Appendix 8.

O'kane (2015c) *Rum Jungle – Waste Storage Facility Waste Placement and Loading Modelling.* Memorandum from Pearce. J. Environmental Geochemist to O'Kane Consultants Pty. Ltd. December 2015.

NORTHERN TERRITORY GOVERNMENT

Department of **Primary Industry and Resources**

O'Kane Consultants

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

Memorandum

To:	Andre Kemp – General Manager, Western Australia, O'Kane Consultants Pty Ltd.
From:	Josh Pearce, Environmental Geochemist
Cc:	Peter Scott; Steven Pearce
Our ref:	871-5
Date:	17 December 2015
Re:	**Rum Jungle – Waste Storage Facility Waste Placement and Load Modelling**

O'Kane Consultants (OKC) has been tasked with designing the new waste storage facility (WSF) at the former Rum Jungle Mine site (Rum Jungle) for the Northern Territory Department of Mines and Energy (DME). As part of this design process, OKC has investigated alternative internal construction methods and the resulting performance of the WSF with respect to oxygen flux, water flux, contaminant production, and contaminant release. This involved three interrelated assessments:

- cover system modelling (VADOSE/W);

- seepage modelling (SEEP/W and GoldSIM); and

- waste placement and contaminant loading simulation using a proprietary load model (PLM).

This memorandum provides model development information, model assumptions and results for the waste placement and contaminant loading simulations only. Details for supporting assessments (cover system and seepage modelling) are provided in separate memorandums.

It should be noted that Robertson GeoConsultants Inc. (RGC) and DR Jones Environmental Excellence (DRJ) are undertaking all geochemical assessments for the preferred rehabilitation strategy. The loading estimations presented in this memorandum are completed as part of OKC's PLM application and are required for assessing waste placement options. The results from contaminant loading estimation function in the PLM are not intended to be absolute values, however, can be used by RGC and DRJ to identify the required lime dissolution and efficiency rate.

Development of proprietary loading model Inputs Assumptions:

Inputs used for the contaminant loading function are provided in Table 1. The source of the inputs are as follows:

- At the time of model development no method had been developed to distinguish between PAF-II and PAF-III waste rock. Therefore, as a conservative approach, all initial runs assumed all waste in the WSF had the potential and existing acidity properties of PAF-II waste. 80th percentile existing and potential acidity values provided as summary tables by DRJ in email correspondence with OKC (RGC and DRJ, 2015). 80th percentile values for existing and potential acidity were used in preference to mean values after consultation with DRJ. Note that this is a very

conservative scenario with the intention to run an alternative scenario should results indicate significant acidity release in toe seepage. The alternative scenario assumes the WSF will comprise 23% PAF-II, 50% PAF-III and 27% NAF.

- Construction phase pyrite oxidation rate (unconstrained-POR) is the maximum field pyrite POR published in *"Rum Jungle Monitoring Report 1993-1998"* (ANSTO, 2002).

- Post cover installation POR (constrained-POR) is oxygen supply limited estimated by the PLM waste placement function for 2m and 5m lifts; which also incorporates cover system oxygen diffusion modelling (OKC, 2015).

- Acidity concentration formed in pore water of PAF-II material was estimated from seep quality data provided in *"Geochemical Characterisation of Waste at the Former Rum Jungle Mine Site"* (SRK, 2012).

- Alkalinity concentration formed in pore water of added lime layers was assumed to equal acidity concentration of water contacting the lime layer. An efficiency rate of ANC layering within the WSF was estimated from Weber et al. (2014).

- Monthly toe and basal seepage data were extracted from the GoldSIM probabilistic simulations (OKC, 2015).

Table 1: Contaminant loading inputs

Parameter	Units	Value
Potential acidity – NAF Waste	kg H_2SO_4/t	1.8
Existing acidity – NAF Waste	kg H_2SO_4/t	1.3
Potential acidity – PAF-I Waste	kg H_2SO_4/t	142.6
Existing acidity – PAF-I Waste	kg H_2SO_4/t	20.5
Potential acidity – PAF-II Waste	kg H_2SO_4/t	62.7
Existing acidity – PAF-II Waste	kg H_2SO_4/t	13.3
Potential acidity – PAF-III Waste	kg H_2SO_4/t	9.8
Existing acidity – PAF-III Waste	kg H_2SO_4/t	7.2
Unconstrained-POR[1]	kg O_2/m^3/sec	2.7×10^{-7}
Constrained-POR – 2m lift[2]	kg O_2/m^3/sec	5.8×10^{-10}
Constrained-POR – 5m lift[2]	kg O_2/m^3/sec	5.1×10^{-8}
[Acidity] formed in pore water	mg $CaCO_3$/L	178
[Acidity] safety factor		2
[Alkalinity] formed in pore water	mg $CaCO_3$/L	178
Toe seepage	m^3/month	Refer to OKC, 2015
Basal seepage	m^3/month	Refer to OKC, 2015
Waste volume	m^3	5,100,000
Waste density	t/m^3	1.85

[1]POR assumed constant

[2]POR applied to WSF's previous month's total remaining pyrite

Key linkages with seepage model:

The seepage modelling carried out to date indicates potential ranges of toe and basal seepages expected during and post construction. The key linkages between these data and considerations regarding potential AMD loads and therefore water quality within toe and basal seepage are:

- A solubility constraint has not been identified to date based on existing geochemical testing information; however the dissolution of soluble secondary minerals is considered to be directly proportional to seepage rate. That is to say if seepage rate is doubled the AMD load will be doubled. As part of this assessment a fixed value of acidity in seepage has been set at 178 mg $CaCO_3$/L based on test data available (site seepage data). Seepage quality will be inherently controlled by the maximum solubility value for secondary minerals dissolving into pore water, which will in turn be controlled by the liquid to solid ratio (L:S) and seepage rate. Further testwork is required to better determine what the maximum likely solubility value is for secondary minerals that may contribute to AMD loads in seepage, the effect of L:S on secondary mineral solubility, and the link between concentration and L:S (i.e. seepage rate). The estimations of acidity mobilised to seepage calculated herein are directly and proportionally linked to the assumptions of solubility constraints and estimated pore water concentrations of dissolved phase AMD species. Given uncertainty about this factor the estimates given may have an error of an order of magnitude.

- The addition of lime has been proposed as a solution to mitigate AMD impacts related to existing stored acidity products (dissolution of secondary minerals). The effectiveness of this as a mitigation measure will depend on the relative rate of alkalinity production within seepage compared to the rate of acidity dissolution. This will be controlled by the solubility of the lime product as a function of seepage rate and time, and the identification of the maximum solubility limit. At this time an arbitrary solubility limit value has been fixed at 178 mg $CaCO_3$/L which is the same as the acidity solubility limit. Further testwork is required to determine the likely alkalinity release rate into seepage from the lime product and therefore effective AMD load neutralisation capacity of lime material.

Key results from seepage modelling are shown in Table 2, these results show the range in expected seepage volumes that may occur during the construction period. Rates of up to 1,700 m^3/d have been calculated based on a scenario where temporary covers are not used or are ineffective. Given the large range in seepage estimates calculated the relationship between acidity dissolution rate, lime dissolution rate, and seepage rate will be important factors to consider in defining seepage management measures to be employed during the construction period.

Table 2: Key seepage modelling outputs

Scenario	Toe seepage rate construction period m^3/d	Basal seepage construction period m^3/d
2m covered average daily rate 50% (most likely result)	0.1	0.4
2m un-covered average daily rate 50% (most likely result)	29.4	8.2
2m uncovered max daily	1,700	16

OKC memo: 871/5 Rum Jungle - Numerical Modelling for New WSF Construction

Results:

GoldSIM seepage data used in the PLM represents a range of potential seepage results and are referred to as the 5%, 25%, 50%, 75% and 95% seepage results herein. This range of results are bound by end members 5% (low seepage) and 95% (high seepage) with 50% representing the most likely seepage result. Although the 5% and 95% values are the lowest and highest seepage results used in the PLM, the 25% and 75% values represent more realistic upper and lower seepage limits.

Table 3 and Table 4 present results of the PLM's contaminant loading function. The key AMD parameters listed in each of the tables are:

- cumulative acidity produced and stored;

- cumulative acidity released in toe and basal seepage; and

- maximum monthly acidity load released in toe seepage.

Table 3 presents the summary data for the construction phase which were modelled to commence in April 2016 and finish in September 2018 (3 years 6 months). The reported maximum monthly acidity load released in toe seepage was in the final month of year three (March 2018 – 3 years 11 months).

Key observations for the construction phase were:

- Produced and stored acidity: acidity produced during the construction period is equivalent for the 2 m and 5 m options as the same oxidation rate was applied for this period. Therefore, the difference in acidity stored between the different scenarios is a function of seepage for the construction period.

- Comparison of cumulative acidity released between the interim and no cover scenarios (Figure 1) showed that utilising an interim cover would reduce acidity released during the construction phase significantly:

    o 2 m (50% seepage data) – cumulative acidity was reduced from 11 to <0.5 t H_2SO_4 when applying a cover.

    o 5 m (50% seepage data) – cumulative acidity was reduced from 4 to 1 t H_2SO_4 when applying a cover.

- Comparison between the interim and no cover scenarios for time taken for cumulative acidic release to exceed 0.5 t acidity (as H_2SO_4) within toe seepage showed:

    o Using an interim cover for the 2 m lift method extends the time taken to release more than 0.5 t acidity (as H_2SO_4) within toe seepage from approximately 1-5 years (*basal seepage from 1.5-5 years*).

    o Using an interim cover for the 5 m lift method extends the time taken to release more than 0.5 t acidity (as H_2SO_4) within toe seepage from approximately 2.5-3 years to three years (*basal seepage from 2.5-4 years*).

    o Using the upper confidence limit of 95% seepage data reduces the time taken to observe acidic toe seepage to approximately 1 year.

Table 3: Key AMD parameters after completion of construction phase (0-3.5 years).

Scenario	Parameter	5%	25%	50%	75%	95%
5m lifts – no interim cover	Acidity Produced			34,993		
	Acidity Stored*	160,479	152,364	152,358	160,399	160,142
	Acidity Released in BS	<0.5	<0.5	1	3	5
	Acidity Released in TS	<0.5	<0.5	4	77	332
	Max. Monthly TS Acidity Load	N/A	N/A	0.296	0.304	0.312
5m lifts – interim cover	Acidity Produced			34,993		
	Acidity Stored*	160,479	160,479	160,478	160,455	160,398
	Acidity Released in BS	<0.5	<0.5	<0.5	2	4
	Acidity Released in TS	<0.5	<0.5	1	22	77
	Max. Monthly TS Acidity Load	N/A	N/A	0.295	0.299	0.306
2m lifts – no interim cover	Acidity Produced			34,993		
	Acidity Stored*	160,479	160,478	160,465	160,370	160,039
	Acidity Released in BS	<0.5	1	3	4	7
	Acidity Released in TS	<0.5	1	11	105	433
	Max. Monthly TS Acidity Load	N/A	0.296	0.298	0.308	0.315
2m lifts – interim cover	Acidity Produced			34,993		
	Acidity Stored*	160,479	160,479	160,479	160,471	160,313
	Acidity Released in BS	<0.5	<0.5	<0.5	2	5
	Acidity Released in TS	<0.5	<0.5	<0.5	6	161
	Max. Monthly TS Acidity Load	N/A	N/A	N/A	0.297	0.313

*Includes 125,486 tonnes of existing acidity (as H_2SO_4) transferred from old WSF.

All values, except maximum monthly toe seepage acidity load (kg H_2SO_4/m^3) are cumulative tonnes of H_2SO_4. TS = toe seepage; BS = basal seepage; N/A = not applicable.
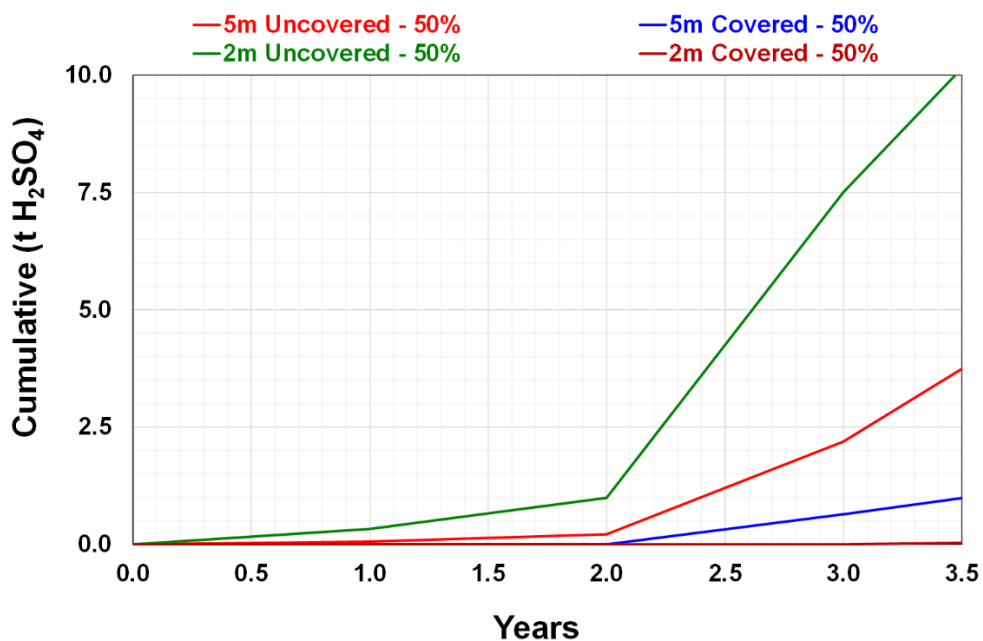

Figure 1: Cumulative acidity released in toe seepage during construction using 50% seepage data.

Table 4 presents summary data after 100 years post-construction commencement. Key observations for this phase were:

- Due to the incorporation of different pyrite oxidation rates post construction, acidity produced is approximately five times greater for the 5 m construction method after 100 years (187,905 t H_2SO_4) than compared with the 2 m method (37,036 t H_2SO_4). Figure 2 illustrates the difference observed in stored between the two construction methods where interim covers have been used.

- Comparison of cumulative acidity released after 100 years between the interim and no cover scenarios (Figure 3) showed that utilising an interim cover for the 2 m lift method would reduce acidity by more than 30% (494 to 333 t H_2SO_4); when using the 50% seepage data.

- If comparing the 2 m to 5 m lift option (using the 50 % interim cover seepage data), the 2m option produces 30% less acidity over 100 years than the 5 m option (481 t H_2SO_4).

- After 100 years, acidity released in basal seepage is approximately equal across all four scenarios (142-157 t H_2SO_4).
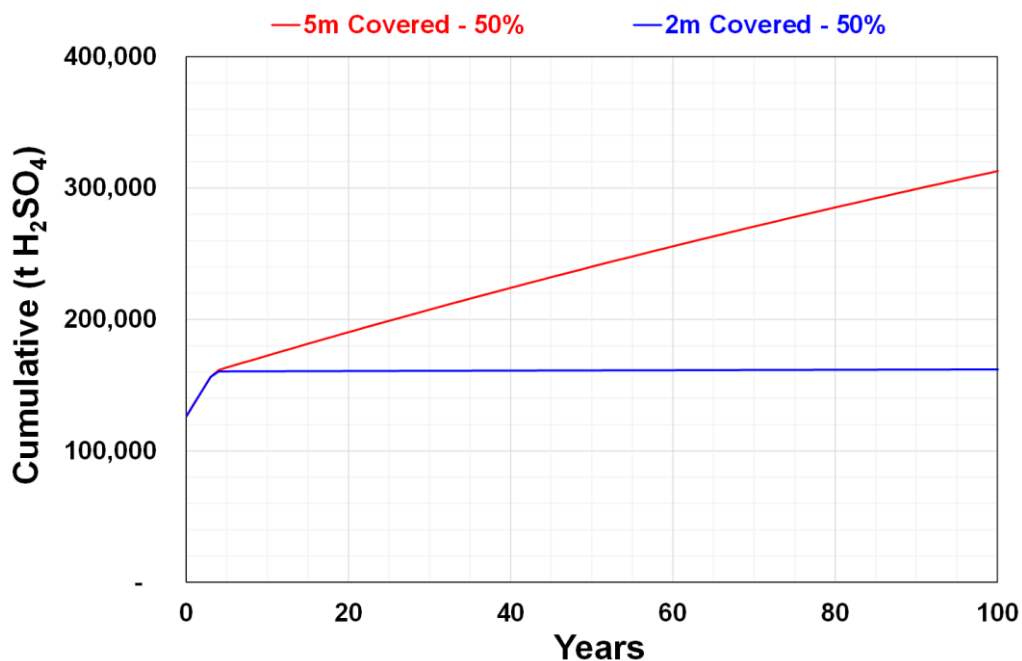

Figure 2:   Comparison of cumulative stored acidity after 100 years between 2 m and 5 m construction methods with interim covers.

Table 4: Key AMD parameters 100 years after commencement of WSF construction (97 years post-construction). All values are cumulative tonnes of H_2SO_4.

Scenario	Parameter	5%	25%	50%	75%	95%
5m lifts – no interim cover	Acidity Produced			187,905		
	Acidity Stored*	313,369	313,186	312,843	311,931	309,875
	Acidity Released in BS	21	112	146	173	223
	Acidity Released in TS	1	92	402	1,287	3,293
	Max. Monthly TS Acidity Load	0.295	0.296	0.298	0.301	0.308

Scenario	Parameter	5%	25%	50%	75%	95%
5m lifts – interim cover	Acidity Produced			187,905		
	Acidity Stored*	313,359	313,206	312,764	311,905	311,223
	Acidity Released in BS	30	104	146	174	198
	Acidity Released in TS	2	81	481	1,312	1,969
	Max. Monthly TS Acidity Load	0.295	0.296	0.298	0.301	0.304
2m lifts – no interim cover	Acidity Produced			37,036		
	Acidity Stored*	162,495	162,165	161,871	160,976	158,192
	Acidity Released in BS	26	126	157	188	232
	Acidity Released in TS	1	231	494	1,358	4,099
	Max. Monthly TS Acidity Load	0.295	0.297	0.298	0.301	0.310
2m lifts – interim cover	Acidity Produced			37,036		
	Acidity Stored*	162,485	162,302	162,047	161,581	159,631
	Acidity Released in BS	31	110	142	171	226
	Acidity Released in TS	6	110	333	769	2,665
	Max. Monthly TS Acidity Load	0.295	0.296	0.297	0.299	0.306

*Includes 125,486 tonnes of existing acidity (as H_2SO_4) transferred from old WSF.

All values, except maximum monthly toe seepage acidity load (kg H_2SO_4/m^3) are cumulative tonnes of H_2SO_4. TS = toe seepage; BS = basal seepage; N/A = not applicable.
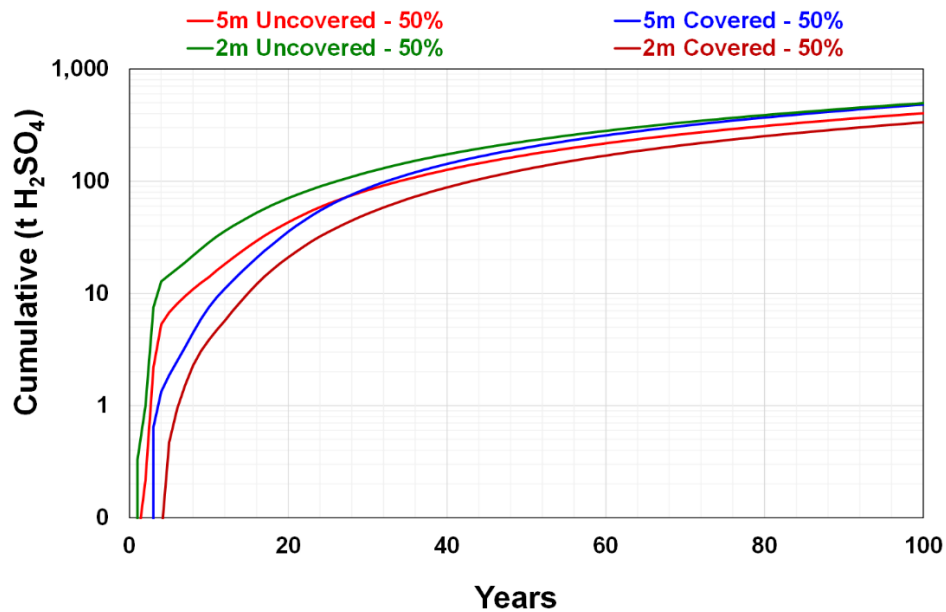

Figure 3:   Cumulative acidity released in toe seepage after 100 years using 50% seepage data.

To illustrate the range of loading results generated, Figure 4 and Figure 5 present cumulative acidity release in toe and basal seepage respectively for the 25%, 50% and 75% seepage data for all four scenarios.
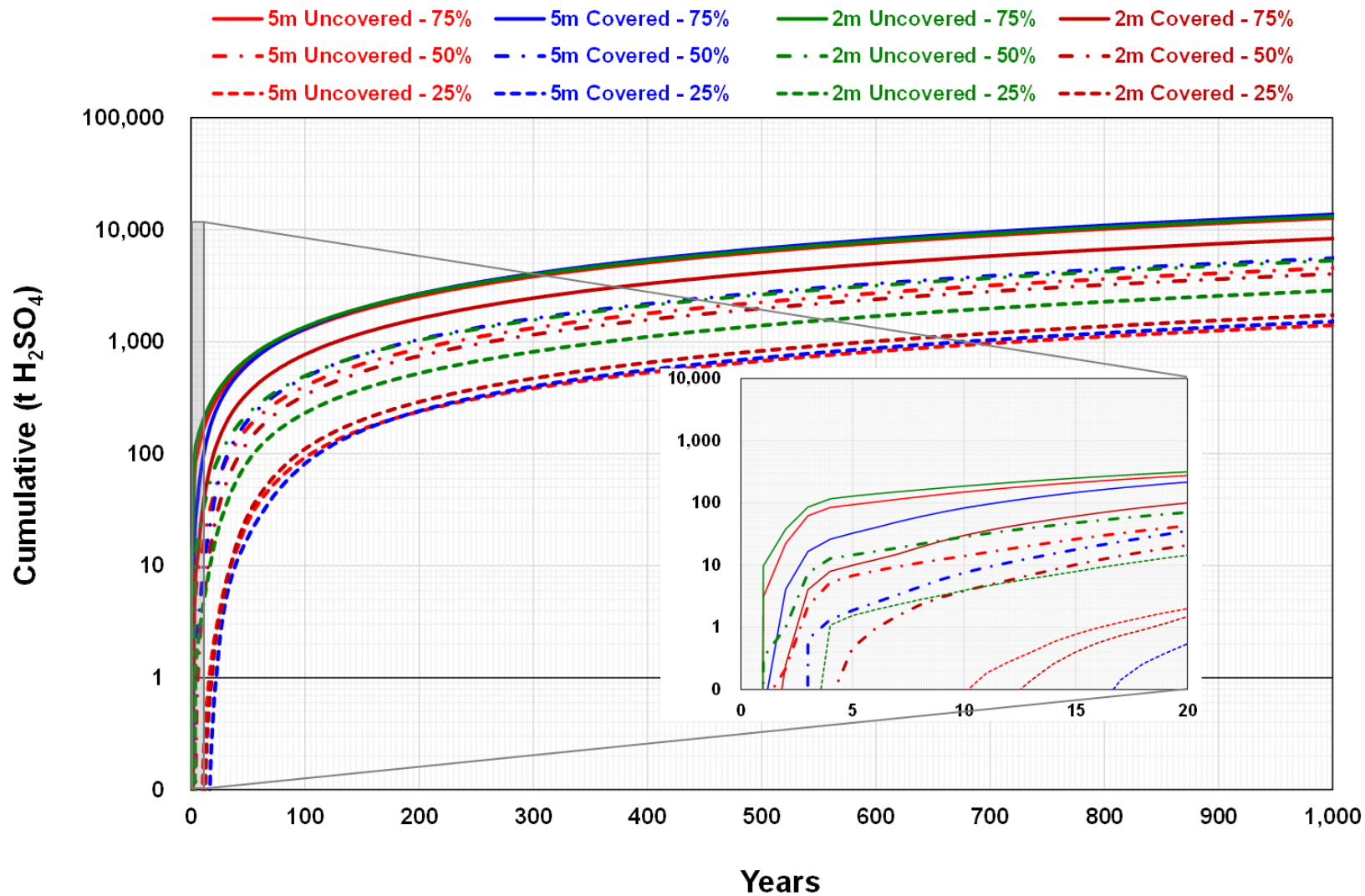
Figure 4:   Cumulative acidity released in toe seepage for all four scenarios using the 25%, 50%, and 75% probability seepage data.
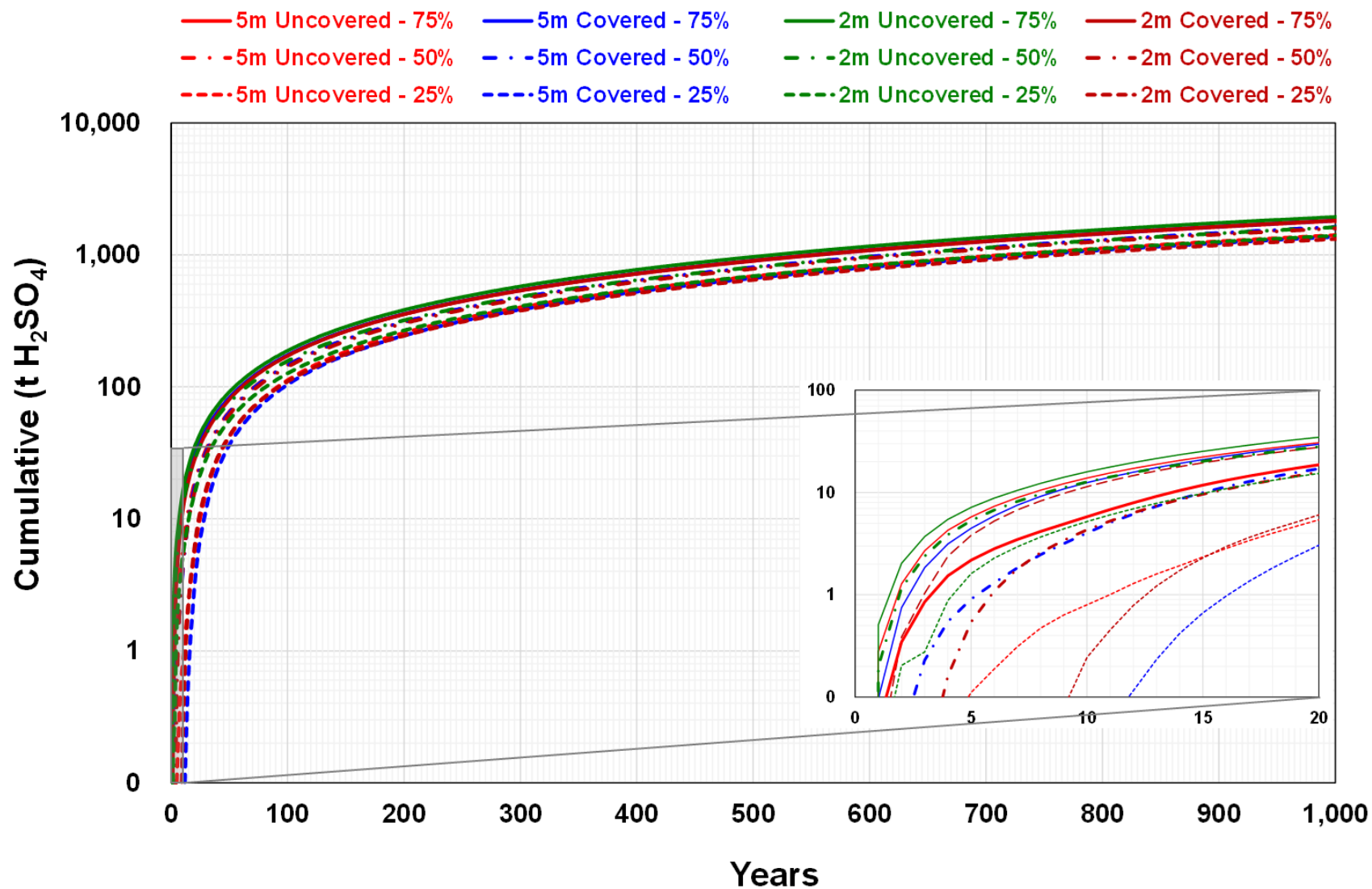
Figure 5:   Cumulative acidity released in basal seepage for all four scenarios using the 25%, 50%, and 75% seepage data.

Waste placement method comparison:

When applying the 50% seepage data to the PLM contaminant loading function, the interim cover scenarios show a delayed onset to acidic toe seepage; 3 and 5 years for the 5 m and 2 m lift methods respectively. The time estimated to observe acidity in toe and basal seepage is approximately 1 year when taking the upper confidence limit of 95% seepage data.

After 100 years from the commencement of construction of the WSF, the PLM shows approximately 30% less acidity (cumulative) was generated for the 2 m interim cover option when compared with the 2 m no cover and 5 m interim cover methods.

A key observed difference between the 2m and 5 m lifts is in the degree of oxidation that is inhibited by constructing the WSF in 2 m lifts. The waste placement function of PLM estimated oxygen availability (kg O_2/m^3/sec) to be more than two orders of magnitude lower for the 2 m lifts when compared with the 5 m lifts. Therefore, although the seepage data may not indicate a significant difference between the scenarios, the stored acidity component of the WSF will be substantially higher for a 5 m constructed WSF. Having a large stored acidity component subsequently increases the AMD risk associated with the WSF.

Assumption and Input Refinement:

The contaminant loading function can be refined by completing further assessment:

- The estimations of acidity mobilised to seepage calculated herein are directly and proportionally linked to the assumptions of solubility constraints and estimated pore water concentrations of dissolved phase AMD species. Given uncertainty about this factor the estimates given may have an error of an order of magnitude. Further detailed laboratory testwork is required to better estimate the likely AMD loading and seepage water quality.

- Once the field testing procedure is developed, more confidence can be placed on the composition of the WSF and the assumption that all material is going to behave as per PAF-II could be substituted for a more realistic composition such as 23% PAF-II, 50% PAF-III and 27% NAF (RGC and DRJ, 2015).

- The ANC efficiency rate has been estimated from published literature. The validity of this rate should be investigated by assessing the effectiveness of the chosen liming material (fine grained aglime) to neutralise existing acidity within Rum Jungle waste material with varying flow rates. Hydrated lime should also be assessed as an alternative to fine grained limestone (aglime) due to its higher efficiency in reducing acidity and adding alkalinity to the WSF. The higher efficiency of hydrated lime will likely result in lower volume requirements as well as lower construction costs.

- The post-construction pyrite oxidation rates should be validated by measuring actual oxidation rates when air flow rates equivalent to those predicted by PLM waste placement function are applied to Rum Jungle waste material.

References:

ANSTO, 2002, *Rum Jungle Monitoring Report 1993-1998*, Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW.

OKC 2015, *OKC Internal Memorandum - Rum Jungle New WRD Simulations - v2 - November 12-15,* O'Kane Consultants Pty Ltd, Perth, Australia.

SRK, 2012, *Geochemical Characterisation of Waste at the Former Rum Jungle Mine Site*, SRK Consulting (Australasia) Pty Ltd, Sydney, NSW.

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Weber, PA, Olds, WE & Pizey, M 2014, *Geochemical and geotechnical investigations at the Reddale Coal Mine, Reefton, New Zealand*, H. Miller & L. Preuss (eds), The Proceedings of the Eighth Australian Workshop on Acid and Metalliferous Drainage, JKTech Pty Ltd, Adelaide, South Australia, 455-466.

Closure:

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at +61 8 9445 9698 or jpearce@okc-sk.com.au should you have any questions or comments.