Appendix 7.

O'kane (2015b) *Rum Jungle - Waste Storage Facility Waste Placement and Advective Airflow.* Memorandum from Pearce. S. Principal Geoenvironmental Scientist 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

O'Kane Consultants (UK) Ltd
United Kingdom
www.okc-sk.com

Memorandum

To: Andre Kemp – General Manager, Western Australia, O'Kane Consultants Pty Ltd

From: Steven Pearce, Principal Geoenvironmental Scientist

Cc: Peter Scott

Our ref: 871-05

Date: 17 December 2015

Re: **Rum Jungle – Waste Storage Facility Waste Placement and Advective Airflow**

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).

OKC has produced a previous memorandum with the results of VADOSE/W, SEEP/W and GoldSim (OKC 2015). This memorandum provides model development information, model assumptions and results for the waste placement assessment part of the PLM that specifically considers gas flux (advective airflow) and placement technique.

Modelled scenarios

A key outcome of the assessment is to determine the potential for advective gas flux and thus oxygen ingress and the consequent potential for sulfide oxidation based on placement technique. The following waste placement scenarios were considered:

- 2 m lifts (paddock dumping);
- 5 m lifts (end tipping);
- 10 m lifts (end dumping);
- 10 m lifts (end dumping of very blocky material); and
- 30 m lifts (end dumping).

In addition further scenarios were considered in which toe bunds and/or low permeability compacted surface sealing layers are used to control advective gas flux by placement in each lift as part of construction. In this scenario toe bunds were modelled to be able to be constructed to have in service air permeabilities of between 1E-10 m^2 and 1E-11 m^2.

Development of gas flux/advective airflow modelling Inputs Assumptions:

Inputs used for the gas flux/advective airflow model are provided in Table 1.

Table 1: Model Inputs

Parameter	Value	Units
Average pyrite grade	0.87	%
POR (pyrite oxidation rate)	2.7E-07	kg $O_2/m^3/sec$
WRSF volume	5.10E+07	m^3
WRSF Material density	1,850	kg/m^3
WRSF mass (including PAF and NAF)	9.44E+10	kg
WRSF Area	1,700,000	m^2
WRSF Height	30	m
PAF area	1,700,000	m^2
density of PAF	1,850	kg/m^3
density of oxygen	1.31	kg/m^3
Specific heat capacity of shale (PAF)	0.71	kJ/kg/C
Thermal conductivity	1.5	W/m/C
air convection coefficient	22	$W/m^2/C$
density of air	1.182774857	kg/m^3
Average air temperature at site	27.14	°C
Average air pressure	1.01E+05	Pa
Air permeability	2.30E-09	m^2
Air dynamic viscosity	1.80E-05	Pa.s

The model used by OKC is proprietary analytical in nature and utilises 1D analysis to solve gas flux estimation. Technical development of the model is discussed in Pearce and Lehane (2015). The analytical model is a one dimensional, steady state model. The following processes are considered in the analytical model:

- Heat generation in the overburden storage area (OSA): The oxidation of pyrite and organic carbon in carbonaceous shale is considered to contribute to heat generation in the OSA. Organic carbon oxidation is assumed to be insignificant and does not contribute to internal heating.

- Heat transport in and through the OSA: Generated heat from oxidation reactions moves equally upward and downward in the vertical direction. Heat generation and transport induces temperature differences inside and outside the OSA.

- Gas transport: The analytical model assumes sufficient O_2 and water supply to maintain oxidation. However, the oxidation rate is re-evaluated in the model when it becomes apparent that O_2 supply is limiting oxidation.

The specific objectives of the analytical model are to:

- provide a basis for comparison of potential risks associated with different OSA construction techniques;
- inform upon potential waste material management strategies;
- enhance understanding of potential risk; and
- assist with decision-making on waste material disposal with respect to the construction of the waste facility.

Gas ingress into waste can occur through diffusive, convective, and advective gas transport. For the purpose of this investigation, it was assumed that convective gas flow is the dominant gas transport mechanism for gas flow in a porous medium where exothermic reactions are occurring.

Air permeability of the waste rock structure is a key parameter to determining the gas flux, the air permeability function for each scenario was determined by generating functions based on waste rock texture and volumetric water content. In addition a general management factor was applied based on the method of waste rock placement.

An example of air permeability function is given in Figure 1 for a coarse waste rock, the effect of volumetric water content is significant with several orders of magnitude between the ranges considered from unsaturated to nearly saturated conditions. Based on the expected average volumetric water content of the material as placed given in OKC 2015 of 0.1-0.14 cm^3/cm^3 the likely range of air permeability's for coarse waste rock would be 1E-09 m^2 to 1E-10 m^2. Lower volumetric water contents may be expected with coarser material textures such as in basal rubble zones, therefore, although the average volumetric water content may be in the range 0.1-0.14 cm^3/cm^3 coarse rubble zone layers may have volumetric water contents as low 0.02 cm^3/cm^3 which would represent an air permeability of 1E-8 m^2.

To consider the use of toe bund structures an air permeability function for a finer textured material was considered; this is shown in Figure 2. The function generated demonstrates the potential to achieve very low air permeability values using such structures with values at even very low volumetric water contents with corresponding air permeabilities being less than 1E-11 m^2.

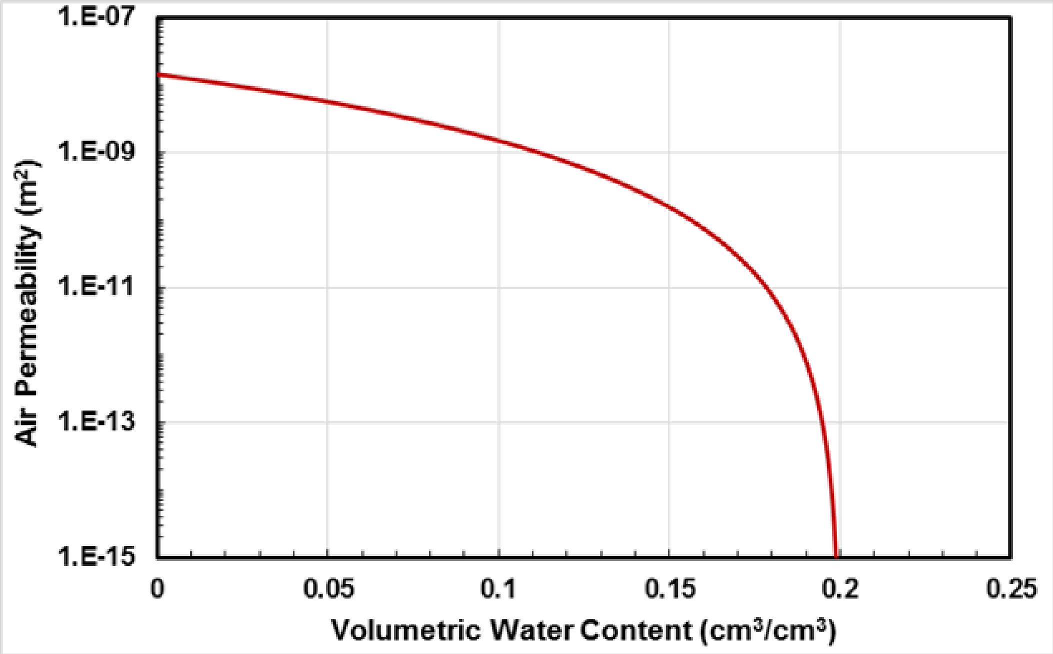

Figure 1: Air permeability function for coarse waste rock

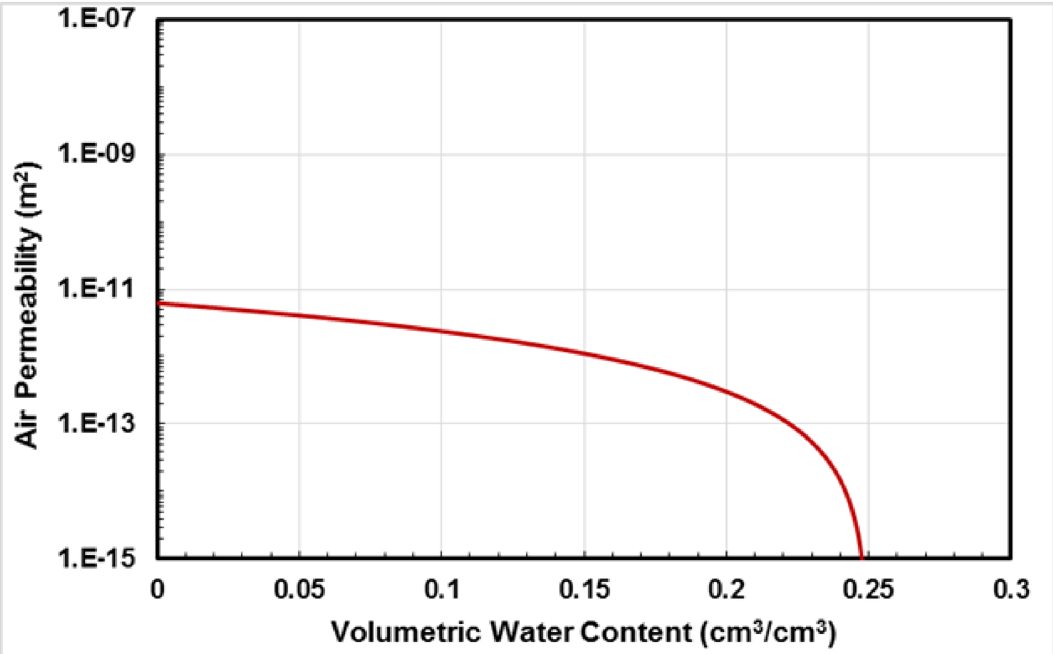

Figure 2: Air permeability function for fine textured material used in toe bund

<u>Results:</u>

The model was run for a number of scenarios based on assumed average air permeability values for the "as placed" waste material. The use of toe bunds as a potential mitigation measure for reducing oxygen ingress via advective air flow has been considered to date, therefore low air permeability values have been considered for all scenarios.

Figure 3 shows the results for the gas flux model, the relationship between advective gas flux and acidity generation rate is clear. The higher lift heights have generally higher modelled gas flux as a result of increased particle segregation related to placement technique which is conducive to advective air flow. The difference between gas fluxes for the modelled lift heights is orders of magnitude indicating that waste placement method is a critical control on the potential for acidity generation.

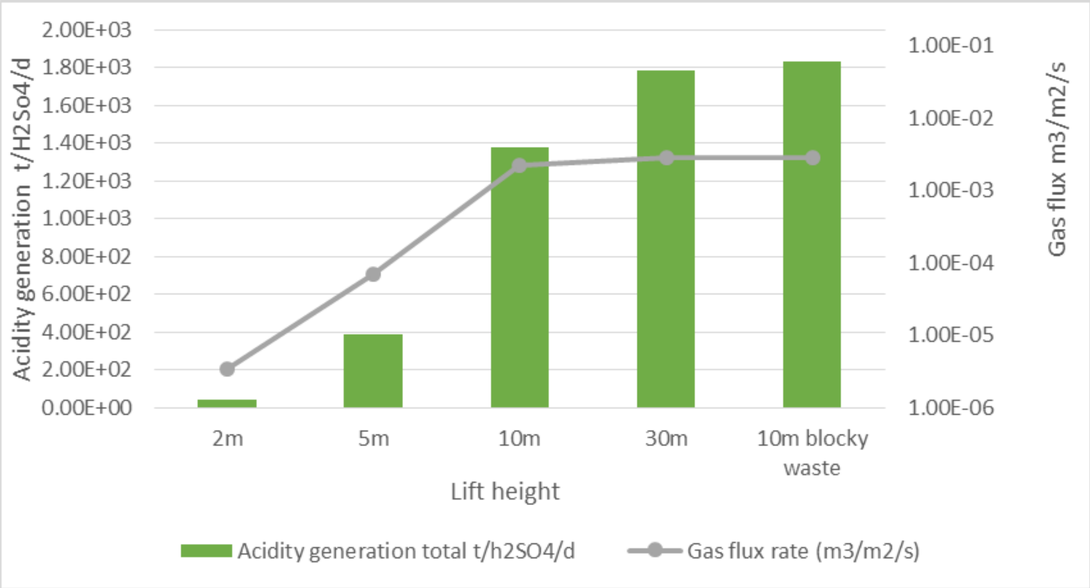

Figure 3: Modelled gas flux and acidity generation based on lift height

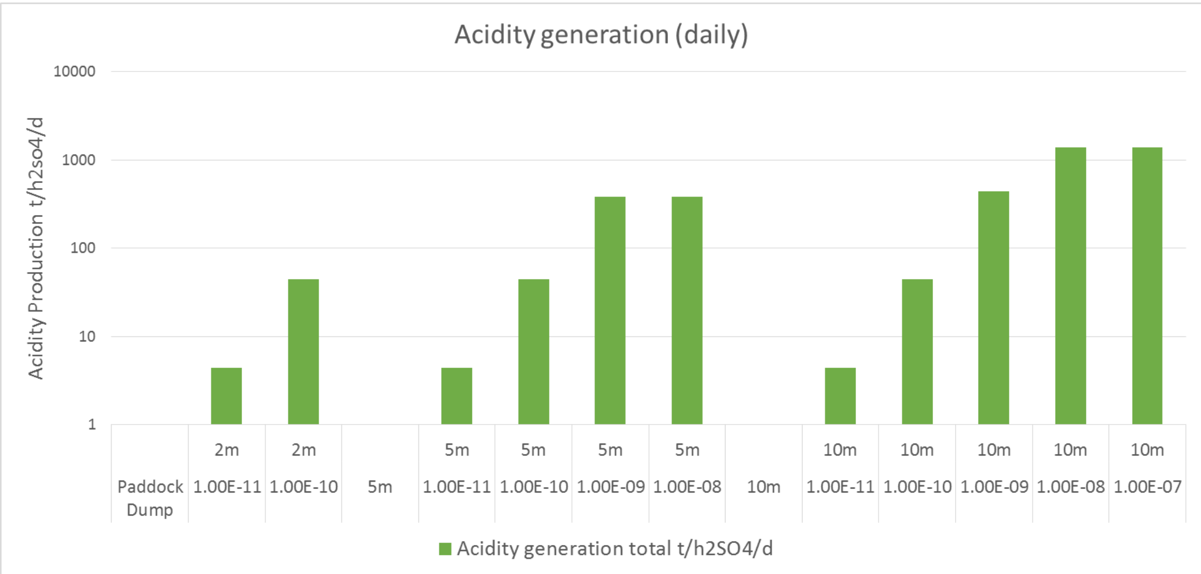

Figure 4: Modelled acidity generation based on lift height and range of air permeability functions

Figure 4 shows the results of the modelling where air permeability function was varied over a range of values for each placement scenario. A maximum permeability for paddock dumping was set at 1E-10 m^2 to reflect the likelihood that this placement technique will not result in the creation of segregated coarse rubble zones. The range 1E-11 m^2 to 1E-10 m^2 was included for all scenarios to account for the use of low permeability toe bund structures as part of the placement technique. The results indicate that two air permeability values are key:

- The range 1E-09 m^2 to 1E-08 m^2 is a key value as acidity generation increases with increasing air permeability from 1E-11 m^2 to 1E-09 m^2, however air permeability above 1E-08 m^2 do not result in additional acidity generation. The reason for this is that the oxidation rate has an upper limit controlled by the maximum POR which is a kinetic limitation to reaction rate. As a result it can be stated that oxidation reactions are not rate limited where the air permeability is somewhere between 1E-09 and 1E-08 m^2. Therefore additional gas flux does not result in increased acidity generation. This range is important because coarser textured materials with low water contents typically lie in this range. End tipping typically results in basal zones of this type of material therefore this placement technique is likely to produce internal conditions where gas fluxes are sufficient to support non rate limited oxidation rates. It can also therefore be concluded that for air permeability's below 1E-09 m^2 the oxidation rates are rate-limited by the gas flux. Material placement techniques/conditions that result in permeability's lower than 1E-09 m^2 include paddock dumping (2 m) and low lifts (5 m) of material with higher volumetric water content (>0.1 cm^3/cm^3).

- At an air permeability of 1E-11 m^2 the acidity generation rates can be seen to be reduced to orders of magnitude lower than other scenarios modelled, it is clear that achieving this low value of air permeability would significantly reduce the potential for oxidation reactions to occur within the waste mass. Figure 2 demonstrates that compacted fine textured material can be expected to have air permeability's lower than 1E-11 m^2 even at lower volumetric water contents (<0.1 cm^3/cm^3).

<u>Key assumptions:</u>

Several processes occur simultaneously within OSAs. These processes include but are not limited to:

- Chemical reactions - pyrite oxidation, oxidation of organic carbon, dissolution of salts, dissolution of carbonates and reactive silicate minerals and subsequent neutralisation of acidity;

- Physical change – compaction, segregation, particle size shrinkage;

- Water flow - rainfall infiltration, seepage flow, matrix and/or preferential flow, vaporisation;

    - Gas transport - diffusion, convective and advective gas transport, and

    - Heat transport - conduction, convective heat transport.

These processes are coupled, and together form a complex system in the OSA. To be able to model these complex processes using 1D modelling analyses, a number of assumptions were made.

1) The model is based on steady state condition such that input and output parameters are not considered to change with time.

    a. External ambient air temperature is set to a constant 27.1˚C, which is the average annual temperature.

2) For heat and gas transport, the model is assumed to be one dimensional.

    a. Heat dissipates equally upwards and downwards.

    b. Gas flows upward.

3) It is assumed that temperature, degree of saturation, construction process, etc. do not have effect on most input parameters except where noted.

    a. Air permeability through the entire OSA is considered unchanged in the model, with a fixed value

    b. Air dynamic viscosity is also considered as a constant of 1.8E-05 Pa.s.

    c. Thermal conductivity of rock does not change with saturation.

4) Waste material is homogeneous and isotropic.

    a. No preferential pathways are considered in the model.

    b. Temperature is evenly distributed in all reactive material.

5) Geochemical reactions with the rock are complex and a very simple conceptual model is proposed:

    a. It is assumed that water flow has no effect on heat transport and gas transport.

    b. It is assumed that water content is not a rate limiting factor.

Because of these assumptions, there are limitations to the analytical model. Despite these limitations, there are valuable conclusions to be made on oxygen ingress, estimated internal gas compositions, potential for AMD. It must be noted that a 1D model is not capable of fully addressing the complexity of a 3D, time dependant problem. It would be more important to consider the modelling results in terms of relative trends rather than absolute values.

Conclusions:

Key conclusions that can be drawn from this assessment are:

- End tipping of material from a height greater than 5 m is likely to result in waste rock mass with gas fluxes higher than that required for unconstrained POR to occur. Based on expected site material properties and "in place" volumetric water content of 0.1 cm^3/cm^3 the potential acid generation rate could be greater than 300 $t/H_2SO_4/d$.

- Paddock dumping of material in 2 m lifts is likely to result in significantly lower gas fluxes that will limit the POR. The "in place" volumetric water content, and material texture profile for material placed using this technique has a significant effect on the magnitude of the reduction in POR that can be achieved. Based on the currently available site particle size distributions (PSD) data and an assumption that volumetric water content would be around 0.11 cm^3/cm^3, post placement, paddock dumping may reduce air permeability to around 5E-11 m^2 which translates to an acidity production rate of around 20 t/H_2SO_4/d. Site validation of PSD profiles and volumetric water content would be recommended as part of construction practice to determine if "as placed" material properties lies within an acceptable range with respect to gas flux potential.

- Although end tipping of materials in lifts 5 m or higher is likely to result in higher gas fluxes the use of finer textured material for the construction of toe bunds and/or low permeability sealing layers is likely to reduce the POR by orders of magnitude. The use of toe bund structures would introduce a significant element of certainty with respect to reducing gas fluxes to values where POR are reduced to negligible values. It is likely that construction of toe bunds is only practical for lower lift heights of 5 m or less. It would be reasonable to expect air permeability's to be reduced to 1E-11 m^2 which translates to an acidity production rate less than 5 t/H_2SO_4/d.

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.

Pearce, S., Lehane, S., 2015. Quantitative risk assessment tools to assist with waste management and placement guidelines. In Proceedings of 10th International Conference on Mine Closure, 2015, Vancouver, Canada

Closure:

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at +44 01745 582 015 or spearce@okc-sk.com should you have any questions or comments.