Tailings and Mine Waste Management for the 21st Century

27-28 July 2015, Sydney, NSW

Quantitative assessment tools to assist with waste placement guidelines

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Waste Rock Management

The characterisation and assessment of waste rock forms the initial stage of waste-management strategy planning that extends through the life of the mine to assessment of closure risk.

Prior to operational decision making, waste-management strategies should evaluate short-term and long-term closure risks associated with the exposure, stockpiling and placement of waste materials

Waste Rock Management

This includes risks such as:

- ***Spontaneous combustion***
- ***Toxic gas production***
- ***Acid and metalliferous drainage***

Common practice to classify waste rock based on geochemistry alone (e.g. PAF/NAF).

And then manage all PAF in same manner without considering key field parameters.

Why Quantitative method?

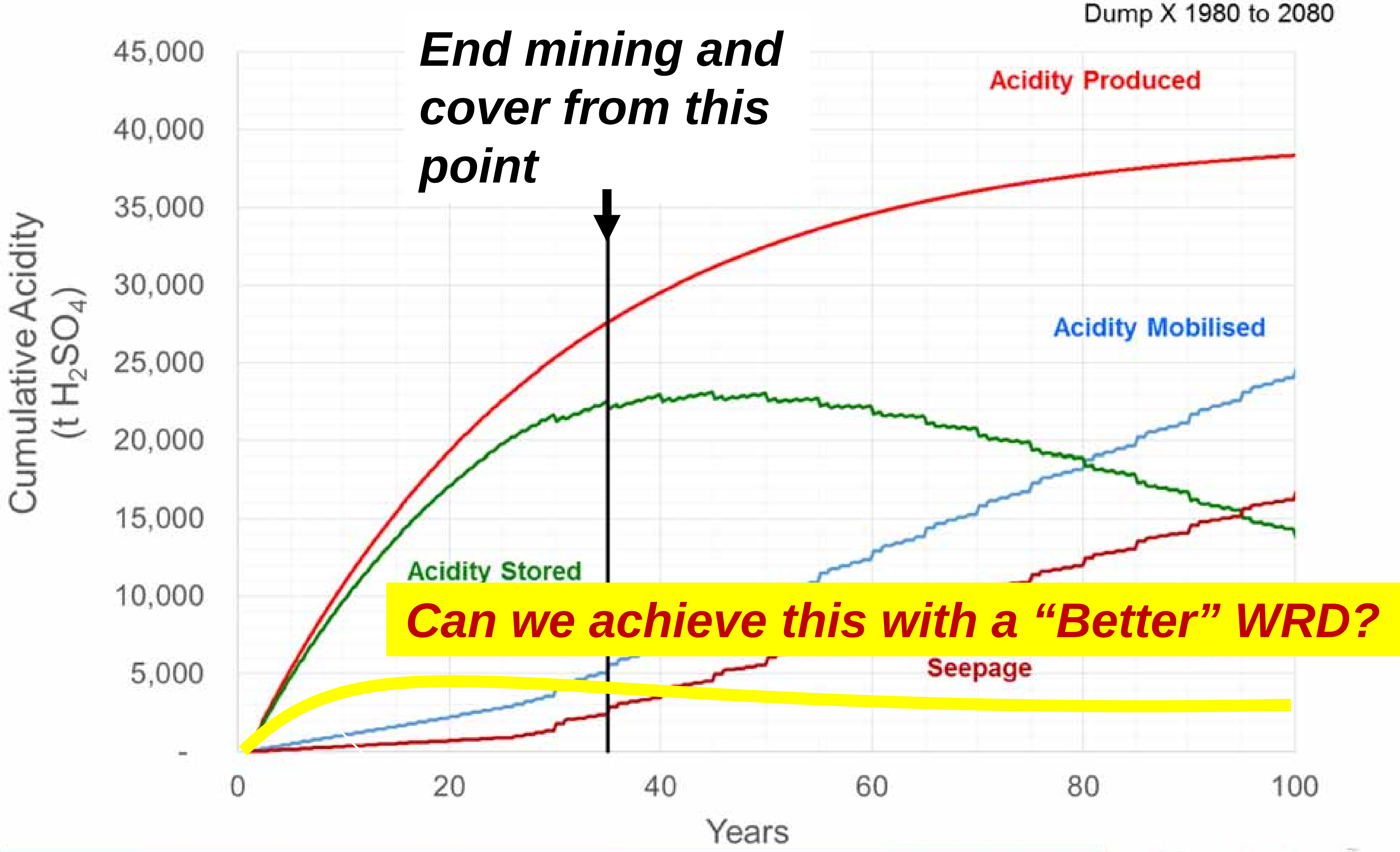
- ***Variables that influence AMD risk***
  1. ***Sulfide content of material***
  2. ***Physical properties of material (grain size and distribution, weathering rate)***
  3. ***Structure of waste rock storage facilities due to placement (pathways for air and water movement)***
  4. ***Climate (temperature and rainfall)***
  5. ***Closure mitigation measures (such as cover systems)***

- ***Complex and interrelated factors requires a quantitative method***
- ***We only have control over point 3 and 5 on most sites, and most emphasis is given to 5 to manage AMD by default.***
- ***The relative benefit of optimising 3 can be assessed to determine how to reduce AMD risks more effectively and cheaply than relying on 5***

Why Quantitative method?

OKC has developed an assessment process based around a risk matrix that captures these multifaceted inputs and employs an analytical model to provide semi-quantitative analysis and outputs.

What are we "quantifying" ?



Quantitative model – focal risks

Focal risk elements were noxious gases, excess heating and acid generation with contributing factors limited to:

- ***Waste placement strategy***
- ***Geometry of the WRSF***
- ***Sulfur grade***
- ***Geo. classification and ANC potential***
- ***Mine schedule***
- ***Application of risk-mitigating engineering***

Quantitative model - objectives

The objectives of the analytical model were to:

- *Provide a basis for comparison of potential risks.*
- *Inform waste management strategies.*
- *Enhance understanding of potential risks.*
- *Assist with decision-making on waste disposal.*

Quantitative model – sub-assessments

In order to achieve the objectives, a number of assessments were completed:

- ***Oxygen ingress modelling***
- ***Sulfide oxidation rate modelling***
- ***Gas emission rate modelling***
- ***Spontaneous combustion risk calculation***
- ***Acidity generation calculation.***

Quantitative model

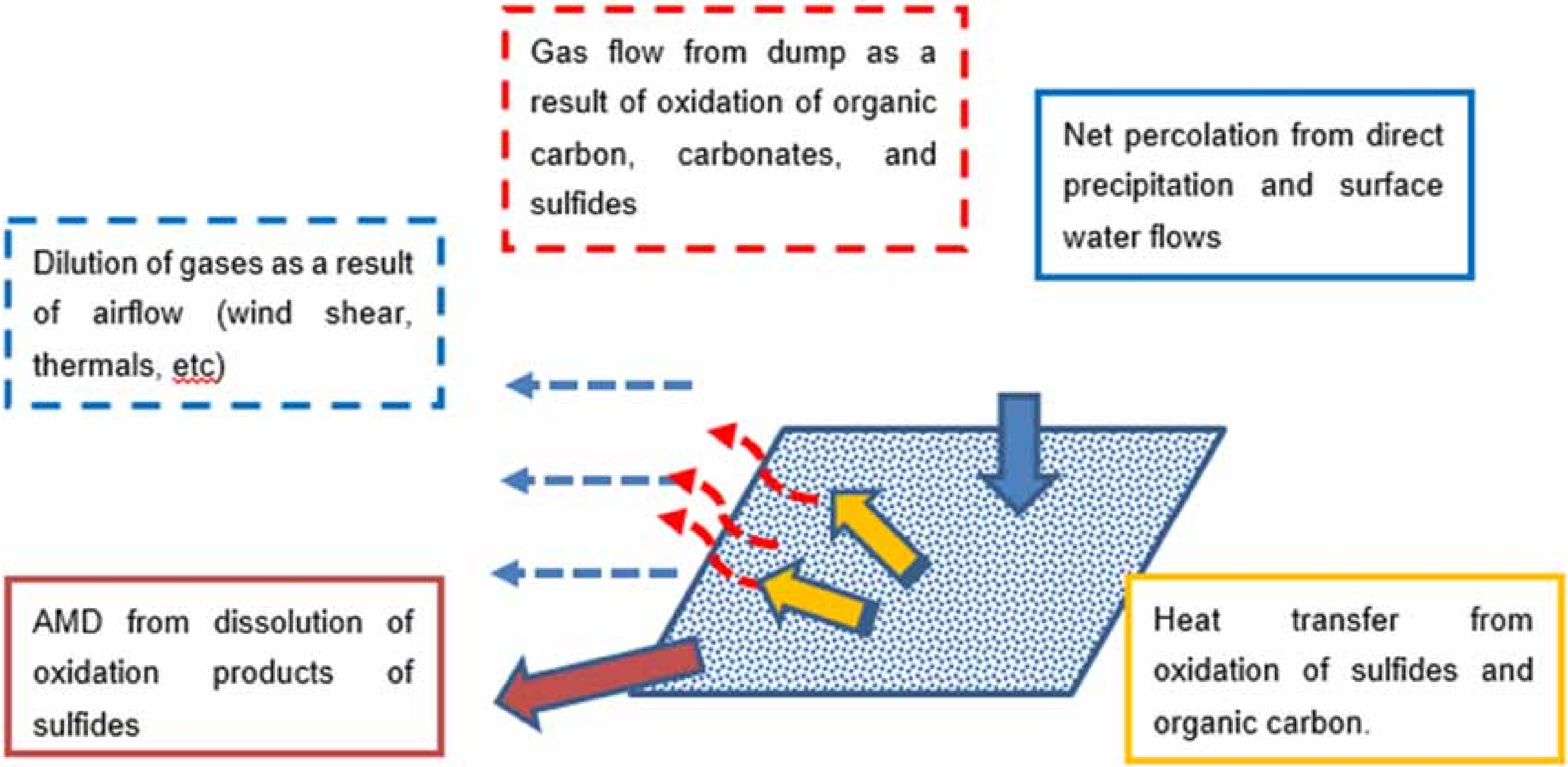
- *Analytical model that has algorithms to determine:*
  1. *Internal heating of waste*
  2. *Acid production*
  3. *Seepage rate (and acid load)*
  4. *Gas generation (CO2)*

$$\frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + Q_H = \lambda \frac{\partial T}{\partial t}$$

$$C_{g-CO2} = C_{a-CO2} + \frac{F_{CO2}}{q_a}$$

- *Produces numerical output so waste placement techniques can be compared quantitatively*
  - *How much less acid do we get if we end tip at 5m vs 30m?*

Conceptual model of risks to "quantify"



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Key model parameters

- *Lift height*
- *"Waste rock management factor" for lift*
- *Dump geometry (height/volume)*
- *PAF:NAF ratio*
- *Pyrite oxidation rate of PAF*
- *External air temperature*
- *Sulfide grade of PAF*
- *Air permeability of waste*
- *ANC (availability of ANC in waste material)*

All of these inputs can be derived from typical studies undertaken at site. This model is therefore easy to implement as part of planning

Waste Rock Placement

Waste rock placement and effects on grain size:

- ***End Tipping***
- ***Push-dumping***
- ***Paddock dumping***

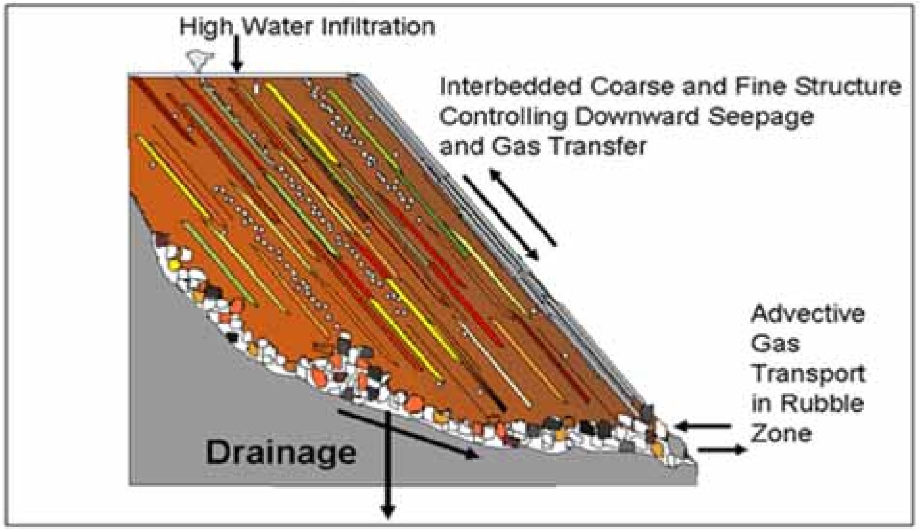
Three scenarios modelled to assess various waste rock placement techniques:

- ***Chimney scenario***
- ***Segregation scenario***
- ***Compaction scenario***

Construction Techniques

End Tipping

- ***Rock is either end-dumped or push-dumped***
- ***Above 4 - 6m in height there is significant segregation of coarser and finer material into layers (at angle of repose)***
- ***A coarser rubble base forms above 4-6m***
- ***These coarser layers are zones of oxygen ingress***
- ***Moisture travels down the finer layers***

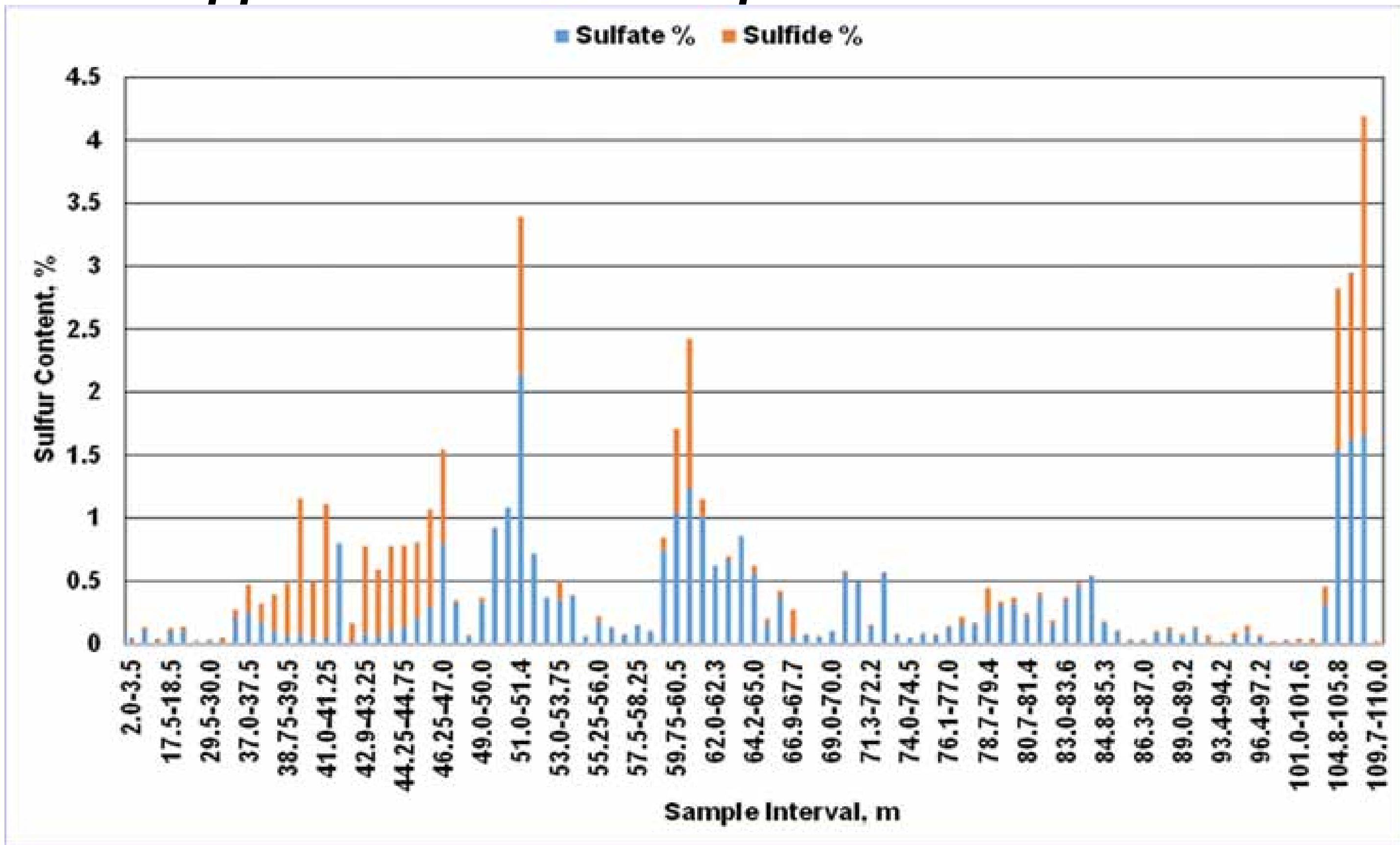


Source: Wilson 2008 (Aussie AMD conference Tasmania)

Construction Techniques

End Tipping

- ***Site data for oxidation in 110m waste dump after 20 years***
- ***30m end tipped – no control on placement***



Construction Techniques

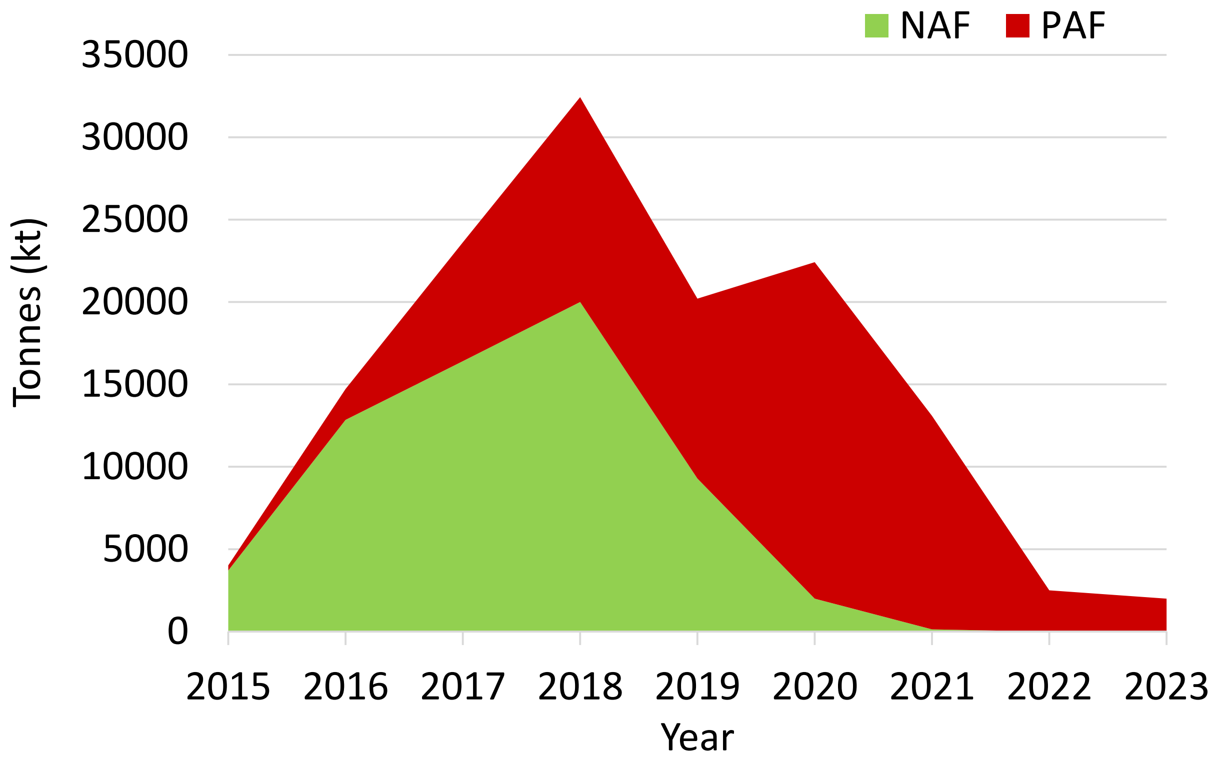
Paddock Dumping

- ***Extremely Beneficial for Managing Gas Transport…***
- ***Civil Engineering Approach***

Waste rock management factor (WRMF)

Lift height (m)	Plume width (m)	Waste rock tipped layer thickness (m)	PSD effects adjustment factor	Segregation adjustment factor	General compaction of WRD	Principal form of oxygen ingress	Combined adjustment factor (co-disposal)
2	10	6.25	0.1	0.1	High	Diffusion	0.10
4	10	3.13	0.2	0.1	Moderate	Diffusion	0.13
6	9	2.31	0.3	0.1	Moderate	Diffusion	0.16
8	9	1.74	0.4	0.4	Low	Convection	0.40
10	8	1.56	0.6	0.6	Low	Convection	0.60
20	7	0.89	0.8	0.9	Poor	Convection	0.85
30	7	0.60	0.9	1.0	Poor	Convection	0.93
40	6	0.52	1.0	1.0	Poor	Convection	0.98
50	6	0.42	1.0	1.0	Poor	Convection	1.00
60	5	0.42	1.0	1.0	Poor	Convection	1.00
70	5	0.36	1.0	1.0	Poor	Convection	1.00
80	5	0.31	1.0	1.0	Poor	Convection	1.00
90	5	0.28	1.0	1.0	Poor	Convection	1.00
100	5	0.25	1.0	1.0	Poor	Convection	1.00
110	5	0.23	1.0	1.0	Poor	Convection	1.00
120	5	0.21	1.0	1.0	Poor	Convection	1.00

Waste rock scheduling (PAF:NAF)



The schedule determines how waste placement can be optimised. Later on in mine life have more PAF than NAF so risk level is higher need to determine how best to manage this risk.

Waste schedule and AMD risk

These results indicate that if 28% of the rock is managed really well then 62% of the acid load can be well managed.

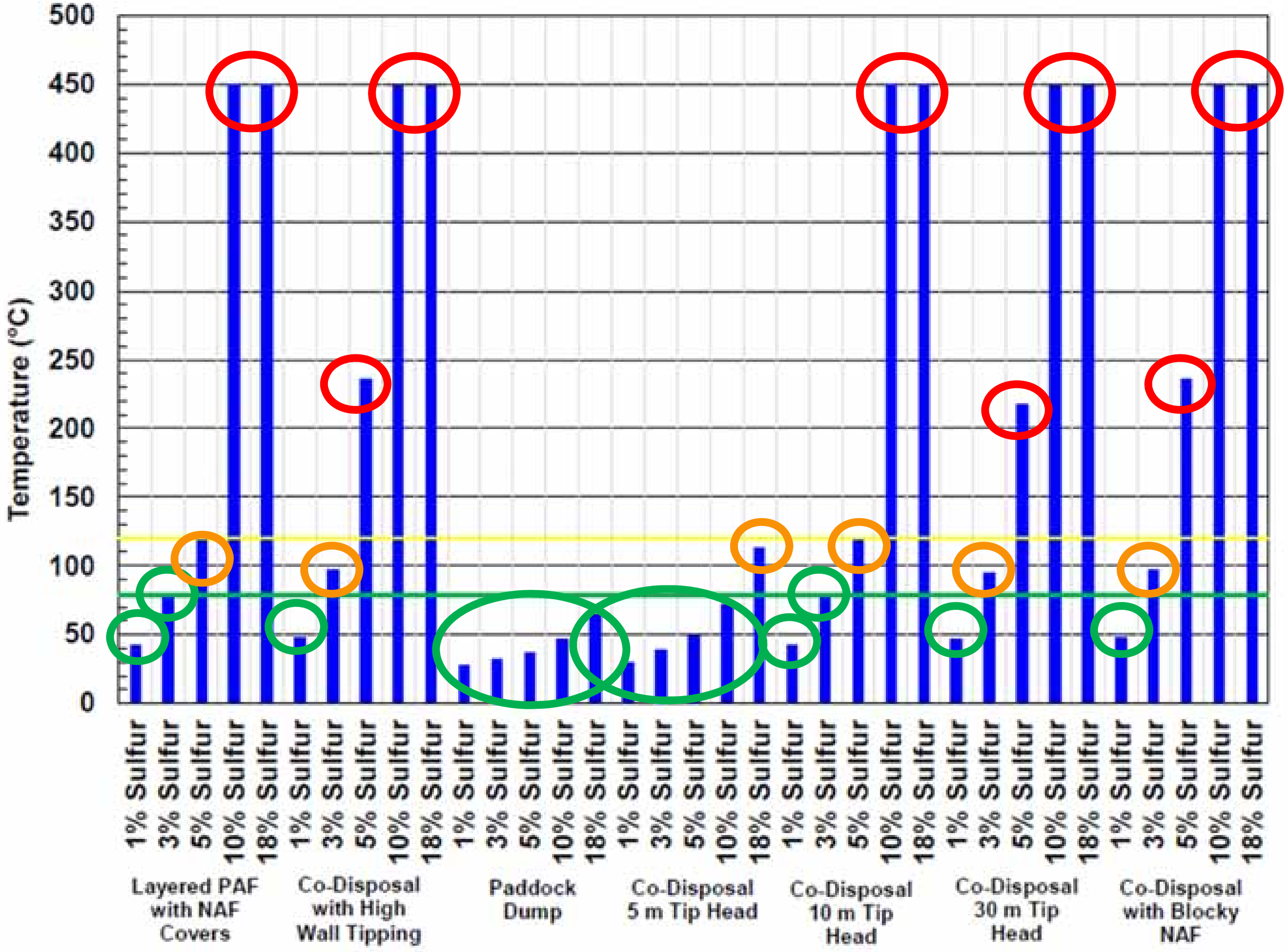
Therefore important to assess quantities of high risk and low risk PAF as these have very different management requirements

Sulfur Grade Grouping (wt.%)	Tonnes of waste rock per group	% of total rock per group	MPA per group (kg H_2SO_4/tonne)	Total acid potential (tonnes) per grouping	% of total acid potential by group
0.2 - 0.5	12,629,562	15.6%	10.7	135,263	2.4%
0.5 - 1.0	20,307,571	25.0%	23.0	466,059	8.3%
1.0 - 2.0	14,044,667	17.3%	45.9	644,650	11.5%
2.0 - 3.0	11,698,781	14.4%	76.5	894,957	16.0%
3.0 - 6.0	19,741,537	24.3%	137.7	2,718,410	48.5%
> 6.0	2,727,485	3.4%	275.4	751,149	13.4%
Total	**81,149,604**			**5,610,487**	

Model Scenarios

- ***Paddock dumping (2 m PAF 2 m NAF);***
- ***Co-disposal NAF + PAF in 5 m tip head;***
- ***Co-disposal NAF + PAF in 10 m tip;***
- ***Co-disposal NAF + PAF in 30 m tip head;***
- ***10 m PAF with 2 m NAF covers;***
- ***Large high wall tip heads (120 m)***
- ***Disposal of "blocky" NAF material***

Example Model Output – Temperature



Higher risk

Potential risk

Lower risk

Example Model Output – Decision Matrix

For 300 Mt waste, average height 120m, 25% PAF

Acid production rate

PAF Sulfur Content	Paddock Dumping	Co-Disposal 5 m Tip	Co-Disposal 10 m Tip	Layered PAF Co-Disposal	Co-Disposal 30 m Tip	Co-Disposal Blocky NAF	Co-Disposal High Wall Tip
<1%							
1-3%							
3-5%							
5-10%							
10-18%							
>18%							

Acid production risk occurs in all scenarios, but relative risk allows quantification

Temperature risk

PAF Sulfur Content	Paddock Dumping	Co-Disposal 5 m Tip	Co-Disposal 10 m Tip	10:2 Layered PAF Co-Disposal	Co-Disposal 30 m Tip	Co-Disposal 10m Blocky NAF	Co-Disposal High Wall Tip
<1%							
1-3%							
3-5%							
5-10%							
10-18%							
>18%							

3-5% S only paddock dumping and 5m co-disposal

<1% S all disposal methods

Effective risk mitigation measures

Identification of effective risk mitigation options:

- ***Construction of low permeability bunds at base of lifts to shut down advection.***
- ***Well compacted surface layers (engineered compaction) to reduce infiltration and advection.***
- ***Progressive compaction to ensure areas of dumps are rapidly "sealed off".***
- ***Tight control of sulfur grade during deposition.***
- ***Use of material with ANC for co disposal.***
- ***Use of finer textured material for PAF co-disposal.***

Summary Comments

This tool allows us to carry out a <u>risk-weighted cost-benefit analysis</u> of construction methods over life of mine to assess closure scenarios

<u>Allows optimised management of material</u> for example paddock dumping may be too costly for all materials, but a sulphur grade cut-off can be established for selective management.

The tool identifies a direct link between WRSF construction methods and the potential development of AMD risks and impacts, highlighting the <u>importance of not relying on laboratory tests and "scale factors"</u>

Allows assessment of the benefit of progressive AMD management as compared to deferring to final closure solutions such as covers: <u>for some sites it may be too late to wait until the cover is put on</u>

Thank You!

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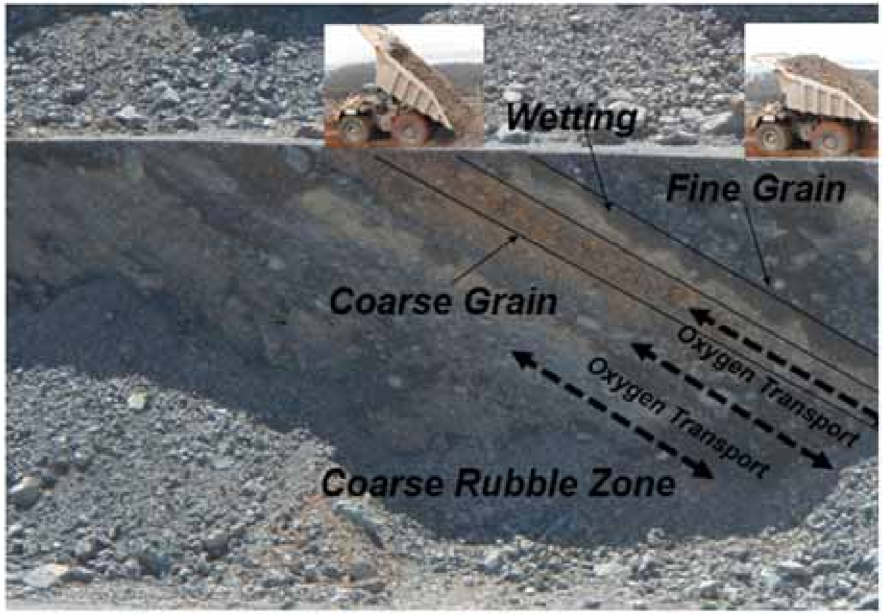
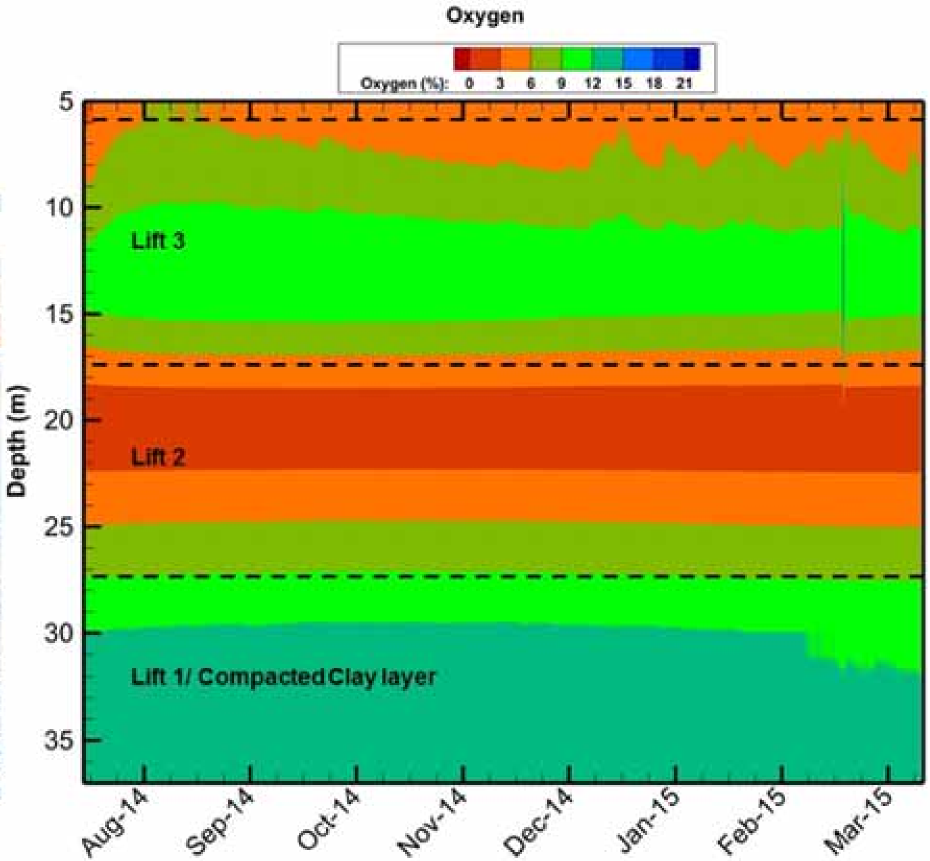
Rainbow of HOPE for Children

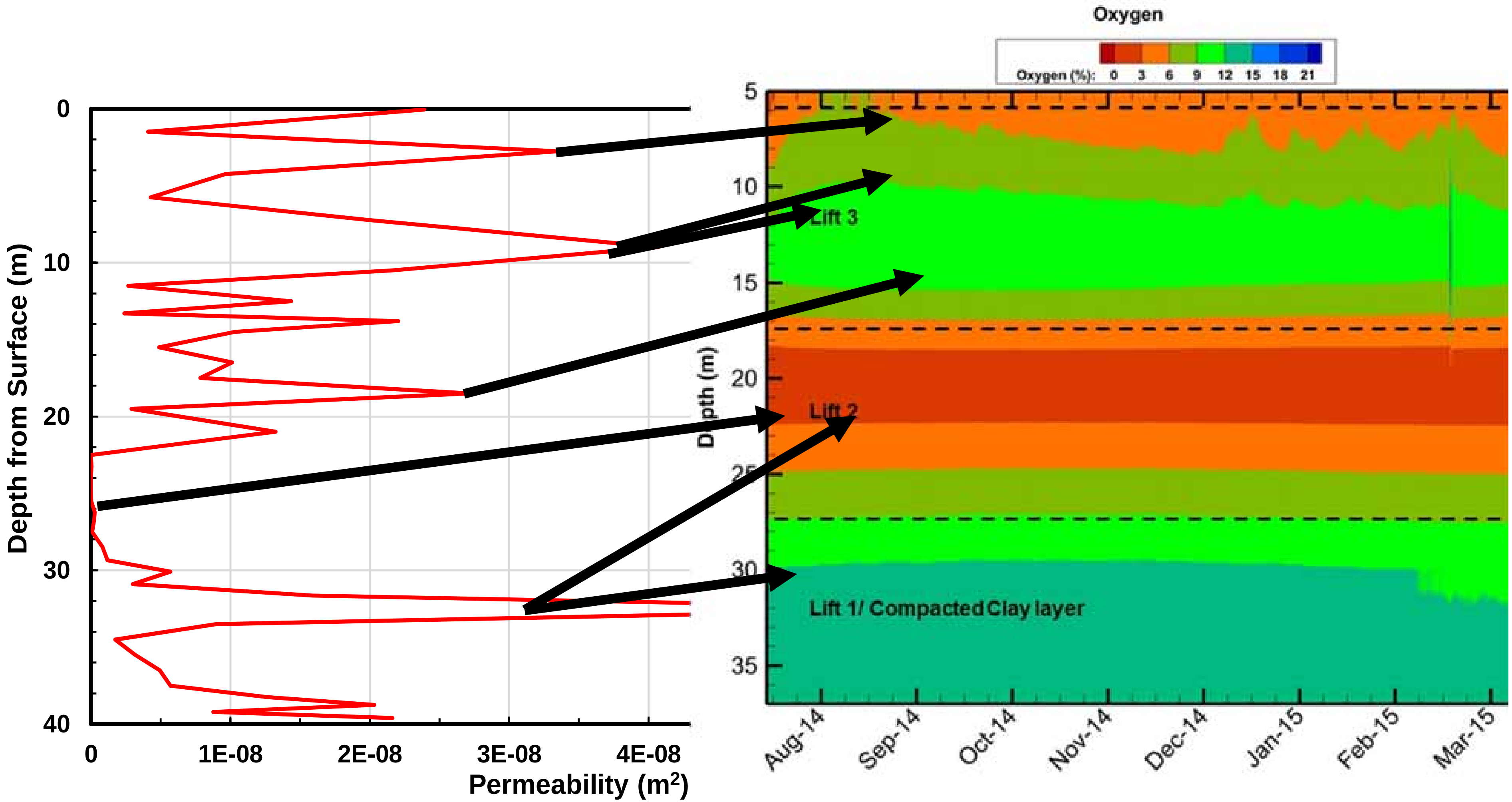
Key design criteria: oxygen ingress

Depends on structure of the lift and material properties

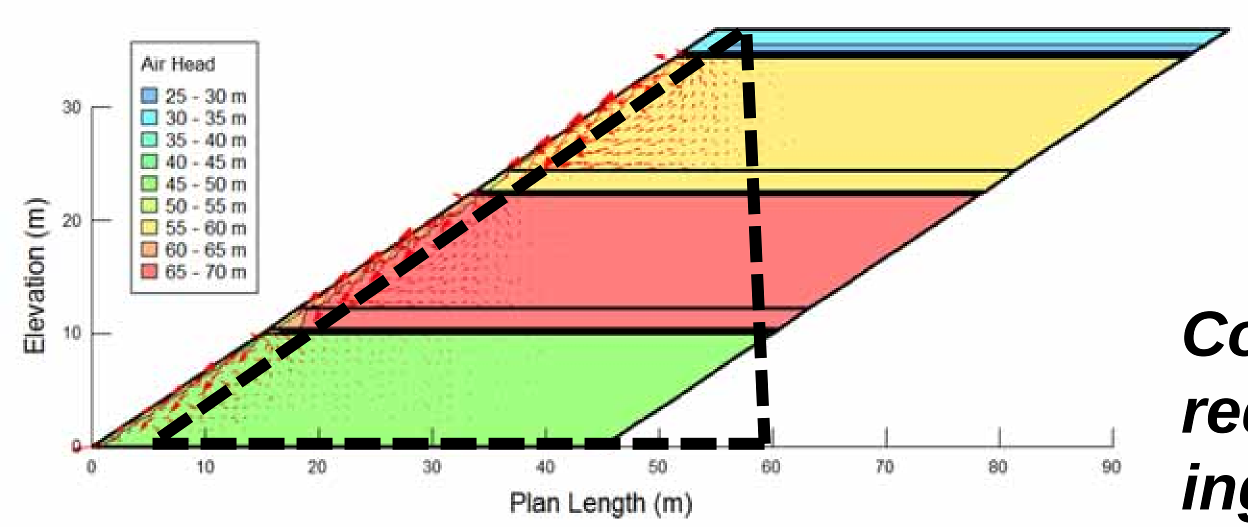


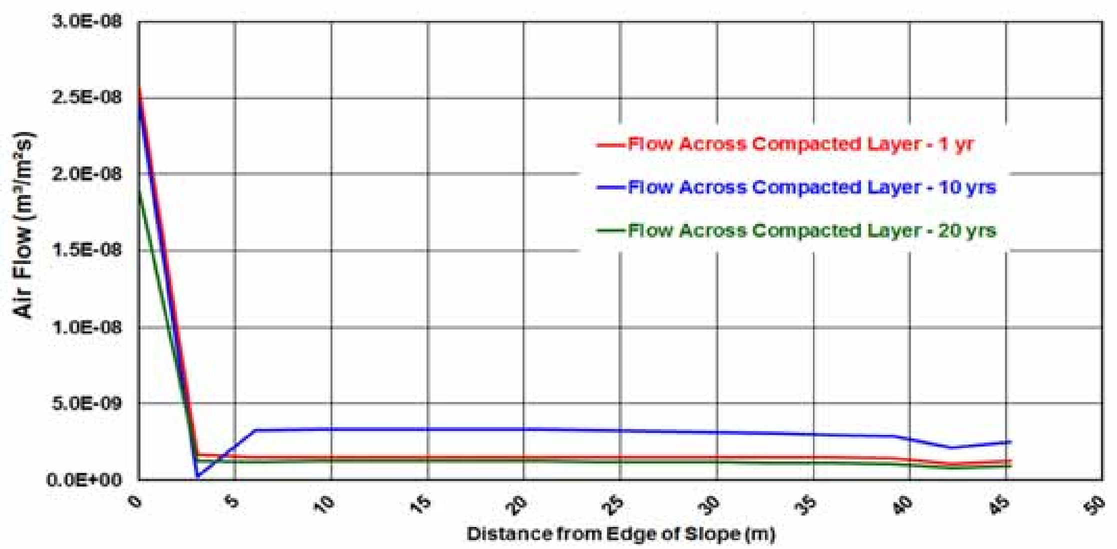


Structure and oxygen ingress 10m end tipping



Air flow into slopes with compacted layers





Compaction reduces oxygen ingress significantly as advection shut down

Assessing model results: defining "cut off" criteria

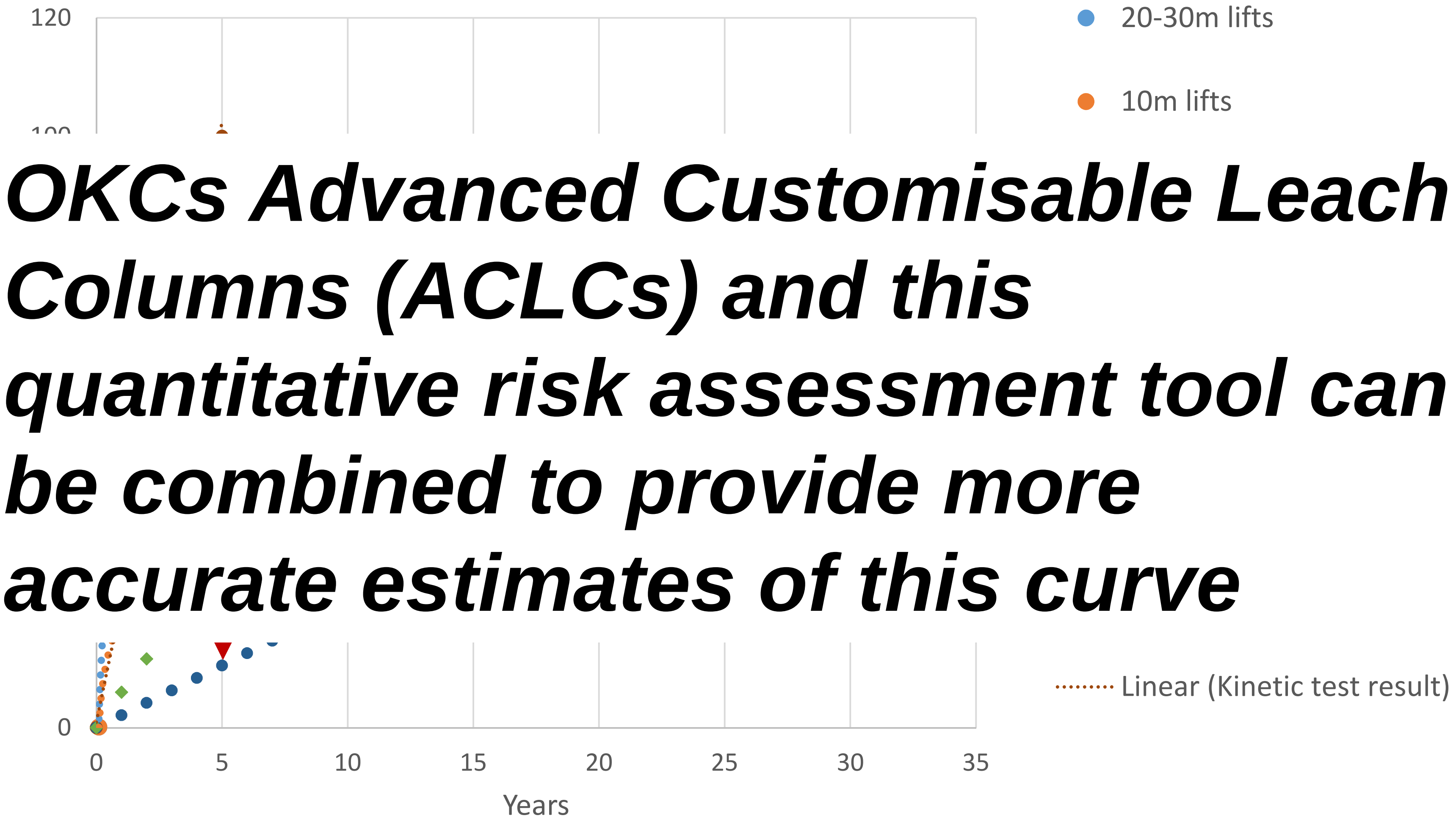
Heat: Approximately 80-120 degrees criteria based on "thermal take off" depends on:

- ***Moisture content***
- ***Sulfur grade***
- ***Carbon grade***

AMD: 30 t H_2SO_4/yr based on "base case" depends on:

- ***Acidity production***
- ***Net percolation rate***

Field data



OKCs Advanced Customisable Leach Columns (ACLCs) and this quantitative risk assessment tool can be combined to provide more accurate estimates of this curve

<u>Field oxidation rates depend primarily on oxygen ingress (structure), kinetic lab tests and use of scale factors is not a sufficient method to predict actual oxidation rates</u>

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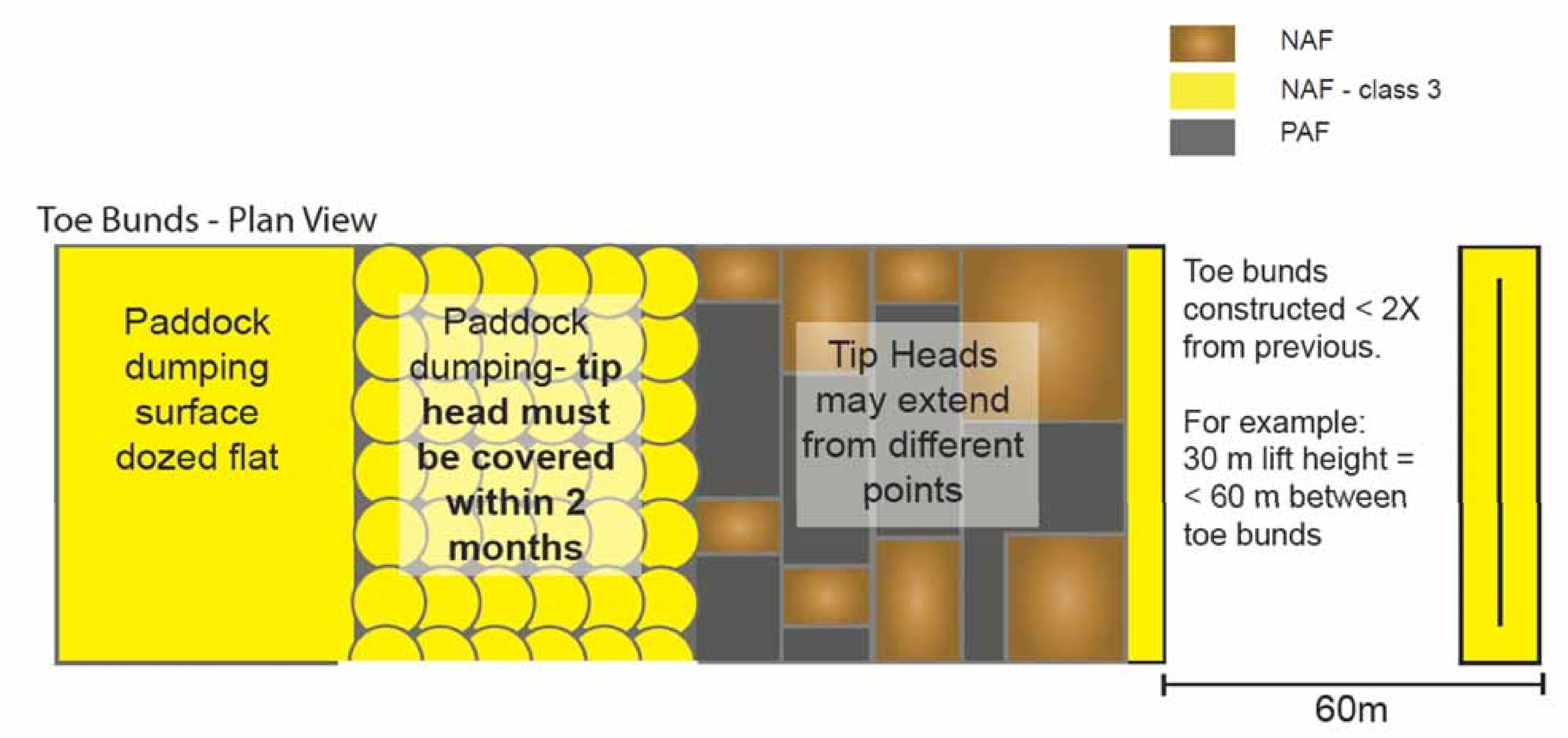
Site specific optimum placement solution example



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