Appendix D

Memo (17 December 2000) – Liese Creek Drystack Tailings Seepage Analysis

Memo (21 December 2000) – Liese Creek Contribution to Water Chemistry in the RTP

amec

Pogo
Project
Memorandum

To	**Karl Hanneman**	File No.	**VM00172 V-2**
From	**Michael Davies**	cc	**Rick Zimmer**
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Date	**17 December 2000**		**Peter Lighthall**
			As Required
			FILE
Subject	Liese Creek Dry Stack Tailings Facility Seepage Analyses - Updated Results		

This memorandum represents an update to the June 15, 2000 memorandum that was appended to the Water Management Plan for the Pogo Project. This memorandum summarizes the additional work that has been carried out as part of feasibility engineering to provide estimates of seepage from the Liese Creek dry stack tailings facility. This additional work includes additional tailings moisture-retention data provided in November from the pilot plant work at Lakefield.

1.0 BACKGROUND

The Pogo tailings storage facility will be constructed using pressure-filtered tailings. Truck dumping, bulldozer spreading, and compaction will be used to develop the facility. All of the tailings placed will be provided with compactive effort, although only compaction of the "summer" shell will be required for structural integrity.

Dry stack tailings facilities have limited seepage potential due to the low saturated hydraulic conductivity of the tailings material, the further suppression of hydraulic conductivity by the degree to which the tailings are dewatered prior to being placed in an unsaturated condition, and the limited potential for the tailings to take on water introduced to the surface of the stack. The lack of infiltration noted with dry stacks is largely a function of the high air entry tension exhibited by the tailings. The air entry tension factor is augmented by the typical geometry and compacted nature of the surface of most dry stacks that promotes runoff of the majority of the water within a reasonable time frame following a precipitation event. Evidence from other dry stacks (e.g. Raglan/La Coipa) indicates that even pooled water on the stack will have very little, if any, infiltration prior to runoff and/or evaporation. As a general rule, unless submerged under an appreciable head of water for prolonged periods, compacted dry stacked tailings do not tend to increase their overall moisture content from their placed condition.

2.0 HYDROLOGICAL ENVIRONMENT

The Pogo project is located in a relatively dry region of central Alaska. Total annual precipitation for the project site, with inclusion of snowfall equivalency, is less than 20 inches. The site is also subject to long, cold winters with little evaporative potential for much of the year. Natural watersheds in the area of the site are characterized by relatively high runoff coefficients (i.e. ratio of water running off the land to that falling onto the land; net of evaporation considerations).

3.0 MATERIAL CHARACTERISTICS

3.1 General

Figure 1 shows a schematic of the hydrological system for the dry stack. The porous media materials of interest from a characterization perspective are:

- Flotation tailings;
- Colluvium/alluvium that mantles the area underlying the dry stack – the thickness of this overburden layer varies considerably over the proposed dry stack footprint.
- Weathered bedrock – a halo of weathered rock appears to exist over the entire area though the depth of weathering varies.
- Fresh bedrock – relatively unaffected by weathering processes and exhibiting a higher degree of induration (~rock quality) and a generally much lower hydraulic conductivity than the weathered bedrock.

The schematic in Figure 1 shows approximate upper bounds to the thickness each of these units (save the fresh bedrock which is assumed for analytical purposes to extend infinitely deep).

3.2 Tailings

Independent laboratories carried out a series of moisture retention tests. In each case, either a Tempe Cell or a device similar to the Tempe Cell was utilized. Tempe Cell tests provide an indication of the soils ability to retain moisture at varying degrees of pore (matric) suction. The tests are actually carried out using pressure and assuming that hysteretic differences between wetting and drying can be ignored if the shape of the wetting and drying curves are approximately the same. For the most part, this is a valid assumption (e.g. Freeze and Cherry, 1979).

The Unsaturated Soil Mechanics Group at the University of Saskatchewan (US) and Klohn-Crippen Consultants (KCCL) in Richmond, British Columbia, were used to provide the test information in 1999 and was the basis for the initial seepage modeling reported in June 2000. The results were very comparable. Saturated hydraulic conductivities for the tailings were determined by triaxial testing in AGRA's Edmonton soil testing laboratory as part of shear strength testing on the tailings carried out in 1999. The US and KCCL results, along with the AGRA laboratory testing, are presented in AGRA (2000).

In the fall of 2000, pilot plant testing was carried out at Lakefield Research in Ontario. Further moisture retention testing was carried out on the flotation tailings as part of the pilot plant program to provide an indication of how consistent the moisture retention characteristic curves were. The work at Lakefield, though carried out at different tailings densities than the previous work (e.g. different initial saturated moisture content), provided a moisture retention characteristic curve that was essentially the same as those obtained previously.

The results of the testing indicate that the flotation tailings will have characteristics curves consistent with non-plastic silts. It is common practice to use "typical" characteristic curves for tailings materials in lieu of project specific testwork. If such an approach had been used (e.g. using the curves suggested by Ho, 1979 or Gonzalez and Adams, 1980), there would be very little difference from the project specific testwork confirming that the Pogo flotation tailings do not appear to be a "unique" material from the perspective of unsaturated media flow mechanics.

From the moisture retention (characteristic) curves available from the three sets of testing information, the hydraulic conductivity of the tailings was estimated by using the saturated hydraulic conductivity as the value at zero matric suction. Figure 2 shows the hydraulic conductivity function for the Pogo flotation tailings based upon the saturated triaxial cell and Tempe Cell moisture retention testing.

For the nominal project moisture content of 15%, the indicated bulk unsaturated hydraulic conductivity for the tailings would be about 1×10^{-3} ft/day or about 3.5×10^{-9} m/s. For comparative purposes, this value of hydraulic conductivity is similar to that for many unfractured rocks and/or glacial till. Due to compaction and depositional effects, there will be some anisotropy to the hydraulic conductivity values and the vertical hydraulic conductivity (the value influences the ability for the stack to seep versus shed water) will likely be 1/10th to 1/20th of the horizontal value with horizontal value being roughly equal to the bulk value determined from laboratory testing.

3.3 Alluvium/Colluvium

Seventeen boreholes have been drilled near the proposed tailings dry stack location over the course of three site investigations (AMEC 2000, AGRA 2000, EBA, 1999). The mantling overburden material encountered in the Liese Creek basin in the vicinity of the dry stack consisted of blocky talus on the steep north facing slopes grading to alluvium and colluvium towards the creek bottom and on the south facing slopes. At the proposed location for the tailings dry stack, overburden thickness ranged from 10 feet on the valley walls to a maximum of 40 feet in the valley bottom. Typically, the alluvium and colluvium consisted of silts and sands with underlying layers of dense to very dense sandy gravels, coarsening to cobbles, and boulders prior to grading into the weathered rock at depth. The vast majority of the gravels, cobbles and boulders encountered in this area were angular to sub angular and appeared to be of diorite origin. Gradation testing of the overburden materials indicated that the finer portion of the colluvium has D_{10} values in the order of 0.08 to 0.2 mm. Using Hazen's law, these D_{10} values correspond to hydraulic conductivities of 6×10^{-5} to 4×10^{-4} m/s. These values correspond well to values measured in a pump test carried out in material of similar gradation near the mouth of Liese Creek. Falling head tests carried out in 1999 in the vicinity of the proposed dry stack also support this range of values. For the most part, this finer portion of the colluvium/alluvium filled the spaces between the larger constituents in the overburden suggesting that, at least in the valley bottom, the sands and gravels would control the bulk hydraulic conductivity of the overburden.

Discontinuous permafrost, up to depths of 9 feet below ground surface, was encountered in the overburden where finer grained materials were present. No ground ice has been located anywhere near the proposed dry stack areas.

Currently, Liese Creek flows on top of the alluvium/colluvium as a result of inhibited infiltration potential. The current water table resides at approximately 10 to 15 feet below Liese Creek and this level would be expected to lower further once the diversion ditch were completed. To maximize the flow capacity of the existing alluvium/colluvium to allow seepage to move in a lateral and downgradient direction (e.g. towards the RTP), maintaining and even augmenting the channels appears logical. The seepage modeling, described below, indicated that having a clear flowpath within the overburden maximizes effective transport of seepage to the RTP and minimizes potential seepage into deeper stratum. The current concept to enhance this flowpath is to strip the majority of the inhibiting organics etc. from the existing channels (main channel and the two upgradient tributaries) and to augment the flow capacity with coarse-grained fill. This fill would act as a flow conduit with hydraulic conductivities several orders of magnitude higher than either the weathered bedrock or fresh bedrock.

3.4 Weathered Bedrock

Seven deep boreholes have been completed near the tailings dry stack. In addition, seismic refraction survey work has been carried out at the midsection of the proposed starter berm. This combined work indicates that the depth of weathering at the proposed dry stack location is relatively shallow. Typically the weathering depth was approximately 20 feet with a maximum depth of 40 feet in the creek bottom. Greater weathering depths, up to 60 feet, were encountered in isolated drainage draws on the slopes above the tailings dry stack. Packer testing carried out in 1999 indicated that the bulk hydraulic conductivity testing of the weathered and highly weathered bedrock is in the range of 10^{-6} to 10^{-7} m/s.

3.5 Fresh Bedrock

The boreholes drilled in the upper portions of Liese Creek consistently revealed fresh, competent diorite, with RQD's typically of 70% and above, at depths of 30 to 40 feet below ground surface. 1999 packer test data suggested that the bulk hydraulic conductivity of the fresh bedrock would be approximately 10^{-9} m/s. Freeze and Cherry would also suggest a number in this range for diorite rock. Several zones of fractured rock were encountered at depth but these were typically clay gouged and would be expected to also have hydraulic conductivities of in the range of 10^{-9} m/s.

Thermistors located in the area of the proposed tailings dry stack indicate that there is no permafrost in the creek bottom and that there is discontinuous permafrost on the valley slopes. Where freezing temperatures are encountered they are typically between 29° and 32°F in the bedrock although in one location one temperature reading of 25°F has been recorded. The presence of permafrost would further suppress the hydraulic conductivity values from the 10^{-9} m/s range but any reliance on such has been ignored in seepage analyses presented in this memorandum.

4.0 SEEPAGE MODEL

4.1 General

The seepage was estimated using the finite element code SEEP/W (GEO-SLOPE, 1998). This code is an industry standard for seepage analyses and can allow modeling of saturated-unsaturated flow regimes. SEEP/W is based upon Darcian mechanics for both saturated and unsaturated flow. In two dimensions, the complex governing equation can be simplified to:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial H}{\partial y}\right)+Q=\frac{d\theta}{dt}$$

where:

- x,y = the two dimensional orthogonal coordinates
- H = the total head at a given point in the porous media
- K_x = hydraulic conductivity (saturated or unsaturated) in the x-direction at a given point in the porous media
- K_y = hydraulic conductivity (saturated or unsaturated) in the y-direction at a given point in the porous media
- Q = applied boundary condition (often a flux)
- θ = volumetric water content at a given point in the porous media

The above equation essentially states that the difference between the flow entering and leaving any given elemental volume in the porous media at a point in time is equal to the change in volumetric water content. In a steady-state system, the transient (∂t term) becomes zero and the more familiar Darcy's Law results.

AMEC has used the SEEP/W program on other dry stack tailings projects with excellent results in all cases where measured in-situ moisture contents are compared.

As described below, the analyses were carried out in two-dimensions using maximum height sections of the drystack (i.e. maximum driving head). An isotropic hydraulic conductivity distribution was also conservatively used to provide upper bound values for seepage rates through the dry stack. Model results were checked against one dimensional column analyses and hand analyses and compared with seepage modeling in other dry stacks to confirm consistency of results.

4.2 Modeling Approach

Initially, one-dimensional column analyses were carried out to check the unit rate of seepage from the dry stack to the underlying colluvium/alluvium. In addition, this column analyses gave estimates for flow into the weathered and fresh bedrock. Values computed from this method presented an upper bound for flow into the bedrock, limited by material hydraulic conductivities since flow could only move vertically in one dimension and eventually would all have to drain through the bedrock foundation. A two-dimensional model was then constructed, based on the previous SEEP/W models. The model was simplified somewhat to allow manual control over the initial pore pressures prior to carrying out transient modeling (e.g. keeping the stack at a an initial moisture content of 15% w/w value from the filtration plant, so as to get a conservative estimate). A flat top, versus the 2% to 10% final and development slopes, was used in modeling the stack with this flat area occurring at approximately the average elevation of the proposed final stack configuration. The geometry under the stack was also simplified by using longer straight sections – this was carried out to assist with numerical stability in the analyses.

4.3 One-Dimensional Model

The one-dimensional model was a simple column of tailings placed at 15% water content (w/w). The column was underlain by 40 feet of colluvium, 40 feet of weathered bedrock and fresh bedrock extended with infinite elements. The properties used were as described in previous analyses (e.g. June 2000) with the exception of the fresh bedrock, which was added with constant hydraulic conductivity function of 10^{-9}m/s. This analysis indicated that the infiltration into the bedrock would be 3 to 4 orders of magnitude less than the flow from the stack.

4.4 Two-Dimensional Model

The two-dimensional model, as stated earlier, was based on the configuration and material properties used in previous analyses. Isotropic hydraulic conductive in the tailings equivalent to the bulk value from laboratory testing was used. Figure 3 shows a sample finite-element mesh used for the analyses. The thickness of both the overburden and weathered bedrock was specified as 40 feet and fresh bedrock extended with infinite elements was added to the bottom of the foundation.

Initial conditions for the transient analyses were calculated by running a steady state analysis on the model with the heads at all nodes in the tailings stack specified, corresponding to the placement moisture content.

The transient analyses was carried out with the following boundary conditions:

- Influx into bottom 15 feet of overburden at upstream end of stack of 1 ft/day (estimated based on ditch leakage and approximate extent of colluvial material).
- Water table kept constant under stack at 10 to 15 feet below original ground (using H(P=0) function – this was required to maintain model conservatism as the diversion ditch leakage estimate was not enough to maintain the water table in its current location.
- Water table downstream of stack specified at 15 feet below ground to be consistent with present conditions.

Transient analysis of the foundation without the tailings stack was carried out using the same initial and boundary conditions specified for the dry stack analyses. This model was used as a basis for comparison with the flows calculated from the tailings stack.

Calculated flows from the stack were similar to the results obtained from previous analyses on similar calibrated drystacks, indicating that the model was calculating reasonable values. A further check on reasonableness is presented later in the memorandum. Seepage flow immediately upon completion of the ultimate dry stack is estimated to be about 6 gpm. This flowrate is a bit higher than would likely be practically realized as the model assumes the stack is placed in its final configuration all at once with a homogenous initial moisture content consistent with initial placement; e.g. 15%. In reality, seepage will take place throughout the operating life of the drystack and the actual average overall moisture content upon drystack completion would be less than 15%. The seepage rate reduces relatively rapidly to less than 5 gpm within 2 years. The flow is projected to decrease to approximately 1 gallon per minute within 50 years. When compared to the flows calculated for the foundation only (e.g. situation where no drystack is present), it was found that the tailings stack caused a slight decrease in flow into the weathered bedrock (in the order of 0.001 gpm) in years 1, 2, 4 and 5 following closure and a slight increase of 0.0005 gpm in year 3. From year 5 onwards, the flow within the weathered bedrock was consistently calculated as identical between having a drystack and not having one. Seepage flow into the fresh bedrock was calculated as 0.010 gpm for all scenarios in each year after closure.

The results tend to indicate that essentially no flow from the tailings stack is expected to enter the bedrock foundation. For all reasonable limits of numerical accuracy, all seepage will tend to remain in the more pervious colluvium/alluvium overburden materials moving laterally to be intercepted by the proposed RTP valley cutoff. This result has been confirmed by simple hand calculations that show that with the relatively steep gradient of the valley, the overburden materials have sufficient capacity to transport the expected ditch leakage and the calculated dry stack seepage.

5.0 SUMMARY OF RESULTS

5.1 Computer Modeling

A number of analyses were carried out. Due to the low degree of saturation of the tailings, model stability was not ideal though the results appeared reasonable and all checks confirmed their reasonableness.

Figure 4 summarizes the predicted total flux leaving the tailings stack as a function of time. Based upon the modeling, the dry stack will provide roughly 6 gpm of seepage at Year 12, which is the first year of the model (e.g. the model conservatively assumes the stack is placed instantaneously at the end of mine life whereas in reality some seepage would be occurring during construction of the stack lowering the initial moisture content below the amount assumed in the analyses). The model assumes the entire drystack has a moisture content of 15% upon closure. Due to the effects of evaporation and seepage during operations, and the predicted minimal infiltration to the drystack, it would be expected that upon closure the average moisture content in the stack would be somewhat less than the placement moisture content. To demonstrate the possible effect of having a lower moisture content upon closure, Figure 4 presents the results for two moisture contents to demonstrate the estimated impact of a modest reduction in moisture content.

For operating seepage estimates, e.g. prior to final stack configuration, estimated seepage rates can be made based upon intermediate modeling using volumetric ratios to the final configuration. During operations, the seepage is estimated to increase approximately linearly from zero to the 4 to 6 gpm range over the life of the mine. Following cessation of tailings placement in the stack, the seepage is predicted to slow to a value of less than 3 gpm after 10 years and continue to reduce over at least the next 40 years.

5.2 Check for Reasonableness of Results

For a simple check of reasonableness, the following computation can be made:

- In-placed moisture content of about 15% on average
- Residual moisture content of about 10% on average (the moisture content that cannot readily be removed from the material by gravity alone – from the characteristic curve for the Pogo flotation tailings, the 10% value appears to be the approximate residual moisture content)
- The 10% residual moisture is further supported by the SEEP/W analyses that shows this as the approximate average moisture content in the dry stack after 50 years, at which time the seepage rate is, for all practical purposes, approaching zero.
- The differential moisture content, 5%, can be assigned a mass by multiplying 5% by 1250 tons/day by 12 years to result in just over 65 million gallons of tailings process water that can seep from the stack by advective processes.
- The seepage modeling by computer indicates seepage will continue over a minimum of 50 years (though diminishing with time as the overall driving head decreases and the in-situ tailings approach their residual moisture content). Using the 50-year timeframe, and averaging the 65 million gallons over the period, an average seepage rate of about 2.5 gpm is indicated. This value is a simplified average but a value that is consistent with the SEEP/W prediction.

Respectfully submitted,

AMEC Earth & Environmental Limited

per Renata K. Wood
Staff Engineer

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per Peter C. Lighthall, P.Eng.
Vice President, Vancouver

[RA2]

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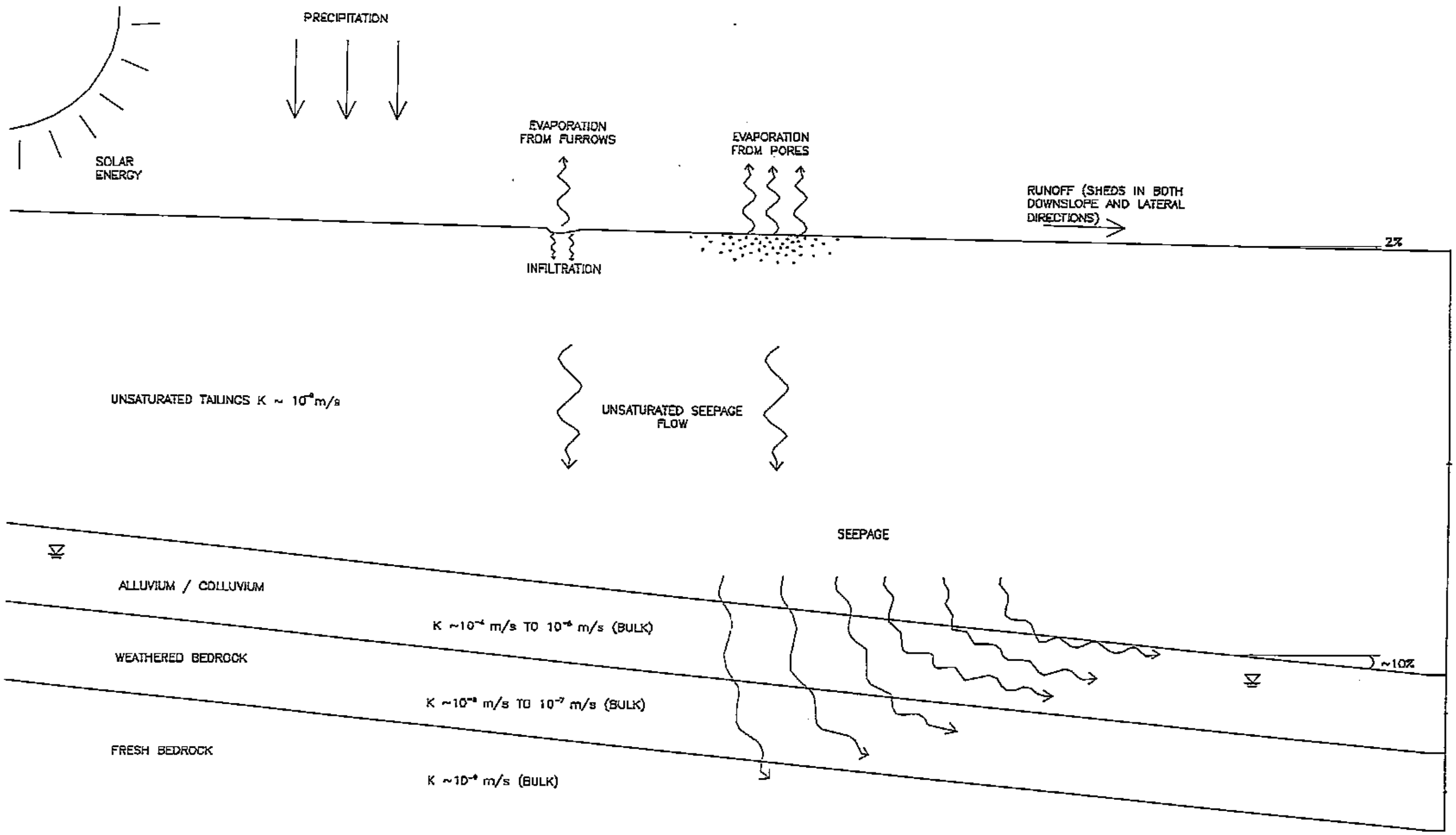

NOTES:

1. SCHEMATIC ONLY (NOT TO SCALE)
2. MAXIMUM SECTION DEPICTED
3. HYDRAULIC CONDUCTIVITIES INDICATED ARE AVERAGE AND BULK (E.G. NEITHER VERTICAL OR HORIZONTAL)

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Client: TECK CORPORATION

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SCALE	NOT TO SCALE

POGO PROJECT

TAILINGS DRY STACK
HYDROLOGIC CYCLE SCHEMATIC

DATE:	DECEMBER, 2000
PROJECT NO:	VM00172.V-2
REV. NO.:	-
FIGURE No.	FIGURE 1

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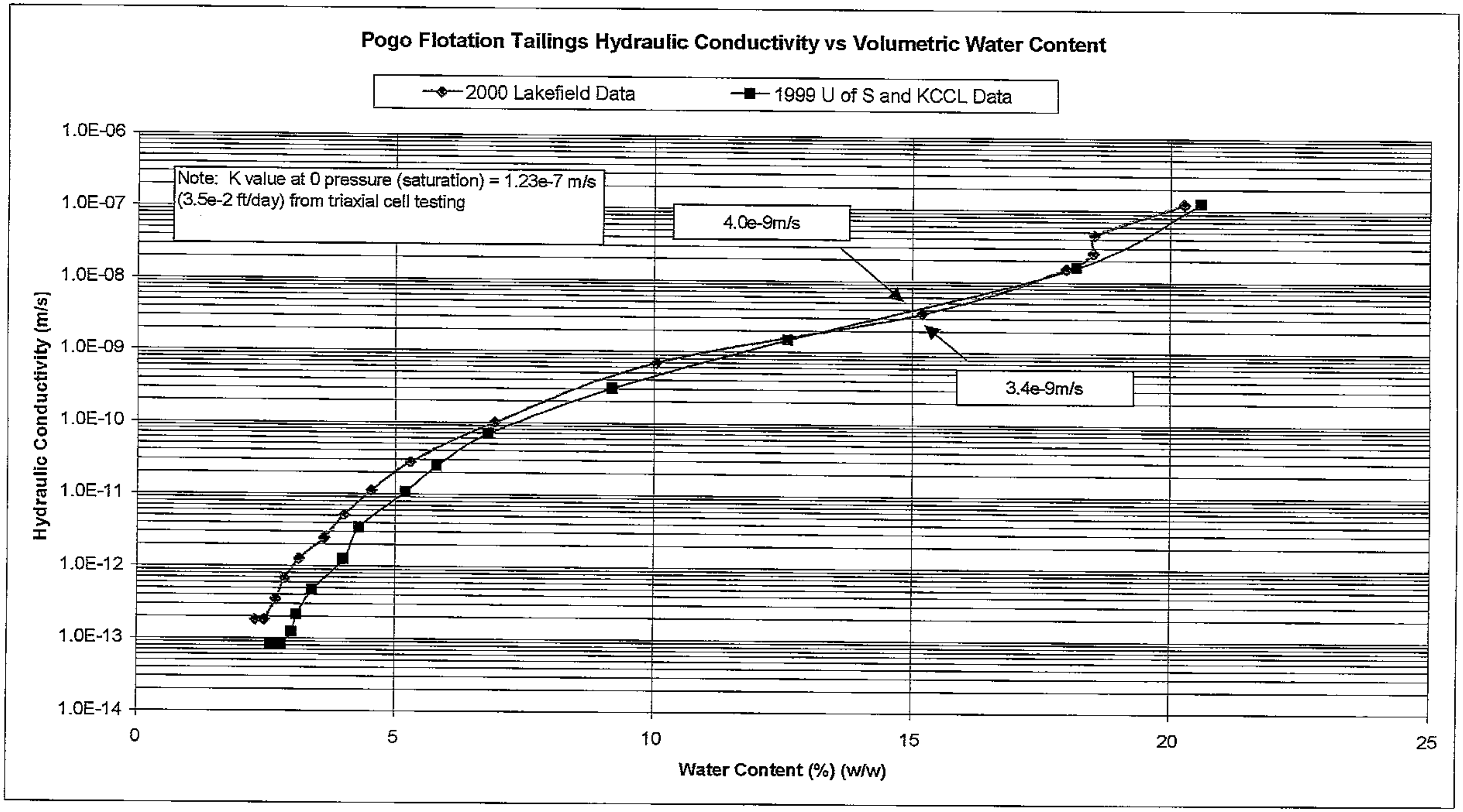

amec	AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. V5C 5A9 Tel. 294-3811 Fax. 294-4664	DWN BY: CHK'D BY: APP.	PROJECT: POGO PROJECT	DATE: DEC.2000 PROJECT NO: VM00172.V-2
Client	TECK CORPORATION	SCALE NOT TO SCALE	TITLE: POGO FLOTATION TAILINGS HYDRAULIC CONDUCTIVITY VS WATER CONTENT	REV. NO.: - FIGURE No. FIGURE 2

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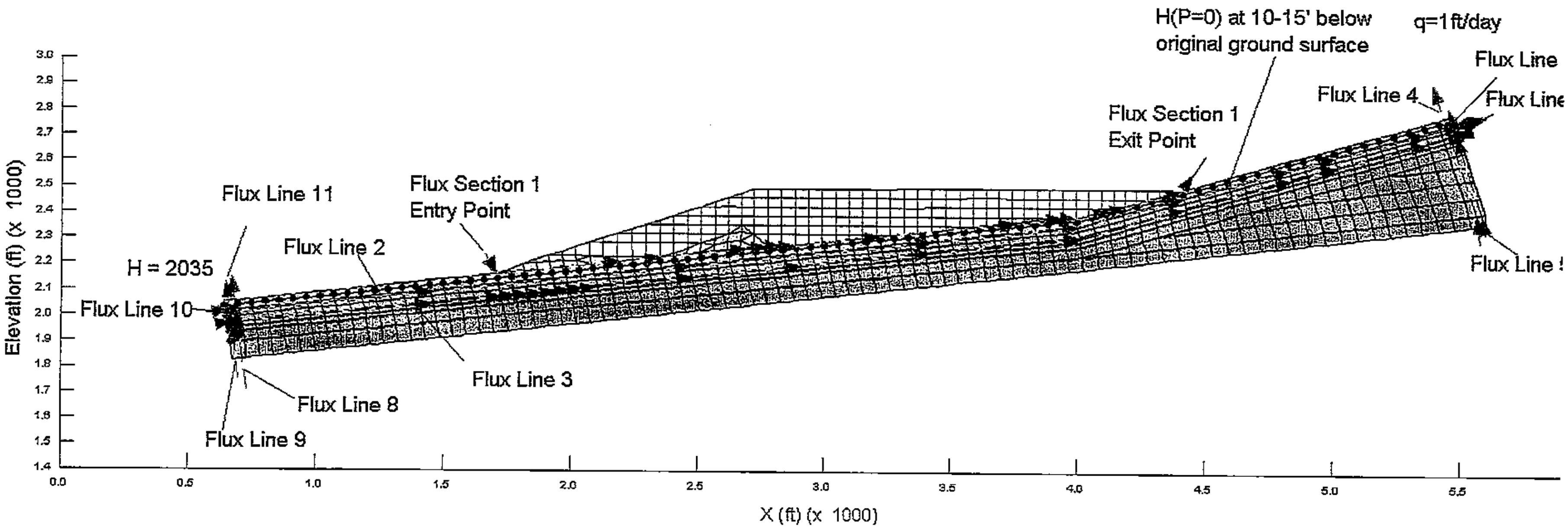
FINITE ELEMENT MESH FOR SEEP/W ANALYSES



amec	AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. V5C 5A9 Tel. 294-3811 Fax. 294-4664	DWN BY:	PROJECT: POGO PROJECT	DATE: DEC.2000
		CHK'D BY:	TITLE: TAILINGS DRY STACK FINITE ELEMENT MESH FOR SEEP/W ANALYSES	PROJECT NO: VM00172.V-2
Client	TECK CORPORATION	APP.		REV. NO.: -
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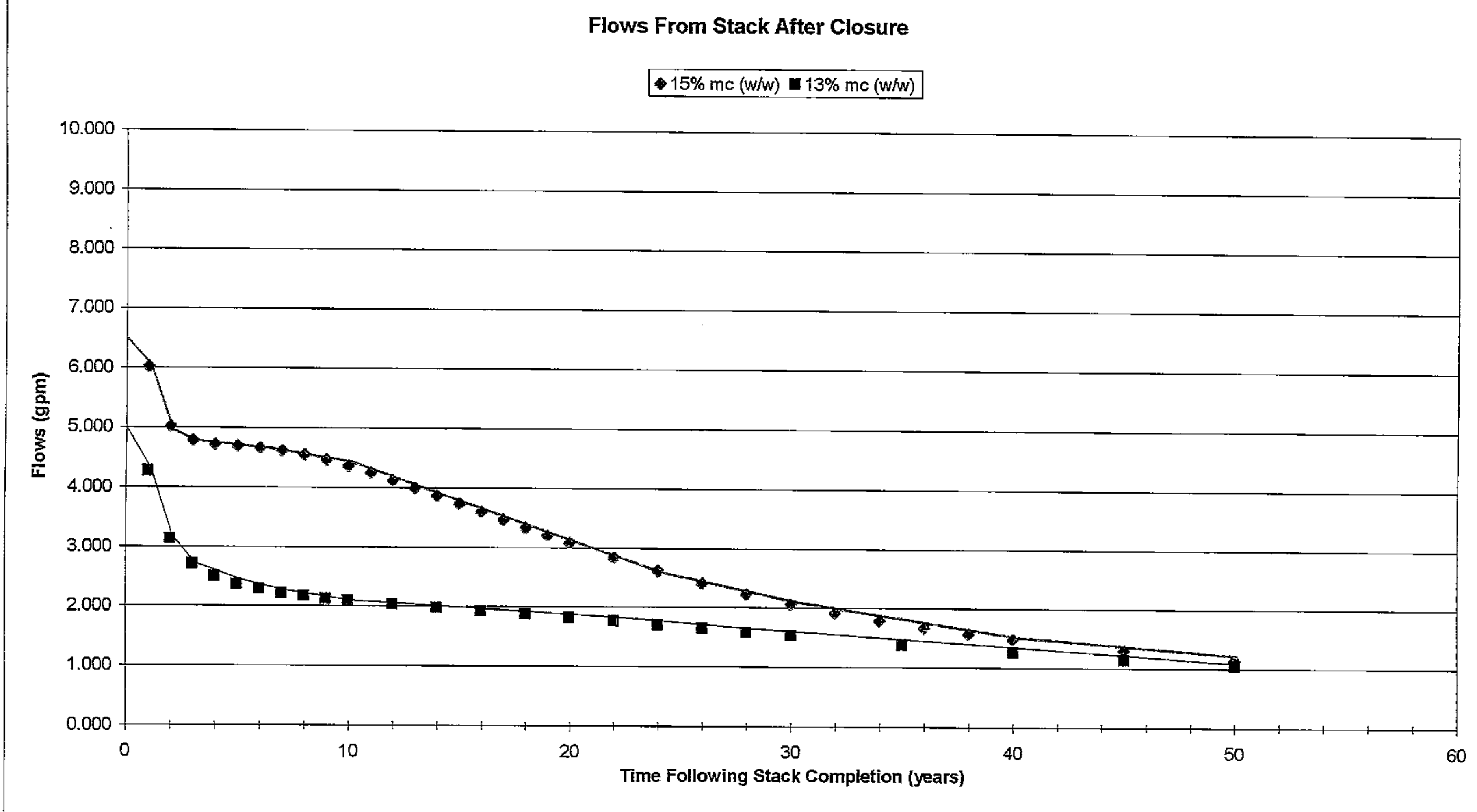

Note: These flows assume the stack was constructed instantaneously.

amec	AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. V5C 5A9 Tel. 294-3811 Fax. 294-4664	DWN BY: CHK'D BY: APP.	PROJECT: POGO PROJECT TITLE: TAILINGS DRY STACK SUMMARY OF FINITE-ELEMENT SEEPAGE ANALYSES	DATE: DEC.2000 PROJECT NO: VM00172.V-2
Client: TECK CORPORATION		SCALE: NOT TO SCALE		REV. NO.: - FIGURE No. FIGURE 4

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Pogo Project Memo

To	**Karl Hanneman**	File No.	**VM00172 V-3**
From	**Bryan Nethery**	cc	**Michael Davies** **Rick Zimmer** **Stephen Day** **As Required** **FILE**
Tel			
Fax			
Date	**22 December 2000**		
Subject	Evaluation of Liese Creek Drystack "Skin" Contribution to Water Chemistry in the RTP		

The purpose of this memorandum is to respond to a request from the Baker EIS team for additional information regarding the potential for the upper layer of the Pogo drystack to contribute leached materials to the RTP. This leaching process is considered to be a combination of evaporative "wicking", in-situ oxidation, and remobilization by precipitation within some finite zone termed the "skin" on the upper surface of the tailings stack.

Some of the material presented in this memorandum has been previously issued in the Water Management Report (Teck, 2000). The testwork presented below was largely presented in the 1999 Geotechnical and Hydrogeological Site Investigation report (AGRA, 1999). Some additional test information is noted below with this latest information coming from the recently competed work at Lakefield Research.

This memorandum was prepared as a collaborative effort with Dr. Michael Davies (AMEC) preparing the material on the drystack characterization and evaporative flow modeling and Mr. Stephen Day (SRK) on the geochemical characterization and predicted runoff chemistry.

SUMMARY

The Pogo drystack would be characterized as a relatively impermeable unsaturated mass of fine-grained tailings - the effective vertical permeability will be in the order of a typical installed clay or synthetic liner with inherent manufacture and installation defects. The Pogo drystack would also be a mass that would have little propensity to either water or air infiltration due to high entry tension in the unsaturated voids.

The drystack tailings mass would have low bulk hydraulic conductivity and a relatively high degree of anisotropy due to placement and compactive methods. Modeling shows that the evaporative potential from these unsaturated materials could be in the order of 3.5 gpm with a depth of evaporative influence of approximately 1 foot (assuming a one month drought). The nature of the materials present at/or near the surface of the stack as a result from this evaporation will impact the runoff water quality. The pore chemistry of the evaporative pore water being carried by run-off water will be somewhat different than the process water chemistry, as some degree of oxidation of the tailings will occur. Based upon the chemical testwork and predictive modeling carried out for the project to date, the run off water quality from the "skin" layer of the drystack would be as estimated in Table 1.

Table 1 – Estimated Water Quality from Drystack Runoff

Parameter	Estimated Water Quality from Drystack Runoff (mg/L)
Ag	0.00001
Al	0.087
As	0.4
B	0.01
Ba	0.008
Alkalinity	90
Ca	97
Cd	0.0004
Cr	0.0001
Cu	0.003
Fe	0.0003
Hg	0.00001
K	1.5
Mg	24
Mn	2.4
Na	6.3
Ni	0.02
Pb	0.0004
SO_4	302
Se	0.0015
Zn	0.06
Hardness	343
TDS	523

Comparison of the data shown in Table 1 with previous work shows only minor differences from previous assumptions.

Figure 1 presents a summary schematic of the hydrological regime for the tailings drystack. This schematic demonstrates approximately how the water will move on/in/about the tailings drystack during operation and upon mine closure.

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TAILINGS TESTWORK

Physical

In support of the initial work on the tailings in 1999, independent laboratories carried out a series of Tempe Cell tests. Tempe Cell tests provide an indication of the soil's ability to retain moisture at varying degrees of pore (matric) suction. The Unsaturated Soil Mechanics Group at the University of Saskatchewan and Klohn-Crippen Consultants in Richmond, British Columbia, were used to provide the test information. The results were very comparable. In October of 2000, Lakefield research carried out additional moisture retention data that essentially confirmed the results of the earlier work (the early work is summarized in AGRA, 2000). The results of the three sets of moisture retention tests indicate that the flotation tailings will have soil moisture retention characteristic curves consistent with non-plastic silts.

Saturated hydraulic conductivities for the tailings were determined by triaxial testing in AMEC's Edmonton soil testing laboratory as part of shear strength testing on the tailings carried out in 1999. The saturated hydraulic conductivity testing showed results in the range of 10^{-7} m/s, which is typical for very fine-grained non-plastic silt.

From the moisture retention (characteristic) curves, the hydraulic conductivity of the tailings was estimated by using the saturated hydraulic conductivity as the value at zero matric suction. This is common practice in unsaturated flow modeling.

For the nominal project moisture content of 15%, the indicated bulk unsaturated hydraulic conductivity for the tailings would be about 3.5×10^{-9} m/s (Teck, 2000). For comparative purposes, this value of hydraulic conductivity is similar to that for many unfractured rocks and/or glacial till, or perhaps more salient to the tailings management scenario, the values are similar to that of many clay or synthetic liners (see below). Due to compaction and depositional effects, there will be some anisotropy to the hydraulic conductivity values and the vertical hydraulic conductivity (the value influences the ability for the stack to seep versus shed water) will likely be $1/10^{th}$ to $1/20^{th}$ of the horizontal value with the horizontal value being similar to the bulk value.

To put the hydraulic conductivity of the tailings into perspective, a perfect liner has an equivalent hydraulic conductivity (computed from vapor transmission rate) of about 10^{-11} m/s to 10^{-14} m/s depending upon thickness and material type (Koerner, 1990). Once installed, with typical manufacturing flaws, installation damage and seaming issues, the typical liner has a much higher equivalent hydraulic conductivity. Work for the EPA (Giroud and Bonaparte, 1989) on determining typical liner performance, noted that leakage rates through actual installed liners need to account for, at a minimum, one hole per acre. For a typical installation, this results in most installed liners having an equivalent hydraulic conductivity of between 10^{-8} m/s and 10^{-10} m/s. Composite liners (e.g. those with clay materials) exhibit similar ranges of hydraulic conductivity.

Geochemical

Geochemical testing on samples of flotation tailings generated by bench scale testing have demonstrated that the tailings will have low total sulfur concentrations (0.06% to 0.4%), neutralization potential of 26 kg $CaCO_3$/t and arsenic concentrations varying from 540 ppm to 3600 ppm. The tailings are predicted to be non-acid generating. Kinetic testing of tailings using humidity cells indicates moderate oxidation rates (18 mgSO_4/kg/week) and arsenic release (0.03 mg/kg/week) under slightly basic conditions. Release of other trace elements occurs at much lower rates.

Implication to Skin Issues

The characteristic curve for the Pogo tailings indicates very high pore suction at the placed moisture content. Coupled with the corresponding low hydraulic conductivity, direct precipitation on the stack will have little propensity for infiltration. Any water falling on the surface will tend to run off, as this will be in the direction of preferred energy state. Infiltration of water not immediately running off the stack will be restricted by the high air entry tension present in the unsaturated tailings voids. Evaporative potential will tend to remove any water prior to infiltration by more than a finite number of pore volumes. This behaviour has been observed anecdotally at other dry stacks when ponded water has remained on the surface for more than a week and had much less than 1 inch of infiltration to the unsaturated tailings mass.

From a geochemical perspective, the unsaturated tailings exposed between lifts will undergo oxidation. Due to the very fine-grained nature and consequent low permeability of the material, oxygen penetration below the immediate grain layer will be limited by the diffusion of oxygen through the pore spaces. Oxidation will result in production of weathering products and their dissolution in the pore water. As the pore water is drawn out by evaporation it will cause the solutes to become concentrated near surface and may result in the formation of efflorescent salt at surface or within the near surface pores. This process is observed in tailings beaches. The relatively short placement cycle for drystack tailings will result in short surface exposure periods for the tailings and consequently limit the amount of oxidation and transport of solutes to the surface which occurs. Consequently no deposition of salts may be observed.

In any case, during rainfall events the water flowing over the surface tailings would comingle with the water at the tailings surface and pick up elevated levels of solute, and dissolve any deposited salts

TAILINGS RUNOFF ESTIMATE

Based upon average hydrological conditions, the average precipitation derived runoff from the drystack will be about 26 gpm. Seepage modeling and the evaporative potential modeling indicate very little infiltration of precipitation into the drystack due to the low hydraulic conductivity of the drystack surface. Evaporative processes will remove moisture and further decrease the conductivity of the drystack surface.

In order to maximize the effect of evaporation no wetting of the tailings "skin layer" was assumed. For modeling purposes, this means it was assumed that no rain infiltrates into the "skin layer", and therefore the full 26 gpm must run off the drystack and report to the RTP. It is this runoff flow that will be the vehicle to move any skin constituents.

EVAPORATIVE POTENTIAL

General

There will be two types of evaporation occurring from the drystack:

1. Evaporation of any temporarily ponded water in furrows that occur within the compacted cover of the stack – this will be water that begins with chemistry commensurate with meteoric water quality. This water is assumed to all evaporate or runoff the tailings surface. The water will act as the transport vehicle for the ionic loading that is "wicked" to the surface through evaporative processes.
2. Evaporation of connate pore fluid from within the tailings voids – this water will be process water that is potentially altered by oxidation processes.

It is the second type of evaporation that can lead to the transport of solutes from the tailings to the RTP with the runoff becoming the transport mechanism. Solutes can become concentrated at the surface of the drystack and be dissolved in the runoff and flow downhill to the RTP. Consequently, the first process is considered to occur over an insignificant surface are of the drystack leaving essentially the entire surface area of the drystack available to connate water evaporative processes.

The computer model SoilCover (Geo2000, 1997) was used to predict the surficial interaction with the atmosphere and the drystack tailings connate water. SoilCover is a soil-atmosphere flux model that links the subsurface saturated/unsaturated Darcian flow system with the atmospheric conditions so as to provide a soil-atmosphere continuum. The model has been used on a large number of mining projects for cover designs. It is a column type model (e.g. one-dimensional) finite-element transient model. The theory is based upon Darcy's Law, Fick's Law (flow of the liquid and vapor phases of water) and Fourier's Law (conductive heat flow). Geo2000 (1997) provide a comprehensive summary of the code whereas, save the freezing component, Wilson (1990) provides a comprehensive summary of the theory.

Wilson (1990) lists the three main factors that dictate the nature of water flow between soil and atmosphere:

1. supply and demand of water as controlled by precipitation, all net radiation, wind speed and air temperature;
2. ability of the soil to transmit water – e.g. the hydraulic conductivity and storage characteristics of the soil; and
3. the type and density of vegetation.

As noted by Wilson (1990), the three factors do not function as independent variables but rather as a closely coupled system. For the Pogo drystack, the third factor was not considered in the assessment, as the tailings themselves will not be directly vegetated and upon stack completion, there will be an engineered cover over the tailings and vegetative growth would root within this cover.

SoilCover also allows redistribution of water towards, or away from, a freezing front. Thermal influences were not considered in the assessment, as a frozen tailings surface would only reduce any potential influence to the RTP water chemistry as compared to the assumptions used in this analysis.

Many different scenarios were evaluated. The scenarios taken to be most representative were a typical summer period with:

1. A month long drought condition (no 100% humidity days).
2. Evaporation occurring during a typical one month which, based upon site records, includes about 50% days with humidity near 100% during daylight hours.

It was assumed that the direct rainfall onto the stack all runs off providing the maximum volume of runoff along with no dilution assumed in the upper evaporative vadose zone of the stack from any infiltration.

The soil characteristic curve indicated earlier was used for the assessment. It was modified slightly so as to have a cut-off at –3000 kPa (an arbitrary no-flow level set by the program). The model could not represent a thickness of tailings of more than about 40 feet (limited by the number of nodes). The base of the model is taken to provide an unlimited quantity of water for the evaporative process, which, as noted below, is likely a highly conservative assumption. The top boundary was allowed to provide water through evaporation. Precipitation was taken to be zero for some of the model runs (to allow maximum evaporation potential to be modeled). The maximum air temperature for the "summer" months was taken to be 20°C and the minimum 3°C. Net radiation, maximum and minimum humidity (non-rainfall periods), wind speed, tailings porosity and tailings specific gravity were other variables in addition to the characteristic curve and hydraulic conductivity function.

Summary of Results

Table 1 presents a summary of evaporative potential for two of the cases evaluated. These two cases were one-month with no rainfall one month with typical summer rainfall distribution based upon the three years of site-specific information. In Table 2, two depths of influence are presented – the maximum depth as indicated by the model and the model depth over which the large majority of the evaporative contribution to the net evaporation occurs. Net evaporation is that amount of pore fluid reporting to the surface of the drystack minus infiltration from rainfall or runoff. As noted above, to allow a maximized evaporation potential, zero infiltration was assumed. Companion seepage modeling validates this assumption as the tailings are shown to be highly resistant to infiltration.

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Table 2 – Summary of SoilCover Modeling

Case	Net Evaporation (inches)	Net Evaporation (gpm)*	Maximum Depth of Evaporative Influence (feet)	Depth to more than 80% of Evaporative Influence (feet)
One Month Drought	0.22	3.5	1.12	0.88
One Month 15 Days of 100% Humidity	0.14	2.2	0.96	0.67

*Assume an average 24 acres of the drystack providing evaporative potential over the time period (e.g. 30 days)

The modeling indicates that the highest "equivalent" flow rate would be for a one-month drought period that also provides the most "penetration" of evaporative processes.

The indicated evaporative flux rate is quite high in comparison to the seepage rates modeled for the dry stack and is likely not sustainable over a prolonged period. As noted in the December 2000 updated seepage estimate for the drystack, there is a limited amount of available moisture from the drystack (the difference between the pore water transported to the stack and the residual moisture content within the in-situ deposit). The maximum seepage rate from the stack, under maximum driving head and contributing area conditions (e.g. at ultimate height and areal extent of the stack) is estimated to be in the order of 4 to 6 gpm. When this is compared to the magnitude of the net evaporative flux in Table 2, even over a relatively short period, it seems contradictory with respect to the seepage rate. The gravitational forces promoting seepage will be of greater magnitude than near surface evaporative forces and would be expected to decrease the moisture content of the tailing mass and diminish the driving force for diffusion transport and evaporative loss. For these reasons, the evaporative potentials noted in Table 2 are considered to be conservative values but suitable for addressing the potential skin issues raised.

Implications to Skin Issues

The tailings stack during operation will be continuously expanded and no single surface will be exposed for more than a development season prior to being covered by more tailings. Upon closure, the tailings stack will be covered with a reclamation material. However, during the exposed periods during stack development, evaporative processes will be able to provide some degree of transport of connate water solutes to the stack surface where surface runoff can transport this solute loading to the RTP. Based upon SoilCover modeling, this amount could be up to 3.5 gpm of water. Based upon the tailings stack seepage modeling, and an understanding of the overall available water in the pores, this rate of evaporation cannot be sustained for lengthy periods. However, it was assumed that this rate could occur over a period between construction lifts on the drystack.

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ESTIMATED RESULTING GEOCHEMISTRY TO RTP

The approach to prediction of the resulting chemistry of the water is similar to that described previously (SRK Memorandum, July 24, 2000).

The primary limitation on the availability of salts for leaching will be the rate at which soluble load will be extracted from depth. The maximum solute load that could be dissolved in the volume of water evaporated will control this.

The evaporation rate of 3.5 gpm was used to calculate the concentration of solutes that could be expected if all the tailings in the depth of maximum evaporative influence oxidized at the full atmospheric oxidation rate observed in the humidity cells. The actual concentration in runoff was determined by assuming the average annual runoff of 26 gpm. With the evaporative flow estimated, the concentrations of solutes in the pore water were re-evaluated based on mass balance considerations, observed testwork, MINTEQA2 predictions, and site maximum concentrations. These expected values are shown in Table 1 previous. As with all earlier estimates, these concentrations are equivalent to filtered sample concentrations and do not include the possible effects of physical transport of suspended or colloidal matter.

Such physical transport of tailings to the RTP would be controlled and minimized through sediment control measures such as; doming and compaction of the dry stack, armored channels down the stack/original ground perimeters, the compacted shell being designed to help shunt water to the perimeter and not down the front face, and the strategic use of other appropriate measures designed into the drystack to control sediments.

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Comparison of the Reasonable Worst Case (RWC) Concentrations (as presented in the Water Management Plan) to those predicted by the analyses summarized in this memorandum shows that many concentrations are very similar, while some are significantly reduced. Slight increases were obtained for cadmium (0.1 µg/L to 0.4 µg/L), nickel (10 µg/L to 20 µg/L) and Zn (7 to 60 µg/L). Manganese increased from 0.1 to 2.4 mg/L. These revised values will be used in the re-evaluation of the RTP water quality.

Respectfully submitted,

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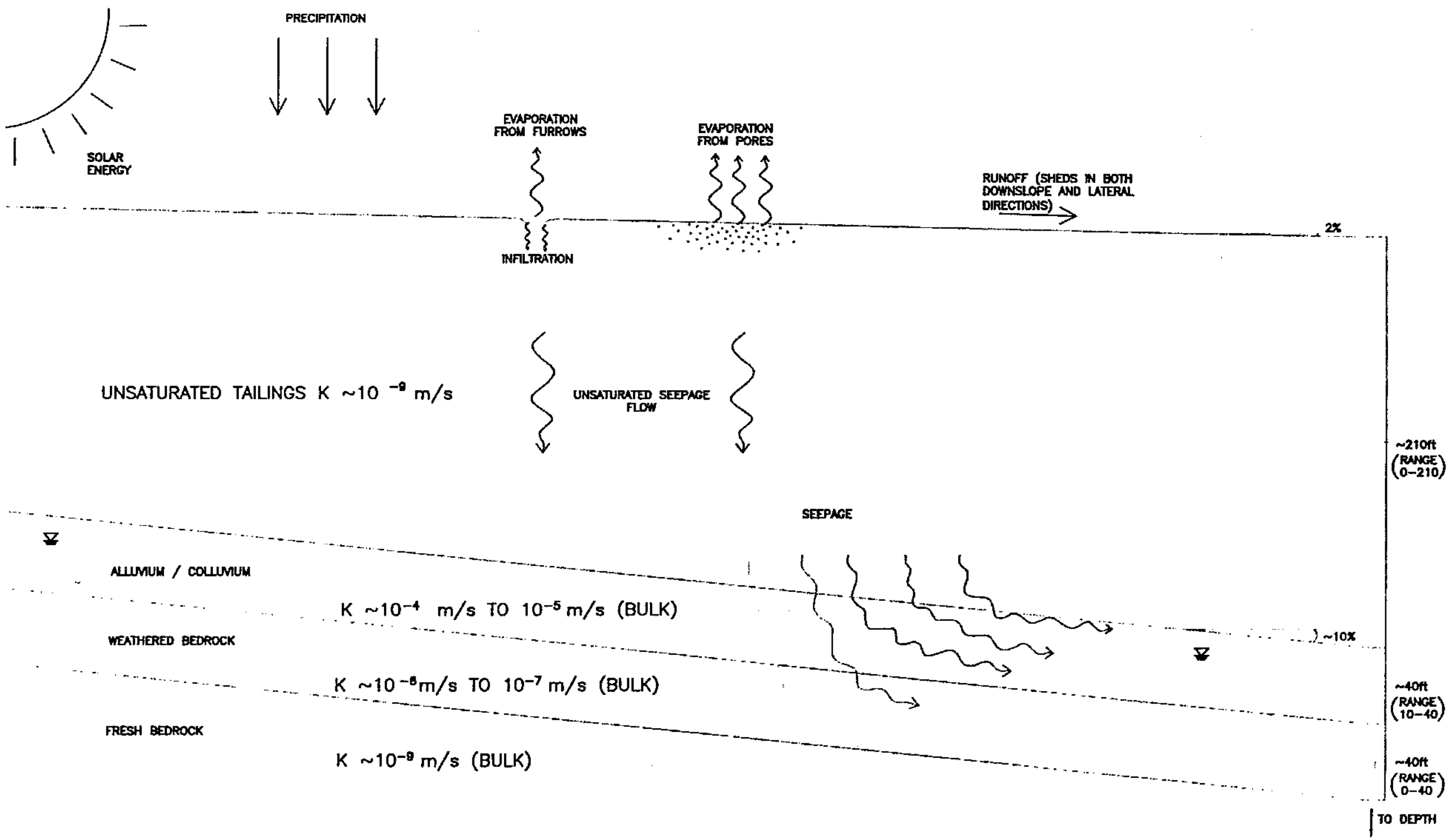

NOTES:

1. SCHEMATIC ONLY (NOT TO SCALE)
2. MAXIMUM SECTION DEPICTED
3. HYDRAULIC CONDUCTIVITIES INDICATED ARE AVERAGE AND BULK (E.G. NEITHER VERTICAL OR HORIZONTAL)

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Client
TECK CORPORATION

DWN BY:
CHK'D BY:
APP
SCALE
NOT TO SCALE

POGO PROJECT

TAILINGS DRY STACK
HYDROLOGIC CYCLE SCHEMATIC

DATE
DECEMBER, 2000
PROJECT NO
VM00172 V·2
REV NO
FIGURE No
FIGURE 1