2 m-high upper lysimeters (qty. 6);
- flow gauges, conductivity, and pH continuously monitored at all outflow;
- TDR and capacitance moisture content sensors (qty. 38; 30 min resolution);
- tensiometer moisture tension gauges (qty. 11; 30 min resolution in summer);

- Soil Water Suction Samplers (qty. ~40; sampled approx. weekly when thawed);
- thermistors (qty. ~500; 4 hour resolution);
- thermal conductivity test ports (qty. 36; measured approx. seasonally);
- gas content (qty. ~750; monthly resolution) and pore-gas pressure ports (qty. 49; 1 min resolution);
- air permeability test ports (qty. 18; tested approx. twice annually); and
- microbiology sampling ports (qty. 9; sampled approx. twice annually).

Experiment design and construction is described by Smith et al. (2009) and Neuner (2009). Hydrologic characterization and results from 2006 and 2007 are given by Neuner (2009) and Neuner et al. (2009). Thermal results from 2006 to 2008 are given by Pham et al. (2009). Air flow is discussed by Amos et al (2009a, b). Geochemistry and microbiology results are not discussed here.

A meteorological station located at Diavik in an area of waste rock fill 1 km from the test piles records ambient air temperature, rainfall, wind speed and direction, total solar radiation, and relative humidity. Pan evaporation has also been measured, but this station was not operational in 2007, when much of the waste rock hydrology presented here was measured. Snow depth at the test piles was estimated visually prior to melt in 2007; safety concerns prohibited direct measurement. Snow depth and density is measured prior to seasonal melt at 3 upland and lowland areas at Diavik and at 19 regional locations (Golder Associates 2008).

As part of the research project, waste rock characterization was carried out both in the lab and field on samples ranging in size from 200 cm^3 to 140 m^3. Characterization included:

- clast size distribution for over 200 samples finer than 10 cm and several samples of 50 m^3 to 140 m^3, porosity of 6 samples of matrix (finer than 5 mm) and one 16 m^3 sample;
- a drain-down test of a 16 m^3 sample to estimate the matrix fraction of the total porosity;
- field capacity of waste rock finer than 1 m filling two upper lysimeters, each with 1.8 m-diameter and 1.7 m height;
- saturated hydraulic conductivity of 18 samples of matrix and one 16 m^3 sample;
- air permeability within the test piles at 6 locations in each pile at depths of 3 m and 6 m;
- infiltration capacity using 90 cm ring infiltrometers at seven locations at the top of one of the uncovered test piles;
- water retention curves generated in the field from three co-located moisture sensors and tensiometers and in the lab with five samples of matrix;

Two tracer tests were conducted at the top surface of one of the uncovered test piles and artificial rainfall events were also conducted at two of the upper 2 m-high lysimeters to investigate flow velocities and the response to high-intensity rainfall.

In addition, monitoring of seepage and any runoff from the full-scale waste rock stockpile at Diavik is incorporated into an annual seepage report for the mine site (Rio Tinto 2010). Inflow volumes and rates to collection ponds are not typically reported. Some of this water is used on site or treated and discharged to Lac de Gras. Seepage rates directly to Lac de Gras are also not typically reported, but are noted to be a minority of the flow as compared to the flow to collection ponds. Two piezometers have been installed near the toe of the waste rock pile to a depth of 0.9 to 1.1 m but each of these have remained frozen and dry since installation (Rio Tinto 2010). Measurements are insufficient to enable an estimate of seepage from the full-scale waste rock pile at Diavik.

2.1.3 Hydrologic and Thermal Findings

Table 2 summarizes the results of hydrologic characterization of the waste rock at Diavik, based on results in Neuner (2009) and Neuner et al. (2009).

Table 2: Hydrologic Characterization of Diavik Waste Rock from Field and Lab Tests

Material Property		Units	Bulk Waste Rock	Waste Rock Matrix
Particle Size Distribution	Boulders	%	32 to 47	
	Cobbles	%	11	
	Gravel	%	29	
	Matrix	%	18	
	Sand	%	11	92
	Silt and Clay	%	1	8
	D_{50}	mm	90	0.5 to 0.9
Porosity		m^3 pores / m^3 sample	0.25	0.23 to 0.27
		m^3 matrix pores / m^3 large-scale sample	0.07	-
Field Capacity		m^3 water / m^3 waste rock	0.05 to 0.07	-
Saturated Hydraulic Conductivity	Minimum	m/s	-	$2 \cdot 10^{-6}$
	Mean	m/s	$1 \cdot 10^{-2}$	$9 \cdot 10^{-6}$
	Maximum	m/s	-	$3 \cdot 10^{-5}$
Air Permeability	Minimum	m^2	$2 \cdot 10^{-10}$	-
	Mean	m^2	$1.5 \cdot 10^{-9}$	-
	Maximum	m^2	$3 \cdot 10^{-9}$	-
Water Retention Curve van Genuchten (1980) model	**α**	kPa^{-1}	0.16	0.1 to 0.9
	n	-	4	1.4 to 2.5
	θ_{sat}	-	0.07	0.16 to 0.24
	θ_{res}	-	0.01	0.005 to 0.05

The granitic and schist waste rock at Diavik is coarse and forms rock-like piles. Porosity of the waste rock was estimated to be 0.25 of the bulk waste rock, based on measurement in a 16 m^3 sample. Drain-down of this sample indicated that approximately 0.18 of the bulk volume consists of large pores available for air flow and rapid water flow under certain conditions. Approximately 0.07 of the bulk volume consists of matrix pores where capillarity affects flow. Estimating the matrix fraction of the porosity crudely by multiplying the total porosity (0.25) by the matrix fraction of the solids (18%) results in an estimate similar to these results from the drain-down test.

Field capacity of the waste rock was estimated to be 0.05 to 0.07 at two 2 m-high lysimeters by evaluating the infiltration over approximately a year that was required to initiate drainage. Saturated hydraulic conductivity determined by a flow test in the 16 m^3 sample was consistent with the mean air permeability of tests conducted within the uncovered test piles. A single hydraulic conductivity function was developed for one of the uncovered test piles by comparing modified Green-Ampt solutions for infiltration events to conductivity functions developed from water retention curves (Neuner 2009; revised in a paper to be submitted in 2010).

The outflow record from the Type 1 uncovered test pile was severely affected by mechanical failure of the drain pipe and outflow estimates from the covered test pile have not yet been reported. The hydrologic findings listed below therefore focus on the Type 3 uncovered test pile.

The following hydrologic findings are reported, based on results from the initial 1.5 years (2006 and 2007) of the research program (Neuner 2009; Neuner et al. 2009):

- Snow Depth prior to melt: 0 cm to 5 cm at top of pile, approx. 150 cm at pile slopes.
- Snowmelt: 0 mm to 15 mm to top of pile, approx. 350 mm to 400 mm to uncovered pile slopes in May.
- Infiltration Capacity and Runoff: 72 mm/h or higher at low-traffic surfaces, 2 mm/h at a moderately-trafficked surface; large-scale surface ponding observed at top of test piles for rainfall 7 mm/h and higher, but no large-scale runoff observed; runoff observed only at high-traffic areas at mine site.
- Infiltration into Frozen Waste Rock: early season rain and snowmelt constituted approximately 20% of annual net infiltration to the top of the test pile and the majority of annual net infiltration to uncovered pile slopes.
- Evaporation: modified FAO-Penman Montieth method (accounts for approx. near-surface moisture content and frozen conditions) matched lysimetry measurements over 40 day period; modified FAO-PM estimate of 92 mm evaporation from the top of the Type 3 test pile.
- Net Infiltration to Top of Pile: calculated on a daily basis using FAO-PM method to be 40% of rainfall (60 mm/y to 70 mm/y) for approximately mean annual rainfall.
- Initial Change in Storage: wet-up of initially dry waste rock proceeded at 1 to 5 m per year; hydrologic dynamic equilibrium exists when the large-scale moisture content changes by approximately 0.01 about a mean of approximately 0.06 (or approximately 60 mm per 1 m depth per unit area).
- Flow Mechanisms: except under infrequent, high-intensity rainfall events, water flows primarily through the matrix material, even though the test piles are classified as rock-like piles.
- Flow Velocities: pore water and non-reactive solutes travelled an order of magnitude slower than wetting fronts, at rates of <0.01 to 0.03 m d-1 in response to common rainfall events and up to 0.7 m/day in response to intense rainfall.
- Pile Outflow: controlled by seasonal thermal behaviour such that outflow from the ~28,000 m^3 Type 3 uncovered pile was greatest (1.8 m^3 d-1) soon after maximum thaw extent was reached in late July; outflow from the test piles is expected to increase as the piles wet-up to hydrologic equilibrium and may become limited by development of permafrost; total outflow in 2007 originated only from the snowmelt-dominated

slopes and was approximately 130 m^3 from an estimated average contributing area of approximately 700 m^2.

- Preliminary Modelling: it is possible to simulate flow in upper lysimeters and uncovered test pile with a simplified homogeneous domain corresponding to measured matrix properties using the standard Richard's flow equation, but models were highly sensitive.

The following findings pertaining to the thermal and gas regimes are reported, based on the initial 2.5 years (2006 to 2008) of the research program (Pham et al. 2009; Amos et al. 2009):

- the uncovered test piles freeze entirely each winter and have thawed entirely or to a depth of approximately 10 m to 14 m each summer;
- the covered test pile slowly cooled toward freezing in the initial 2 years, and by the summer of 2008 temperatures generally remained at or just below 0°C;
- the till cover appears to effectively limit air flow: (1) Temperatures beneath the cover of the covered test pile have changed much more slowly than within the uncovered piles, on the order of several degrees per year, and (2) Oxygen content has declined due to sulfide oxidation reactions;
- exothermic sulfide oxidation reactions appear to provide an insignificant amount of heat to the uncovered test piles;
- moisture content appears to place a relatively small control on heat transfer in the uncovered test piles;
- gradients in pore-gas pressure within one of the uncovered test piles were measured with strong correlation to wind direction and speed and were large enough to provide air velocities on the same order of magnitude as that of convection (tens of meters per day);
- wind-driven advective heat transfer and conductive heat transfer appear to warm the uncovered test piles in summer;
- convection and wind appear to provide a driving mechanism for displacement of warm air with colder air in winter; and
- the uncovered test piles may be too small to accurately represent the thermal regime in the central region of full-scale waste rock stockpile.

Table 3 summarizes independent measurements and estimates of water balance parameters for the Type 3 test pile for the year 2007, based on values presented in Neuner (2009) and Neuner et al. (2009). These measurements and estimates are applicable to the early period of the waste rock pile in which a dynamic equilibrium with respect to the hydrologic and thermal regimes has not yet been established. The pile in 2007 was wetting up (i.e., the change in storage was large) and permafrost may have been establishing within the pile core. Outflow is considered to be equal to net infiltration to the pile as it was collected using lysimetery methodology for the entire pile, and change in storage is solved. Once hydrologic dynamic equilibrium is reached, change in storage is expected to be close to zero except where permafrost is present.

Table 3: Water Balance Estimates for the Uncovered Type 3 Test Pile for the Year 2007: Prior to Establishment of Dynamic Equilibrium within the Pile

	Central Region of Pile	Pile Slopes
Precipitation (mm)	Rainfall: 153* Snowmelt: 5	Rainfall: 93 Snowmelt: 350
Runoff (mm)	0**	0**
Evaporation (mm)	92	50?
Change in Storage (mm)	~80[#]	~340?[##]
Outflow (mm)	0	54[!]

Notes:

** Rainfall includes three applied rainfall events for application of tracers (not applied to pile slopes);*

*** The top surface of the Type 3 test pile is a low- to moderate-traffic surface without compaction and pile slopes were constructed at angle-of-repose without any traffic;*

[#] Computed as change in moisture content in matrix measured by TDR sensors (~+0.15) observed over depth of approximately 3 m attributable to infiltration in 2007 and multiplied by matrix fraction (0.18);

[##] No measurements available; Computed by solving water balance;

[!] Computed as total measured outflow (130 m^3) divided by the full area of the pile slopes (2400 m^2); outflow is interpreted to have actually originated from only approximately 700 m^2 of that area as increase in storage was high over this time period.

Studies at Diavik are ongoing; however no further information is currently available.

2.2 Ekati: Monitoring of Seepage and Pile Temperature

2.2.1 Description of Study Site

- Site Name: Ekati Diamond Mines (BHP-Billiton; 1998-present).
- Location: 315 km NE of Yellowknife, Northwest Territories, Canada.
- Waste Rock: Three stockpiles totaling approximately 400 ha by 50 m-high.

The Ekati diamond mine site includes several ore bodies and three waste rock piles located within 30 km of Diavik in the Northwest Territories of Canada. The geologic and climatic conditions are generally similar to the conditions at Diavik (Table 1).

2.2.2 Description of Study

The Ekati Diamond Mine monitors seepage from three waste rock piles approximately twice annually and reports the results in a Waste Rock Seepage Report (SRK 2010). Approximately 11 seeps around the Panda/Koala pile, 4 seeps around the Fox pile, and 4 seeps around the Misery pile are monitored. Flow measurements at these seeps are recorded manually during monitoring events. Temperature profiles within the waste rock piles are recorded approximately four times annually at approximately 10 locations in the Panda/Koala pile, approximately 6 locations in the Fox pile, and 6 locations in the Misery pile. Historical temperature data from these locations are also reported in the annual seepage report (SRK 2010).

2.2.3 Hydrologic and Thermal Findings

The Waste Rock Seepage Report (SRK 2010) presents historical flow measurements of seepage from the waste rock piles. The report focuses on geochemistry and provides very little interpretation of the flow data. A preliminary review of these historical flow records by this author indicates that the data record is too sparse to allow for any interpretation of trends or comparison to meteorological measurements. The data record indicates significant declines in flow at several locations. It is unclear in the report, however, whether these declines may be due to any operations at the site or due to changes in infiltration or storage within the piles.

The thermal record is much more complete. Temperatures within the waste rock piles recorded from 2000 to 2009 indicate the following (SRK 2010):

- the depth of the seasonally thawed active layer is approximately 2 m to 8 m and up to ~11 m where rock with higher sulfur content (~0.16 wt% S) is concentrated;
- the base of the regions within approximately 50 m of the outer edge of piles are 10°C to 15°C colder than undisturbed natural permafrost located nearby, which is approx. -4°C;
- in the upper ~15 m of the outer regions of the piles temperatures change in response to seasonal changes in ambient temperature; and
- in the central region of one of the piles temperatures have become more stable in the last several years within a range of -1°C to -4°C at one pile, while temperatures in the central region of a newer pile have remained >0°C after 3 years to depth of 37 m.

2.3 Red Dog: Monitoring of Seepage and Study of Cover Options

The Red Dog Pb-Zn mine site in northwestern Alaska is located in a region of continuous permafrost with a mean annual temperature of -6°C. Operation began in 1986 and is expected to cease in approximately 2030. The waste rock pile consists of relatively fine-grained shale and currently covers 190 acre (76 ha). The following information is summarized from the Red Dog Mine Closure and Reclamation Plan (SRK 2005; SRK 2007; SRK 2009).

Mean annual rainfall is approximately 170 mm, and the mean annual snowfall water equivalent is approximately 300 mm. The waste rock is composed of shale. The shale yields a soil-like waste rock with a D50 determined from particle size distribution of 14 samples to range from 4 mm to 20 mm. Porosity of these waste rock samples ranged from 0.20 to 0.43, and the saturated hydraulic conductivity ranged from 5×10^{-8} to 7×10^{-4} m/s. Air entry of a water retention curve generated from one sample was approximately 0.5 kPa.

One-dimensional and two-dimensional modelling was performed using VADOSE/W to determine the net infiltration and to evaluate cover options. Simulations did not account for redistribution of snowfall, and assumed the snowmelt to the top of the pile to be equal to melt to the slopes. Net infiltration to the uncovered waste rock was estimated with 1D simulations that did not account for frozen conditions, to range from 30% to 52% of total precipitation with an average of 41%. Net infiltration for several closure options were also considered using 2D simulations that did account for frozen conditions. These models incorporated the following strategies: (1) compacted waste rock, (2) an overburden cover with “poor” vegetation. Net infiltration through the compacted waste rock was estimated to range from 6% to 13%, and net infiltration through the vegetated overburden cover were estimated to range from 10% to 31% of the total precipitation.

For the purpose of site water balance calculations, it has been concluded from the analysis summarized above that approximately 25% of precipitation will infiltrate through the waste rock cover (SRK 2007). In 2006, 11 Mgal (42,000 m^3) of seepage from the waste rock pile was collected and treated (SRK 2007). This value represents approximately 33% of the rainfall, or approximately 12% of the total precipitation over the area of the pile. Some of the seepage during freshet, however, was not collected but flowed to the tailings facility, and it is uncertain whether some of the collected water may originate as runoff from the slope above the waste rock. Seepage flow in the catchment that includes the Main Waste stockpile and several other stockpiles has to date been less than the value predicted by water balance calculations (SRK 2007). While other factors may contribute, the role of continued wet-up of the piles, even as much as 20 years after construction, may contribute significantly to the water balance.

A field test program consisting of instrumented cover options was planned to commence in 2008. Based the study of SRK (2005) summarized above, the primary function of the covers appears to be to limit infiltration, while development of permafrost within the waste rock pile appears to be considered as a beneficial possibility.

2.4 Svea: Detailed Research Studies

The Svea coal mine site and 40 other small coal waste rock piles are located on Svalbard, an Arctic archipelago 800 km north of continental Norway. Svalbard has a mean annual temperature of -6°C, is located in a region of continuous permafrost, and has an active layer thickness of 1 m to 1.5 m (Hollensen et al. 2009). Mean annual precipitation is 187 +/- 44 mm, of which approximately 50% is snowfall. Waste rock consists of sandstone and shale, with more than 40% greater than 100 mm and a D50 of approximately 10 mm for the finer-than-100 mm fraction.

At one site, seepage from a 22 m-high, 200,000 m^3 waste rock pile was channeled to a weir for continuously logged flow measurement. Seepage rates were as high as 80 L s-1, and total seepage of 145,000 m^3 was recorded over a 100 day period in summer (Sondergaard et al. 2007). Runoff from the slope above the waste rock pile flows into and apparently through the pile during the course of the summer. This runoff, the seasonal variation in temperature, timing of snowmelt, and rainfall placed strong controls on the pile discharge. Instrumentation was installed to a depth of 7 m to measure temperature, moisture content, and oxygen content. Temperature within that pile was approximately +5°C, approximately 10°C warmer than a nearby instrumented talus slope, due to exothermic sulfide oxidation reactions (Hollensen et al. 2009).

2.5 Study Sites in the Subarctic

A brief introduction to four well-studied sites located in subarctic climates is included here to provide further context for predictions of waste rock hydrology at Kiggavik.

Comprehensive research of a 5 m-high test pile and a full-scale waste rock pile was carried out at the Cliff Lake U mine site in northern Saskatchewan, Canada. Cluff Lake has a mean annual temperature of approximately -1°C and mean annual rainfall of 305 mm. Mean annual snowfall is 150 mm, but wind transports snow away from the top of the pile. Waste rock consists predominantly of sandstone. Major findings include the following: macropore flow comprised <0.1% of the net infiltration, except after high rainfall or ponding when it was ~5%; flow velocity through matrix was approximately 1.5 m/yr (Nichol et al. 2005); net infiltration to the test pile was 44% to 55% of rainfall, based on transient infiltration simulations matched to three seasons of detailed outflow data (Marcoline 2008).

Research at the Key Lake U mine site in northern Saskatchewan focused on a 12 m-high test pile that included a deconstruction study and an evaporation study at full-scale pile. Key Lake has a mean annual temperature of approximately -2°C, mean annual rainfall of 321 mm, and mean annual snowfall of 160 mm. Waste rock consists predominantly of sandstone, with trafficked surfaces breaking down to sand. Major findings include the following: evaporation was 61% of rainfall, based on eddy covariance measurements over an 81 day period in summer (Carey et al. 2005); freshening of seepage was associated with flow through coarse material; and frozen regions were found at base of 12m-high test pile during deconstruction of the test pile six years after construction (Stockwell et al. 2006).

The Faro / Anvil Range Pb-Zn mine site in central Yukon Territory, Canada, has been thoroughly studied in association with its status as a contaminated orphaned site. Faro has a mean annual temperature of -2°C and mean annual precipitation of 316 mm. The Faro Mine Closure Alternatives Report and Closure Plan includes little hydrological interpretation with respect to several waste rock piles. Reports containing detailed study on the waste rock (SRK 2008a; SRK 2008b) were not available within the time-frame of this report

Comprehensive research at the Aitik Cu mine site in northern Sweden has included lab-, pilot-, and field-scale studies, tracer studies, in-situ measurements of temperature and O2, flow measurements, water and mass balance calculations, and assessments of scale-dependency. Aitik has a mean annual temperature of +0.6°C and annual precipitation of 680 mm (Lindvall and Eriksson 2003). The waste rock piles cover an area of 400 ha (300 Mt in 2003, 750 Mt at closure) and are deposited on low-permeability glacial till, promoting collection at toe seeps for reuse in milling. A major finding was that preferential flow paths were apparently not activated during several tracer tests in pilot-scale columns and in the field, in tests in which the largest boulders were excluded (Lindvall and Eriksson 2003).

3.0 SUMMARY AND CLOSURE

Hydrologic studies of mine waste rock piles located at four sites in the Arctic are presented. Expected conditions at the Kiggavik site near Baker Lake, Nunavut, are similar to conditions at the Diavik and Ekati mine sites, located in the Northwest Territories of Canada. Initial results from a comprehensive research program at Diavik are summarized, including characterization of the waste rock and results from instrumented test piles and lysimeters. Hydrologic results from studies of waste rock at the Red Dog and Svea mine sites located in the Arctic and some of the major findings from four well-studied sites located in the Subarctic are also presented.

We trust that this report meets your current requirements. Please do not hesitate to contact us with any questions or comments.

Report Signature Page

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