Practically achieving zero oxygen concentrations in waste storage facilities: Martabe mine as a case study

MEM

The Science Behind Success

AGINCOURT RESOURCES

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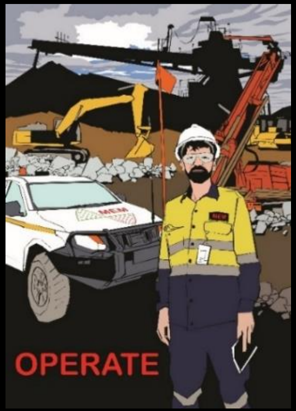
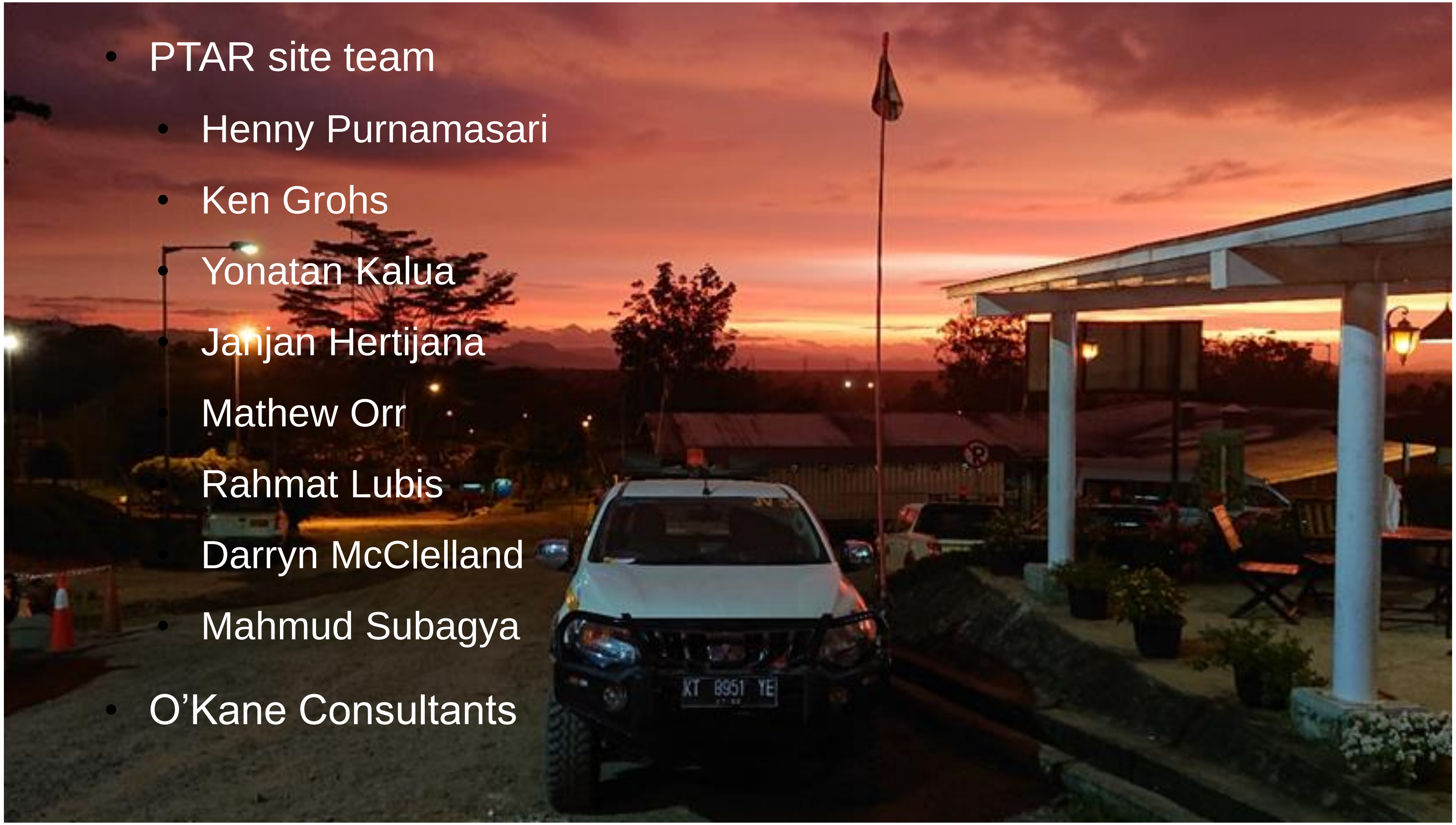
BC MEND ML/ARD ANNUAL WORKSHOP



Credits



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Why “zero” oxygen?

<u>Why?</u>

- Common sense, oxidation of sulfides causes AMD/ARDML don’t need to explain this to the audience of this conference…
- So we don’t create a problem that then needs fixing down the line.
- Demonstrate credible plan for <u>source control and progressive closure (buz words but oxygen control is what is practically needed)</u>

<u>Why not?</u>

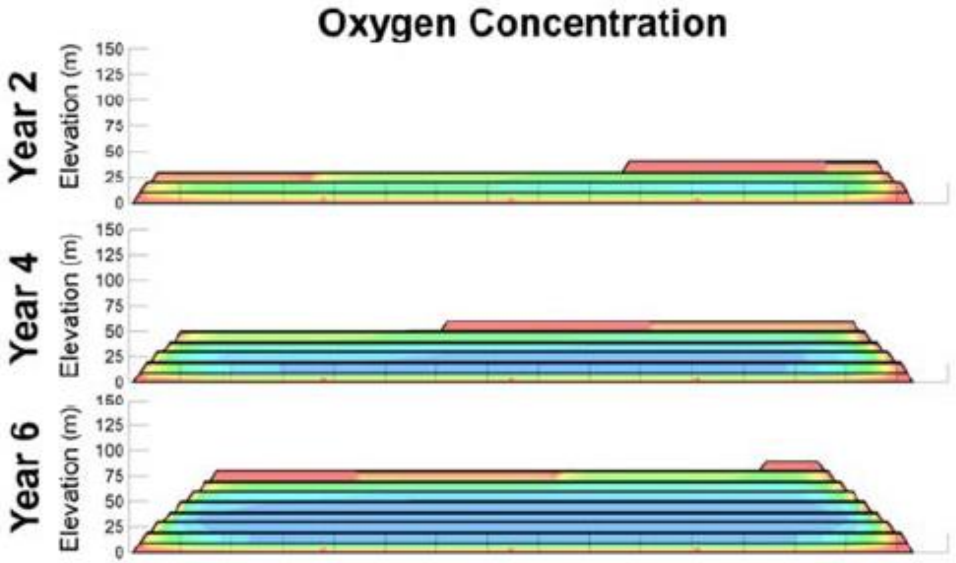
- Because this is largely an operational activity not a closure activity……big difference as operations and closure are often managed separately on site (e.g. budgets)
- Because the current practice of planning to fix the problem created during operations at closure (closure planning..) is accepted as standard practice in the industry
- Because there are practical operational challenges with doing this that are not shown on a neat “conceptual” drawing made by a consultant in an office…..
- <u>Because there is not good understanding around how/when/why to achieve zero oxygen conditions. Oxygen fluxes during construction can be considerable</u>

Oxygen ingress over life of mine

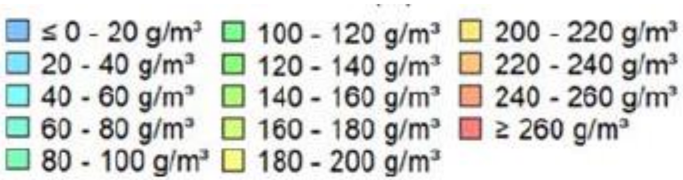
- <u>During operations </u>significant oxygen ingress into waste storage facilities can and does occur. This is particularly true for large facilities that take a long time to construct.

- Waste placement methods alone may reduce advective oxygen ingress (e.g. short tip heads) however diffusion practically is more difficult to control. In fact using short tip heads in many cases likely <u>increases diffusive fluxes at the expense of advective fluxes</u>

- Key objective to get zero oxygen conditions is to reduce advective <u>AND</u> diffusive flux

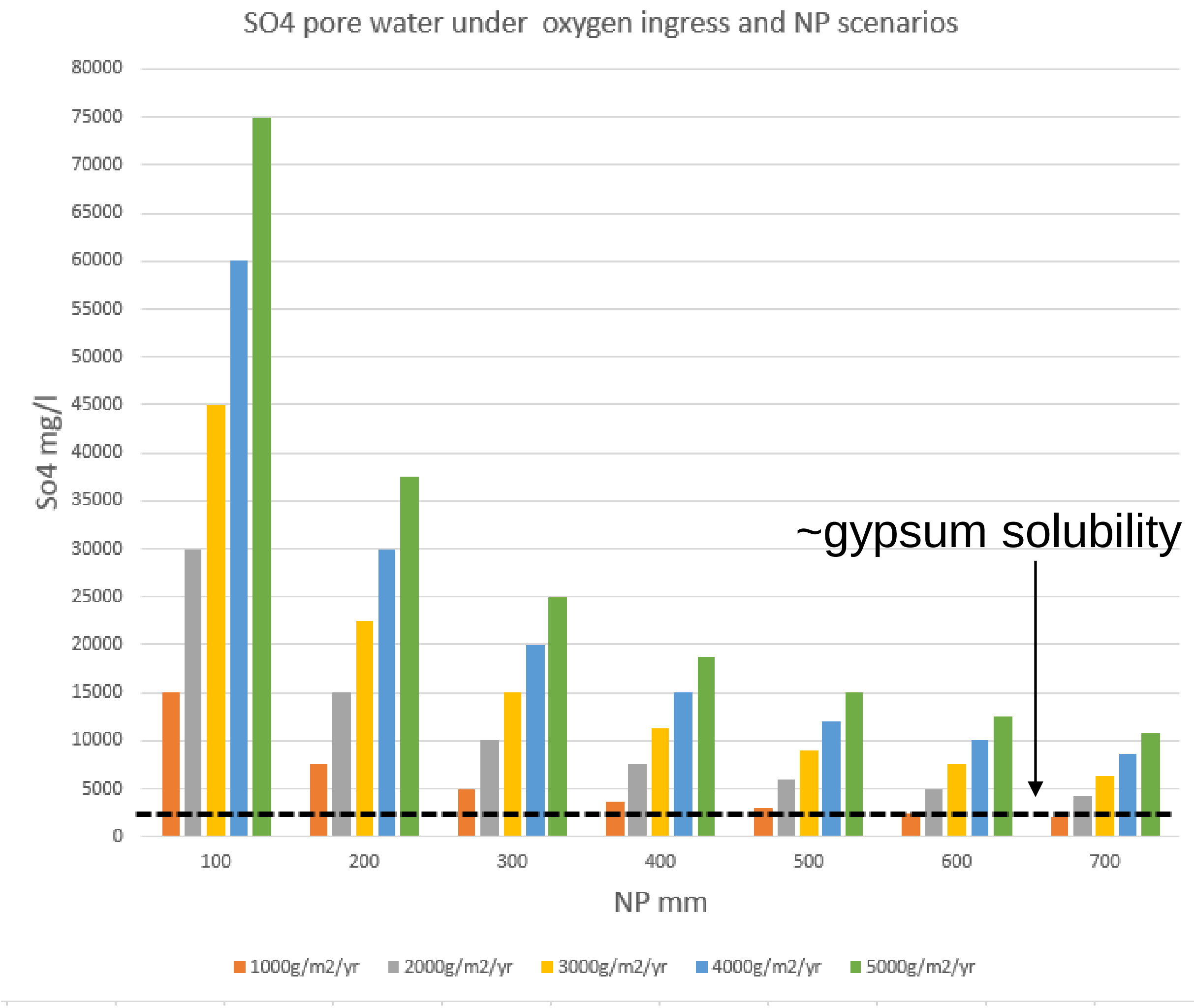


- During construction large dumping surface areas are prone to high diffusive fluxes in upper 10m of profile
- Each bench that is added is increasing the stored load
- 100m high facility as shown would have significant stored load at closure



INAP 2020 (1977.03.04)

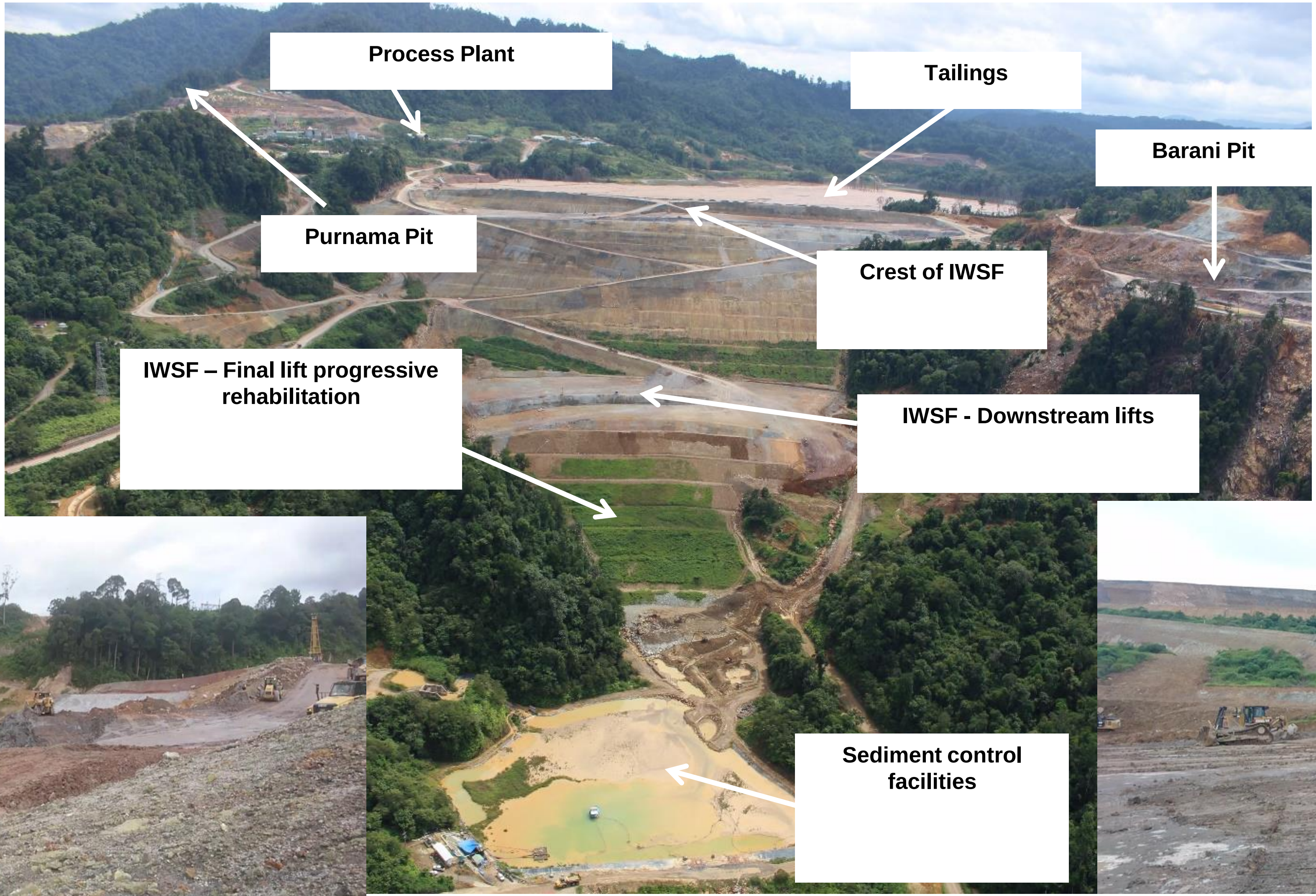
Simple experiment: compare NP rates (flushing) to sulfate generation linked to oxygen ingress rates for a 5m thick bench



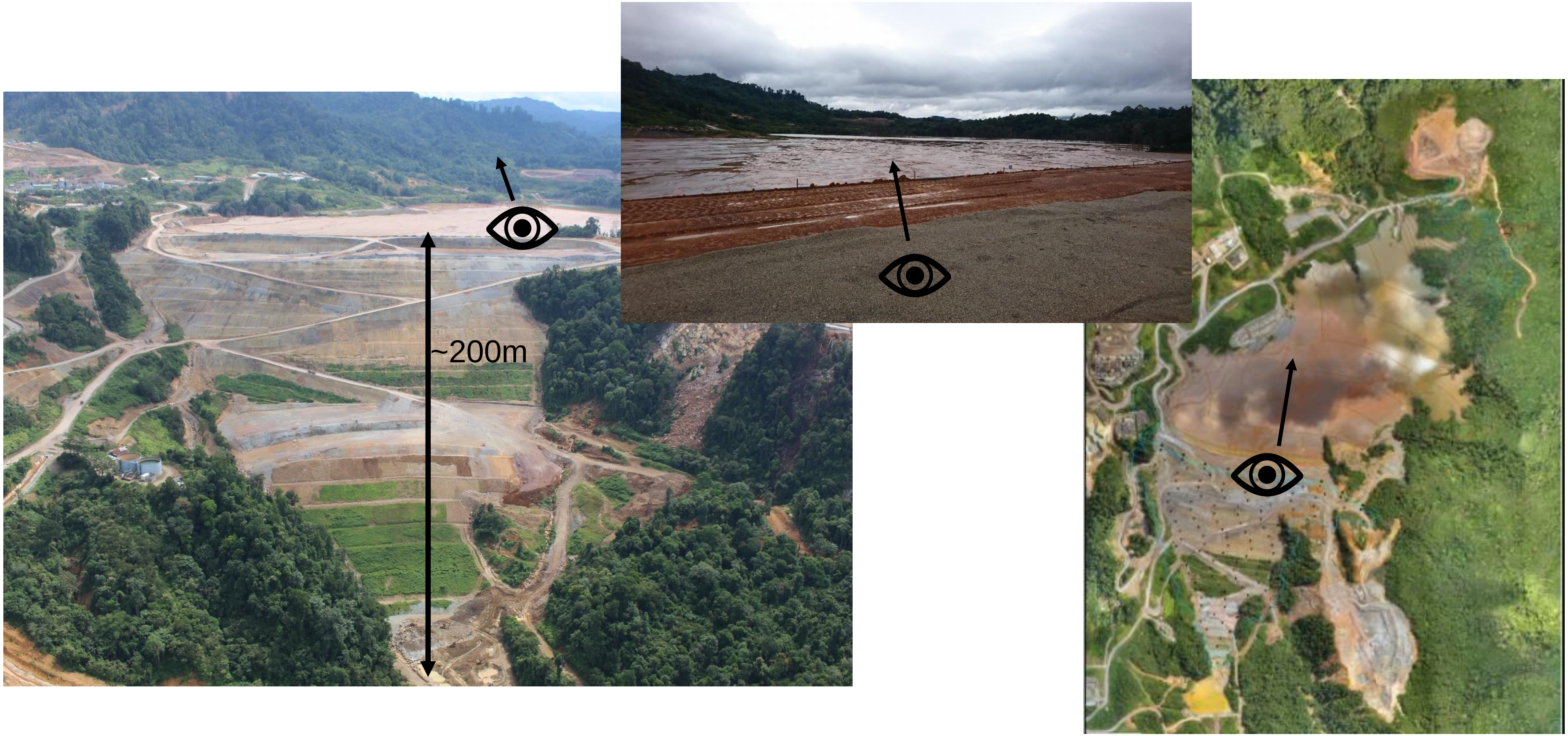
- Air permeability of typical mine waste with sulfide content >0.15% under many climates will provide sufficient oxygen flux for generation of sulfate to produce solubility constrained conditions
- Unless the pH is <4 then gypsum will precipitate which limits pore water SO4 to ~2,500mg/l which will result in storage of secondary sulfate minerals
- At closure a cover system will further reduce NP rates meaning many decades to flush stored products from operational period for waste 50-100m thick

For typical sites oxygen ingress rates need to be <1,000g/m^2/yr during operations before we can prevent storage of secondary minerals and commit to decades of flushing at ~2,000 mg/l SO_4 + metals (ni,as,co,zn even if circum-neutral)

Caste study: Construction of an Integrated Waste Storage Facility (IWSF) at Martabe Mine



Valley-fill tailings dam under downstream raise construction with buttress constructed from waste rock hence IWSF

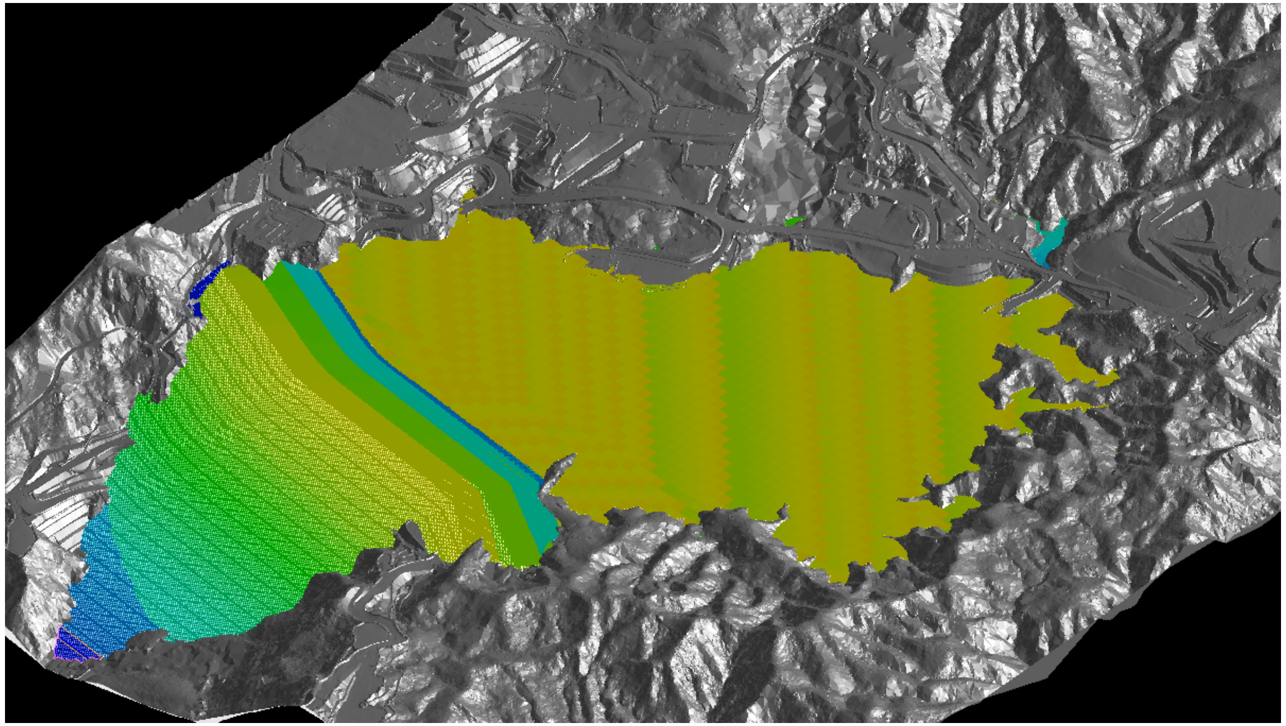


Downstream raise construction

Clay core

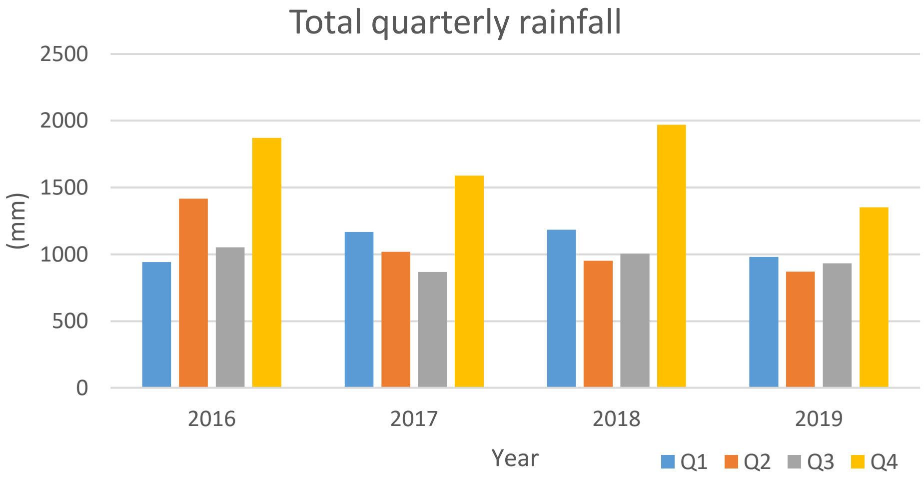
Sand filter/drain

Structural fill is waste rock (mostly PAF/PAG)



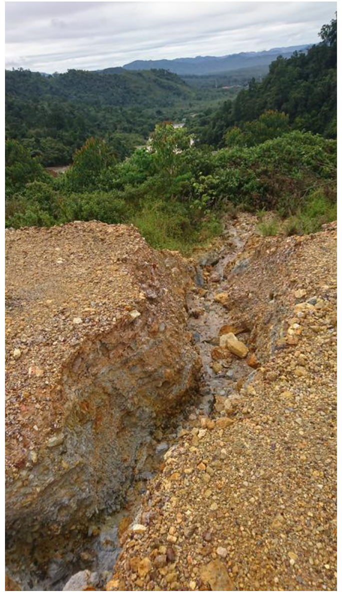
Note that multiple lift schedule provides opportunity for oxygen ingress control

Climate: wet!



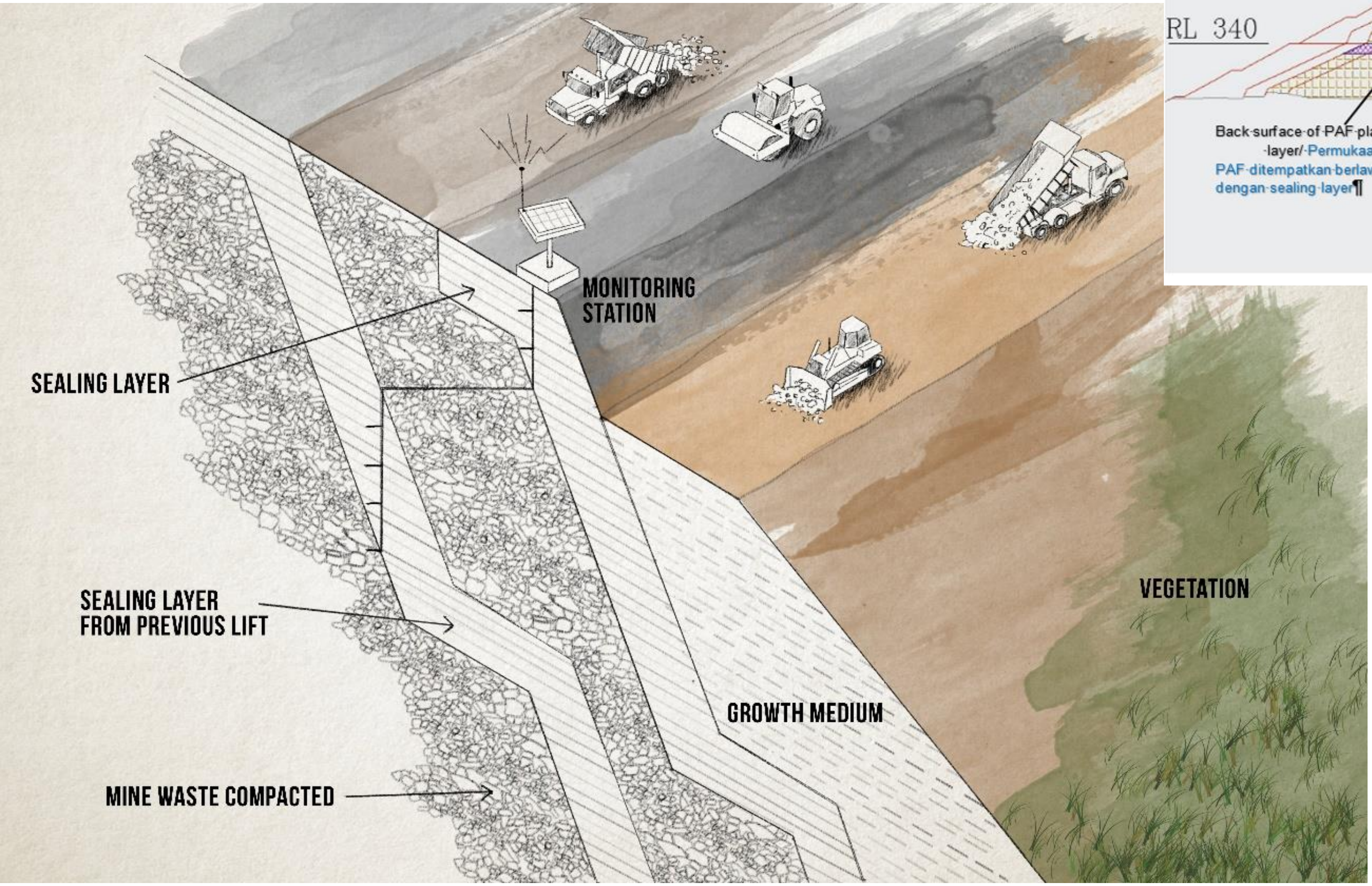
Advantage :0)

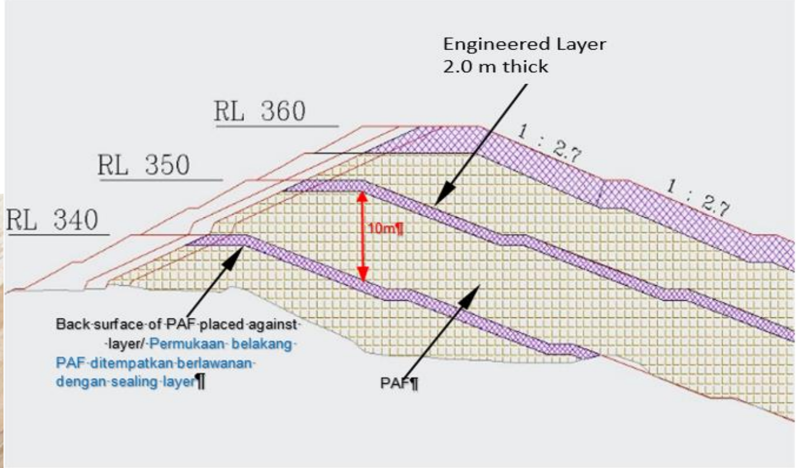
Challenge :0(

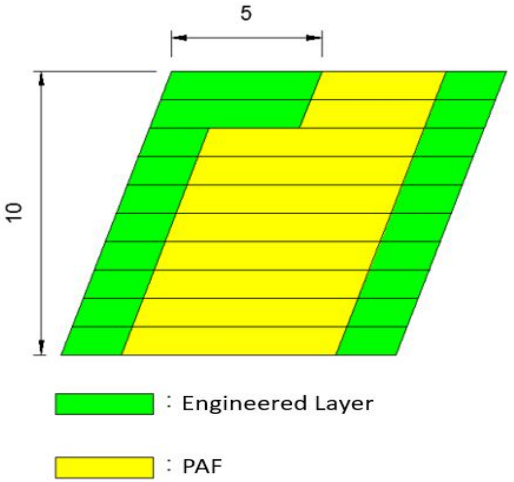


Heterogeneity of materials

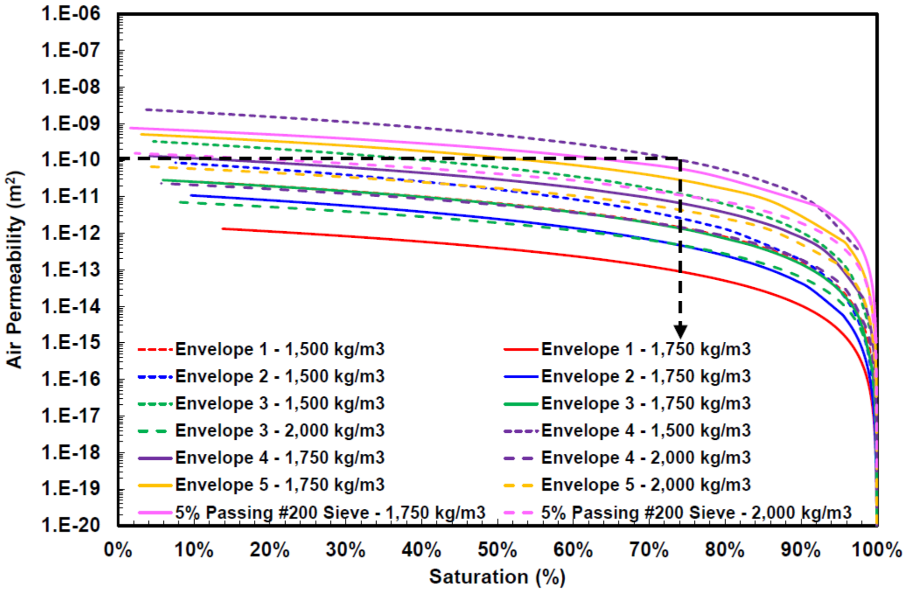
Review of embankment conceptual design (nice drawing in consultants reports..)







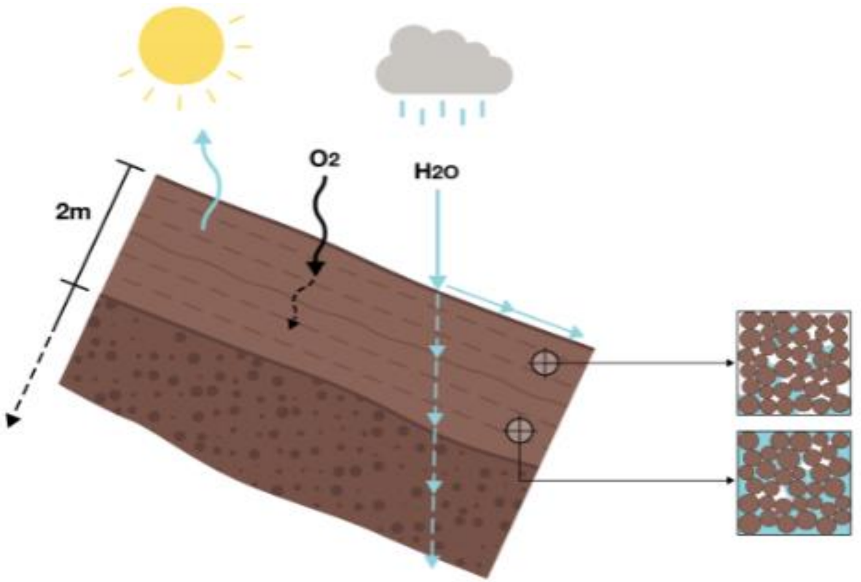
Sealing layer concept



Pearce et al 2017: Progressive management of AMD risk during construction of an Integrated Waste Storage Landform- A case Study at Martabe Gold Mine, Indonesia: Proceedings of IMWA 20127

- If you compact boulders you still get boulders!….
- Use of <u>*"sealing layer"*</u> over entire outer surface of embankment that has <u>consistent properties</u> considered to be <u>safer strategy than relying on low lift compaction alone</u>
- Requires:
  - Suitable ROM material
  - Practical approach for
    - Identifying materials
    - Scheduling materials
    - Placing materials
    - Monitoring performance
- Sealing layer specification determined based on determination of oxygen ingress based on <u>assessment of air permeability at given saturation level for a given material texture at a given compaction</u>
- **Goal is to reduce oxygen ingress to be diffusion limited (i.e. no advection) AND to reduce diffusion of oxygen so it does not penetrate below sealing layer (~2m depth)**

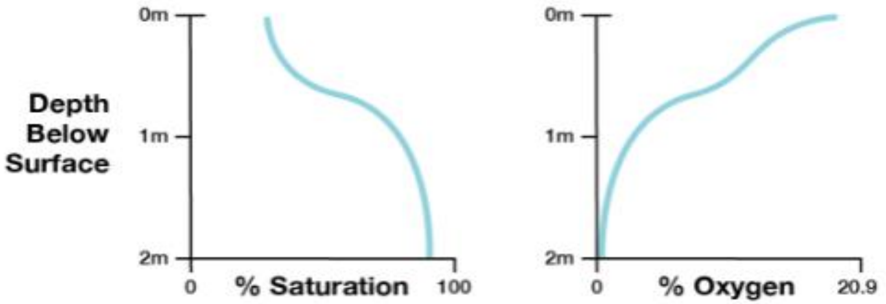
Sealing layer function



PSD Envelope	% Passing #4 Sieve (Sand & Fines Content)	% Passing #200 Sieve (Fines Content)	Compaction requirements	Permeability requirements (cm/s)
1	92%	65%	-3%< OMC < +6% 95% MDD	$1E^{-4}$
2	82%	50%	-3%< OMC < +6% 95% MDD	$7E^{-5}$
3	72%	38%	-3%< OMC < +6% 95% MDD	$4E^{-5}$
4	55%	25%	-3%< OMC < +6% 95% MDD	$3E^{-5}$
5	40%	12%	-3%< OMC < +6% 95% MDD	$2E^{-5}$

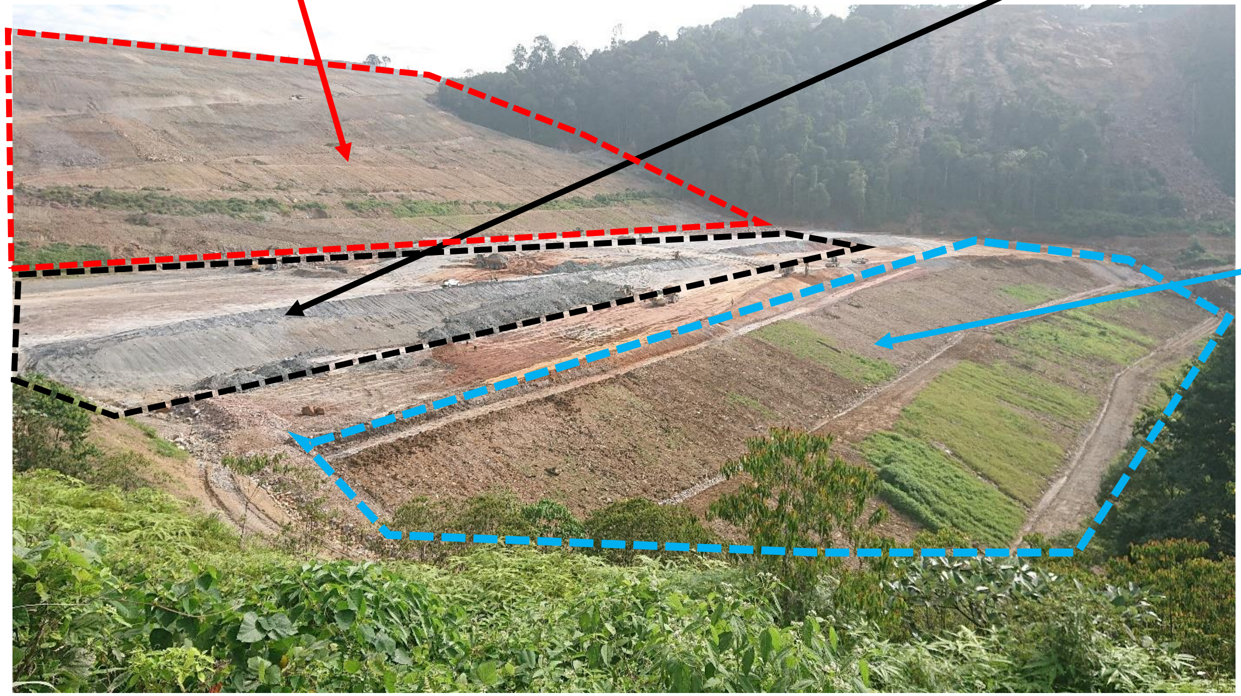
[1] A lift of sealing material must be verified by completion and passing of the quality control / quality assurance (QCA) program

[2] The next lift of sealing material and/or PAF material must not be placed until QCA has been completed on the existing lift of sealing material



Oxygen ingress exposure pathways

Previous embankment slope area with sealing layers limit diffusive oxygen ingress to ~0.5m depth



Active construction bench (compacted in 1m layers) surfaces provide exposure for oxygen and AMD generation. Larger the open area, longer the exposure duration the higher the AMD generation. On the IWSF area is relatively small and placement/rate of rise is relatively fast

Already constructed benches with final growth medium cover will have low oxygen ingress and low AMD generation and better surface water run off quality

Pit staging plan and waste schedule for multi pits

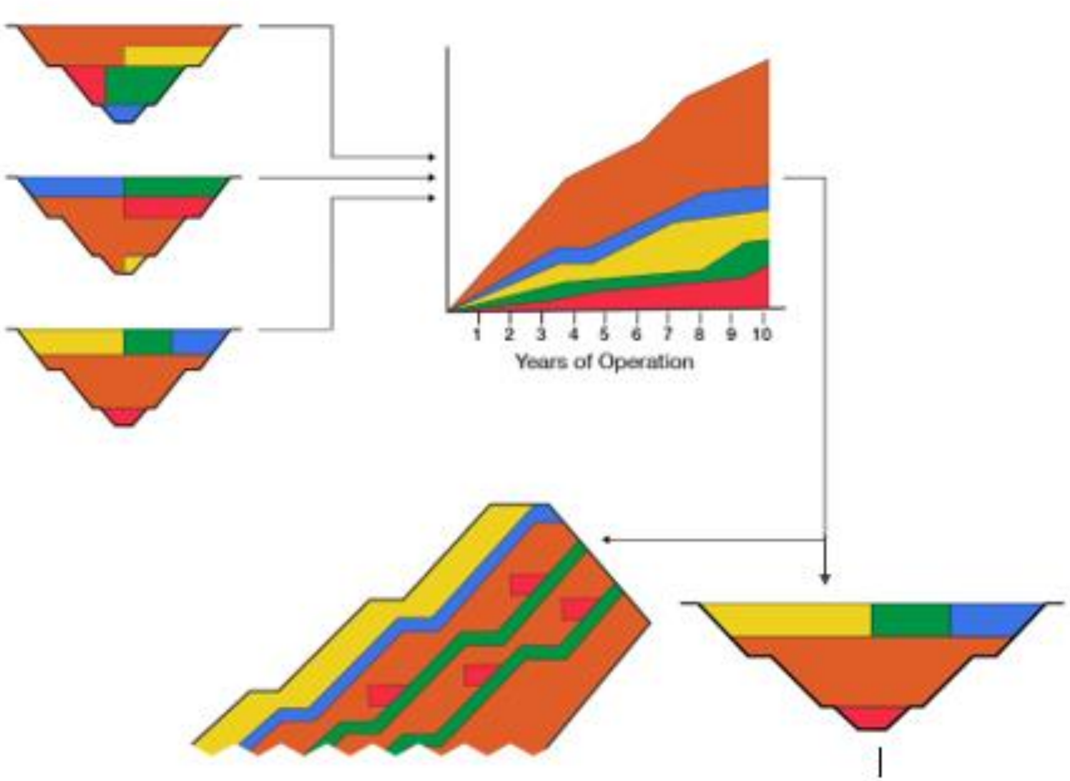
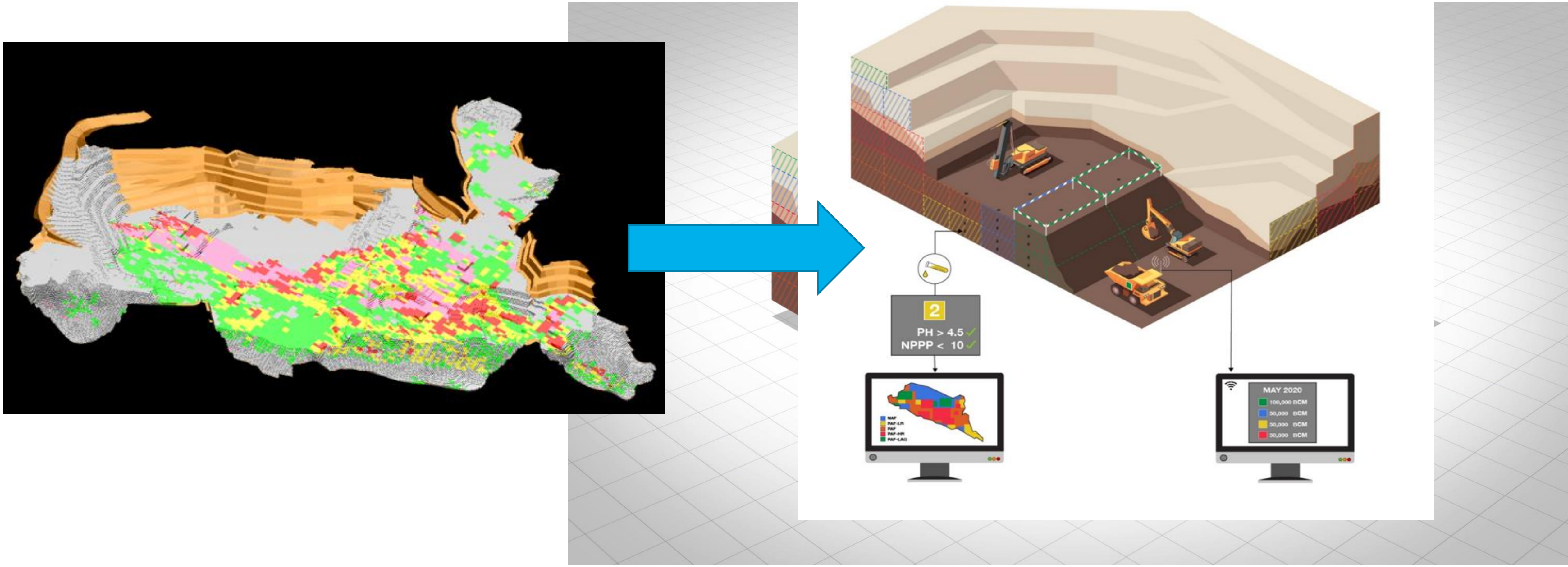


Figure 3-1 Long term planning concept: the process of waste block modelling, multi pit waste scheduling and waste destination planning

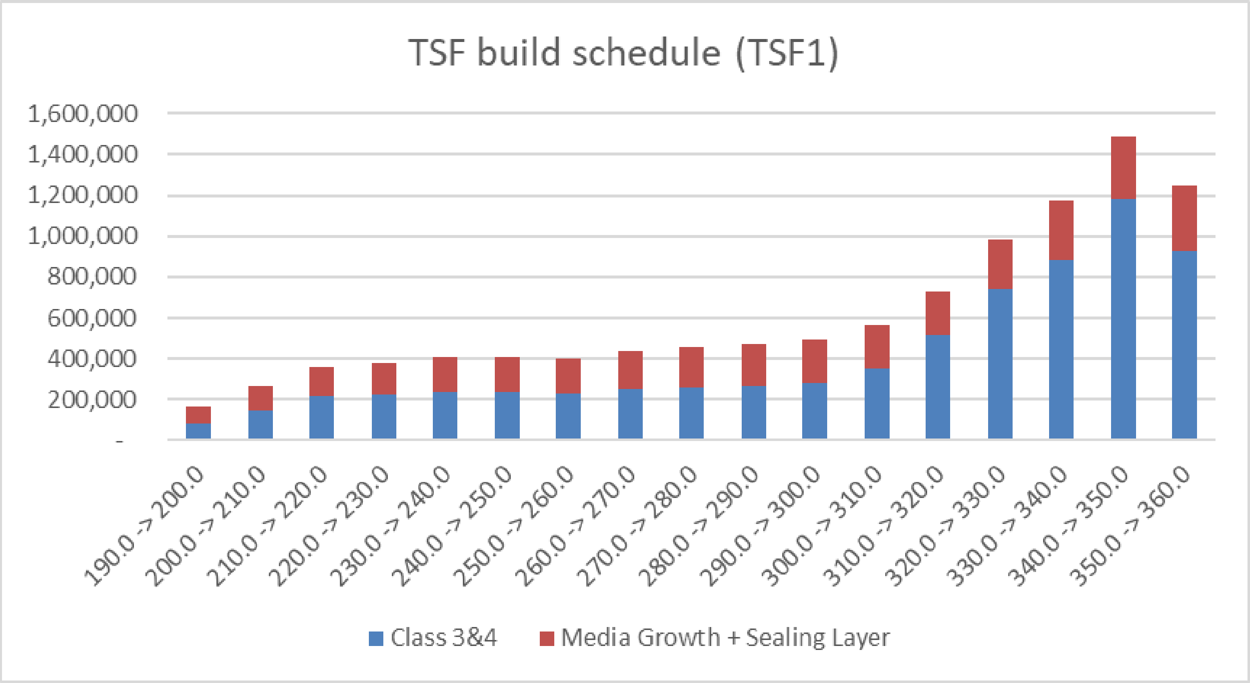
- Long term planning concept
- Recognise that multi pit development means the plan evolving over time
- Recognise that construction of TSF structures requires forward build plan and scheduling from multiple pits over long periods time
- Recognise that materials need to be identified based on geochemical and geotechnical properties

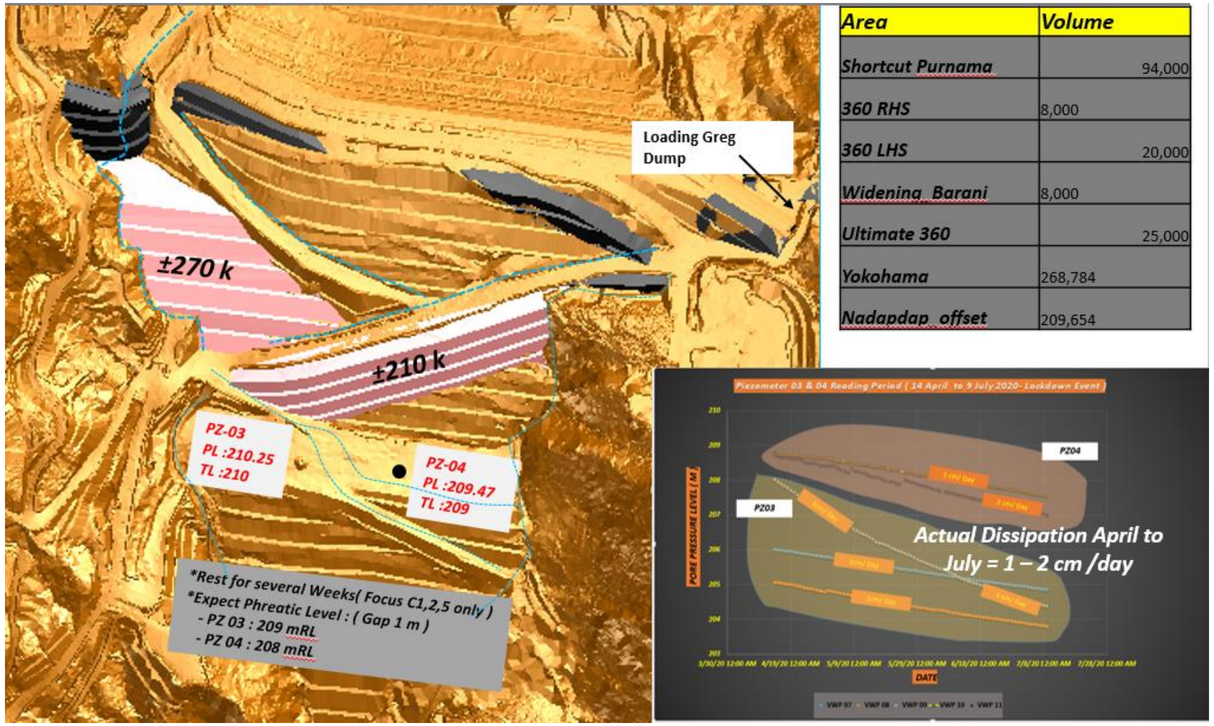
Current best practice waste management



Mine waste using same principal as for ore*

TSF build plan concept





Area	Volume
Shortcut Purnama	94,000
360 RHS	8,000
360 LHS	20,000
Widening Barani	8,000
Ultimate 360	25,000
Yokohama	268,784
Nadapdap offset	209,654

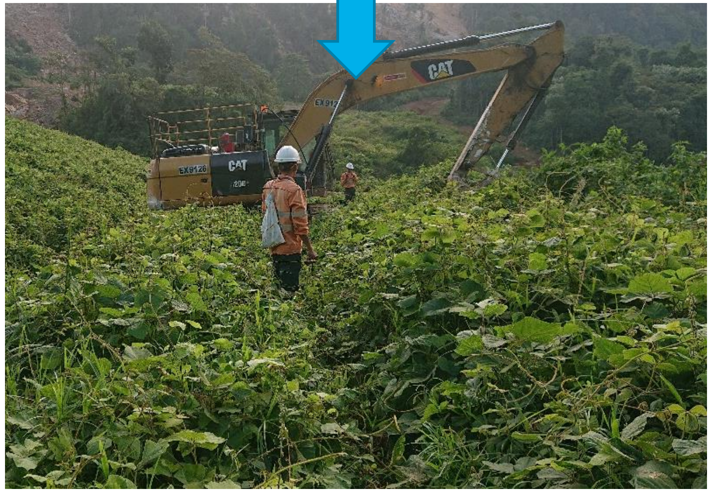
- Note that operational construction planning is more complex than a tidy neat conceptual drawing shown on a plan in a consultants office………
  - Placement in multiple areas at any one time
  - Account for access so not uniform lift morphology
  - Need to account for pore pressure, weather, access etc etc

Field data: proof of concept

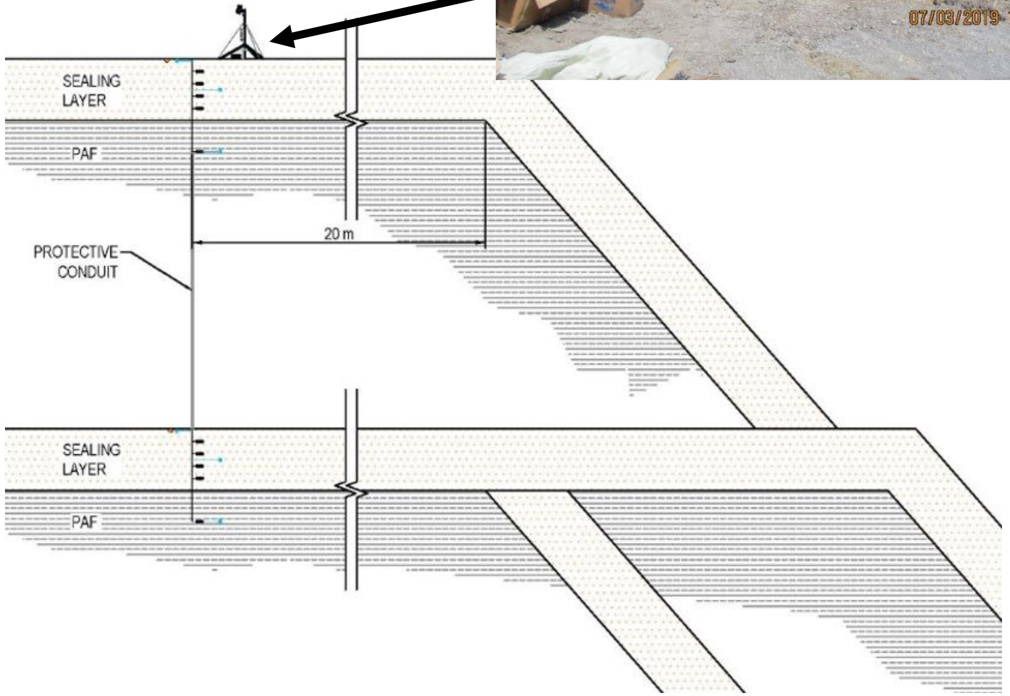
- Key is multiple lines of evidence, <u>oxygen on its own does not tell you enough</u>
  - Monitoring of in sealing layers at surface and after burial post embankment lifting:
    - Oxygen
    - Temperature
    - VWC
    - pore pressure
    - EC
  - Drilling and sampling through embankment profile to confirm internal geochemical conditions
  - Trial pitting of sealing layer to determine geochemical conditions
  - Sampling of toe drainage water quality

Growth medium zone revegetation progress to date <12 months

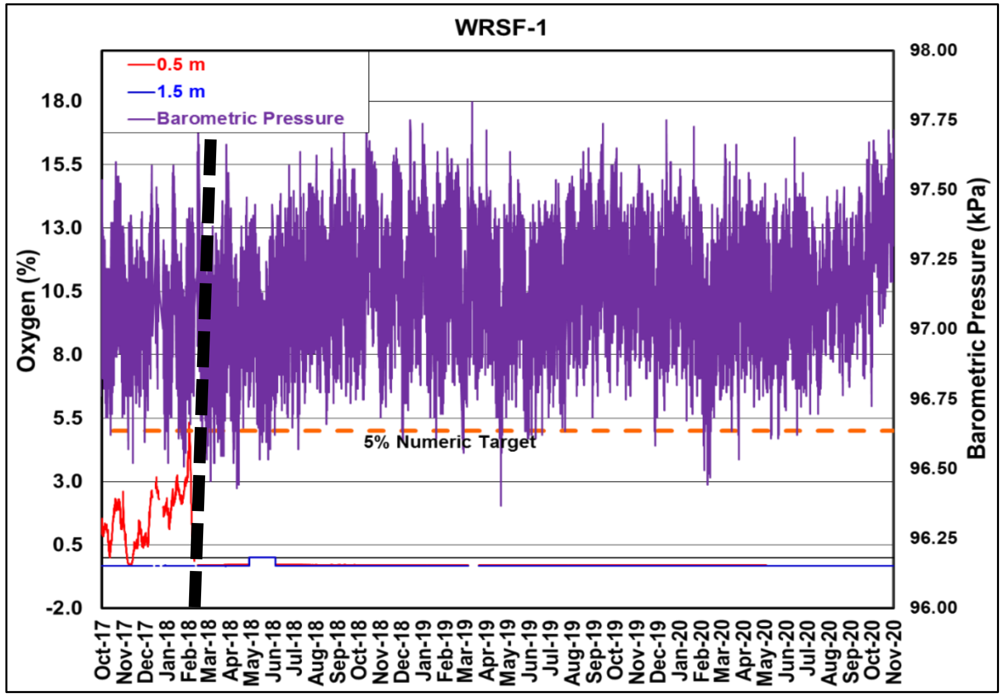
- Establishment of vegetation key to erosion minimisation
- Rapid placement of growth medium topsoil and seeding being achieved
- Growth medium allows for plant root development (rooting zone observed to be <1m depth)
- Climate helps :0)

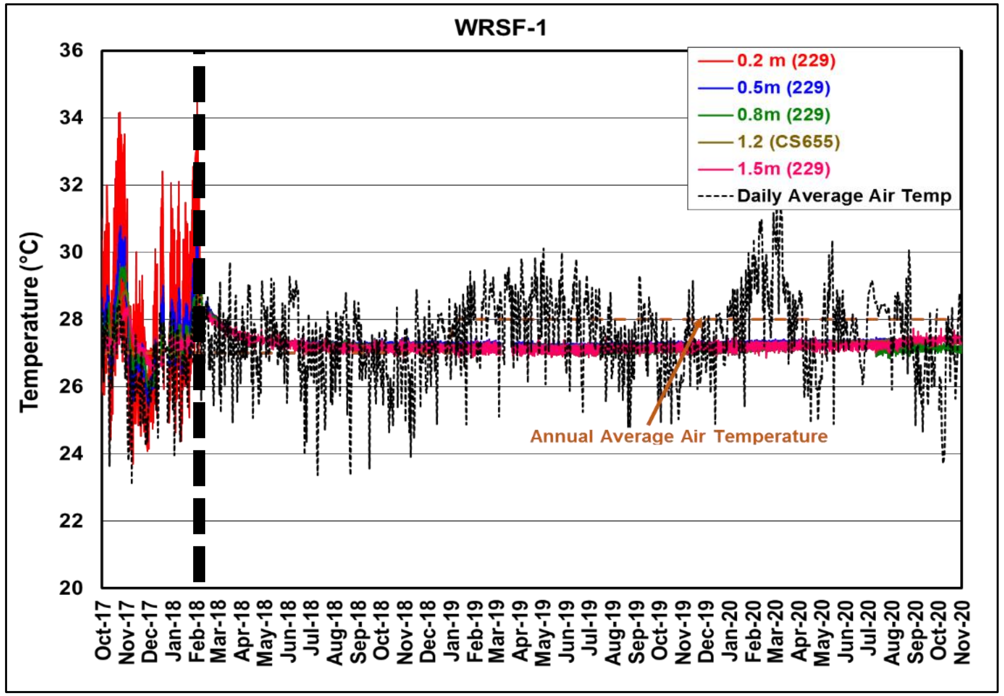


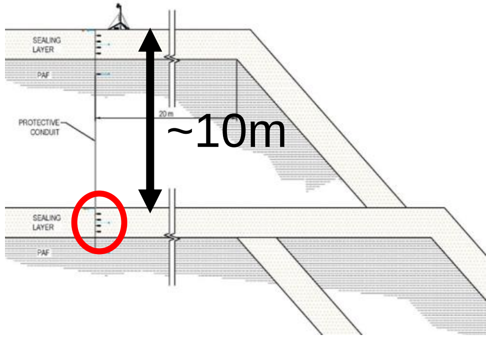
Monitoring data



Oxygen/temperature profile from sealing layer before and after embankment lift (WRSF1)

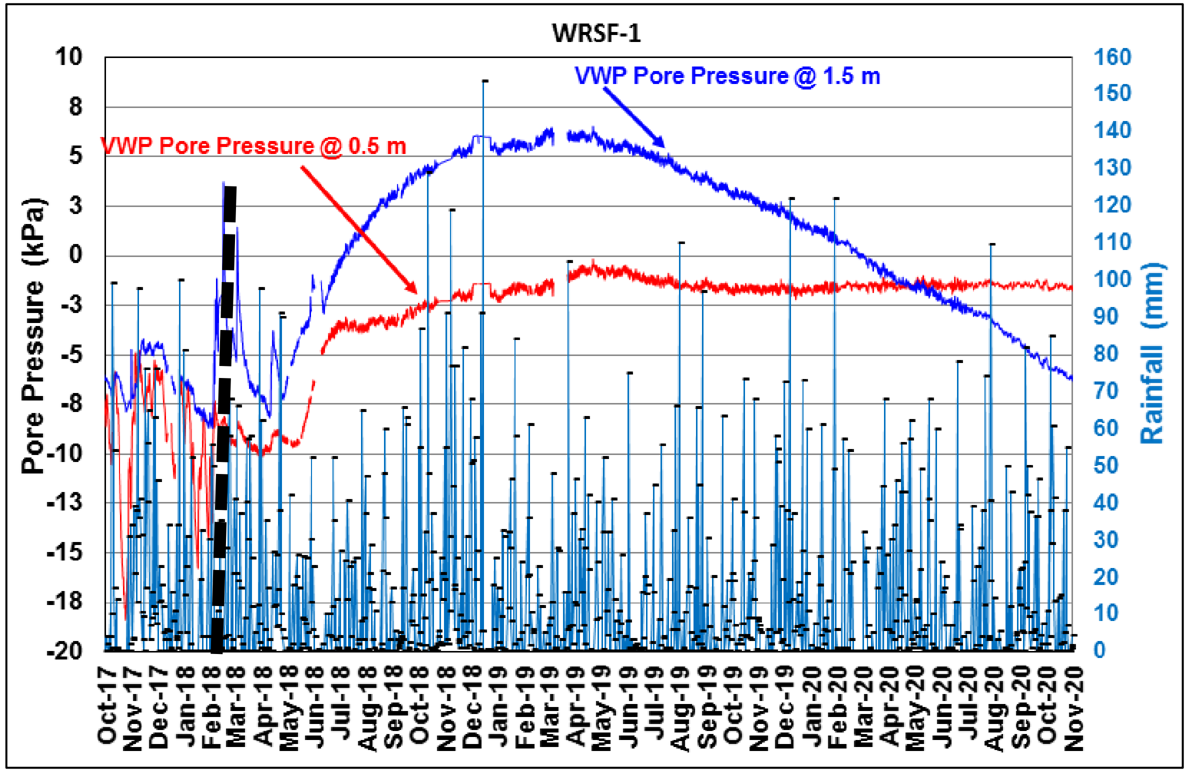


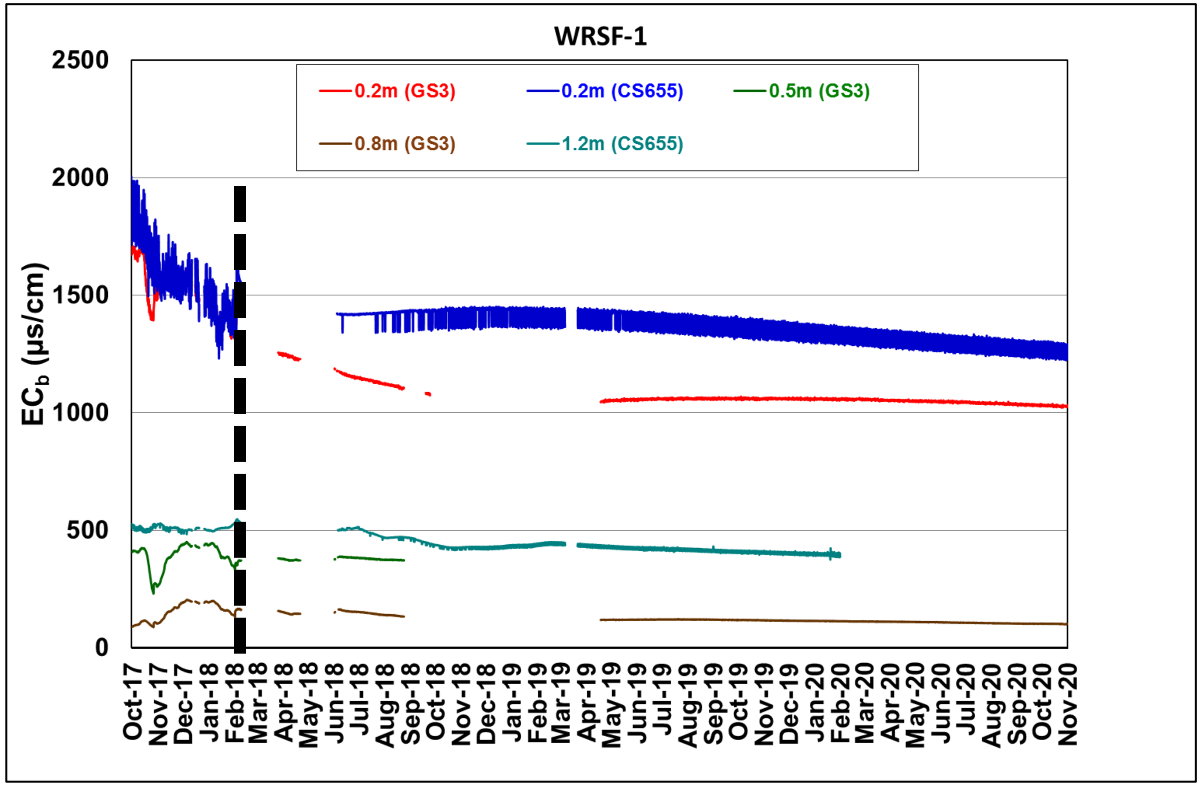




- Embankment lift occurred in Feb 2018, sealing layer buried under ~10m vertical thickness of waste placement
- Before lift occurred positive oxygen recorded at 0.5m depth but not at 1.5m depth
- After lift <u>zero oxygen conditions in both sensors over entire period of 2018-2020</u>
- Temperature slightly below ambient post burial indicating <u>no evidence for exothermic reactions</u>

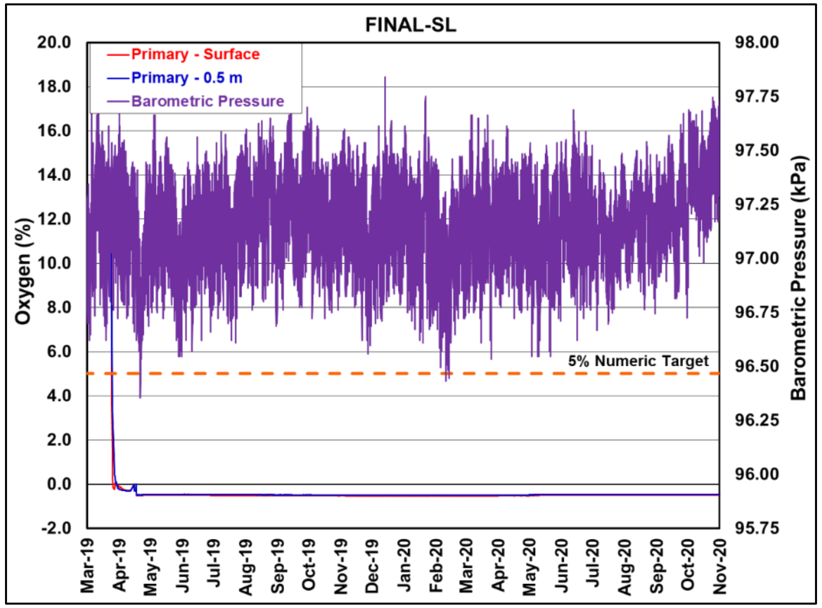
Pore pressure and EC profile from sealing layer before and after 10m embankment lift (WRSF1)

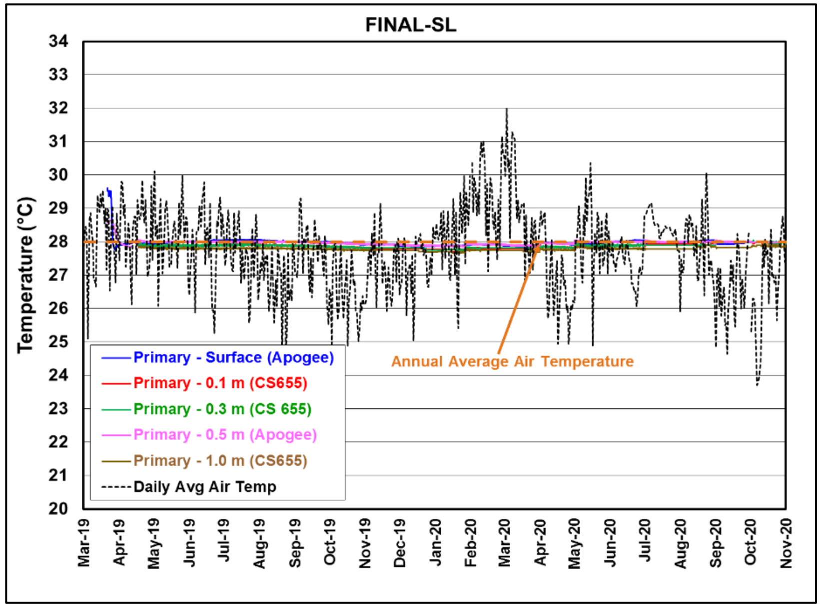


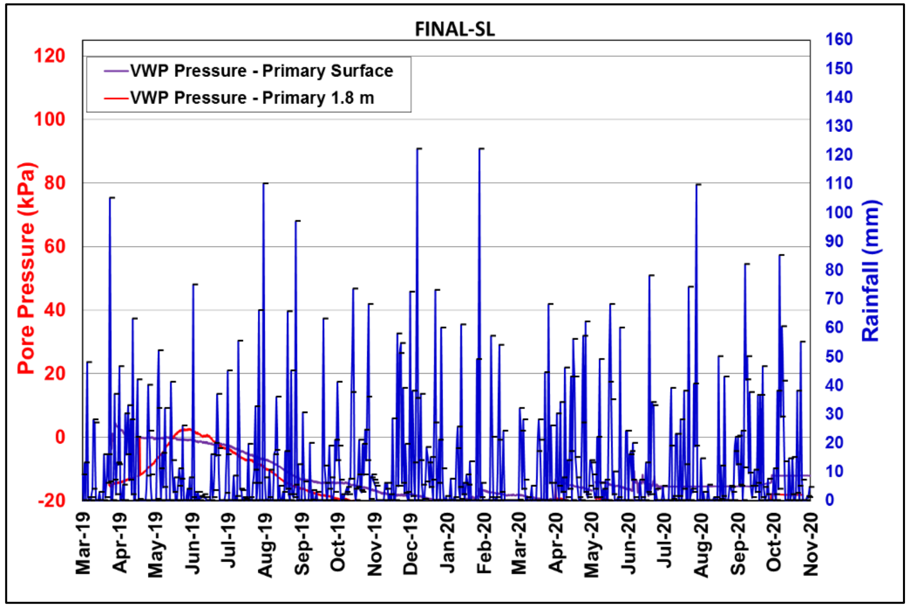


- After embankment lift occurred pore pressure slightly positive at base sealing layer, but over 2019 and 2020 period this has fallen to be negative. <u>No clear evidence sealing layer is causing any issues with seepage flux dynamics within embankment profile.</u>
- EC has generally remained stable since embankment lift indicating <u>stable pore water geochemical conditions</u>

Burial of final sealing layer under growth medium



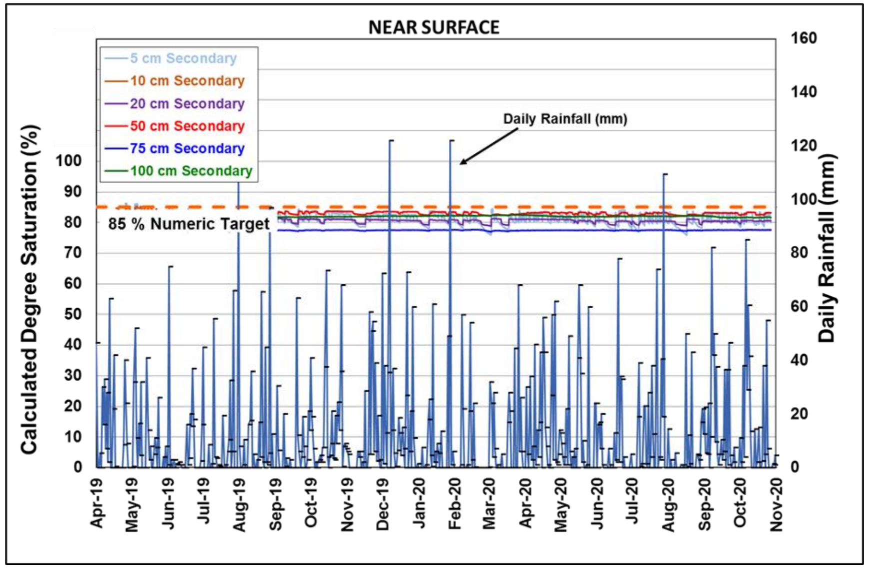


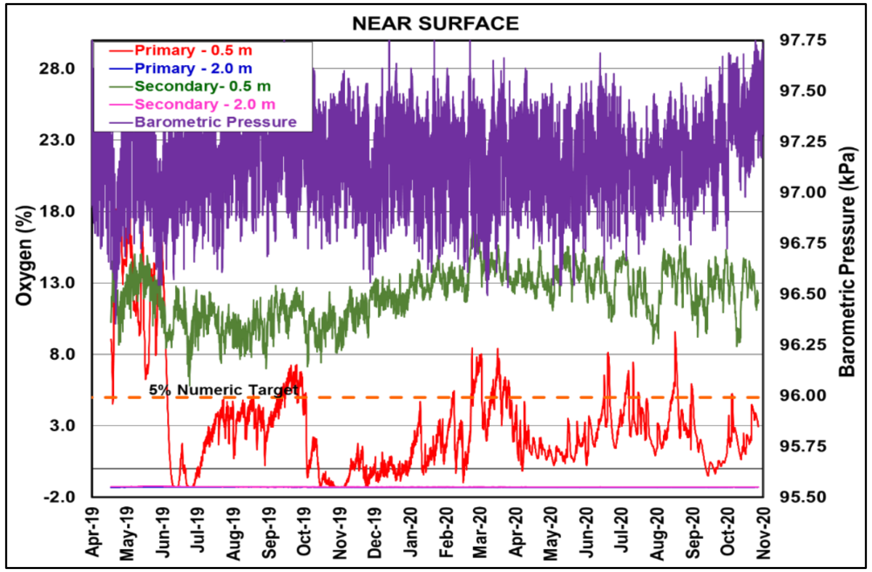


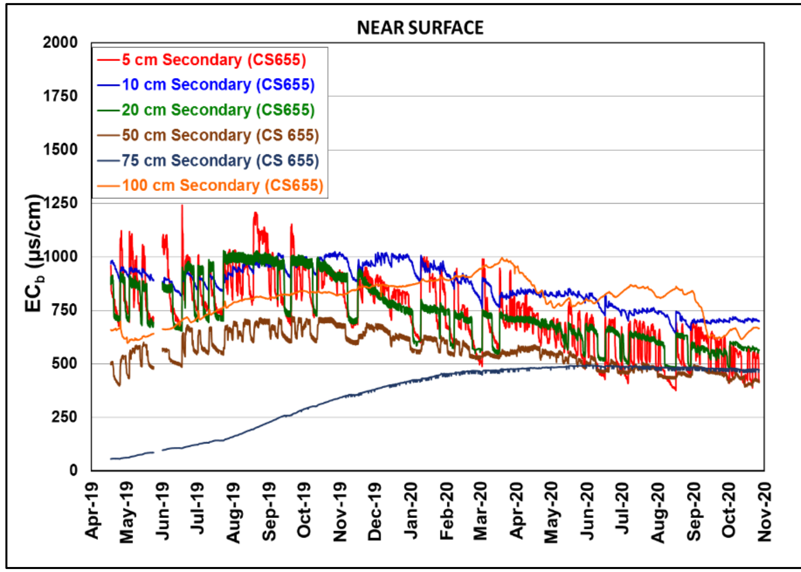
Once growth medium placed over sealing layer in April 2019:

- Oxygen reduces to zero
- Temperature remains ~ ambient
- Pore pressures remain close to zero or negative

Conditions in Growth medium



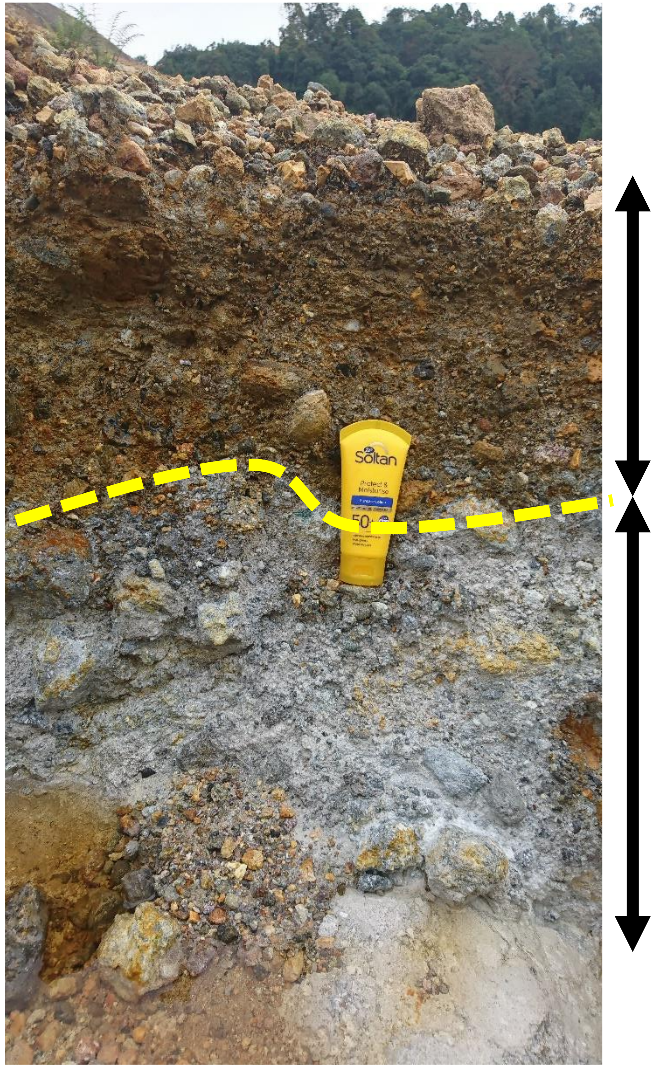




Growth medium conditions

- Oxygen reduces to zero at depth of 2m, positive at depth of ~0.5m indicating shallow diffusion occuring
- Saturation levels are ~80% which are slightly lower than those achieved in sealing layers but still high enough to reduce oxygen ingress
- EC is trending down with time indicating that significant sulfide oxidation in this zone not occurring

Sealing layer degradation (~2-3 years), results from 10 trial pits in 2020

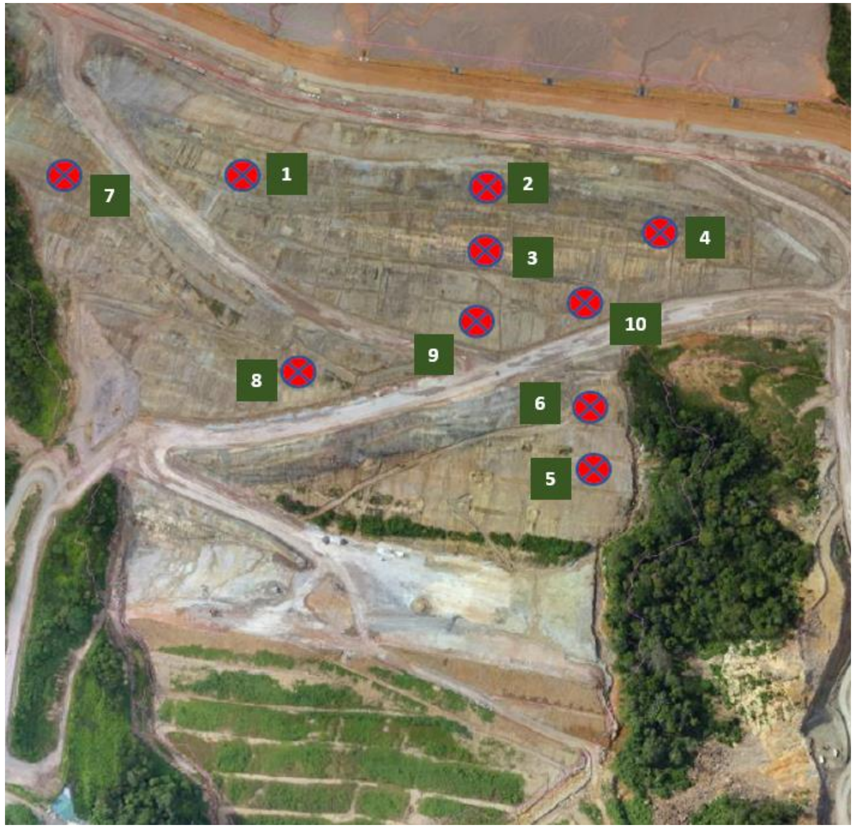


Oxidised zone <0.5m

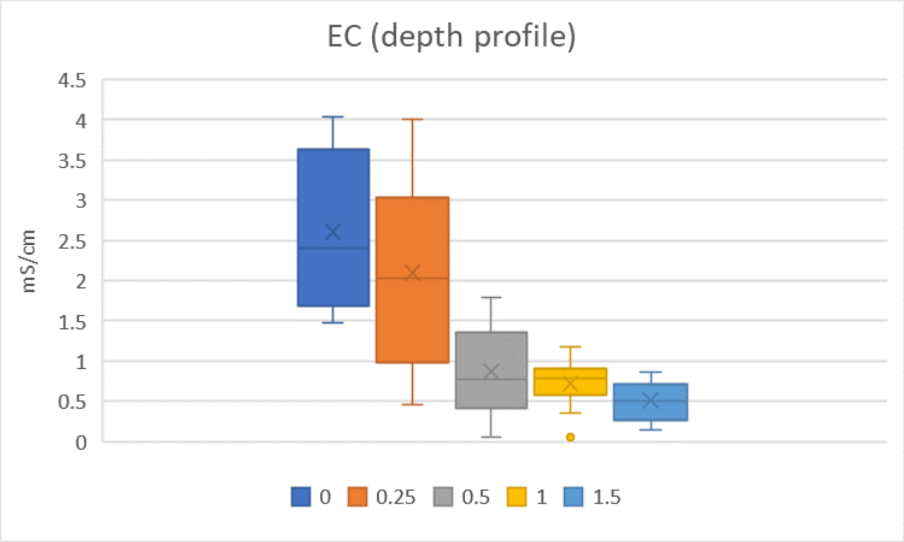
- Sulfide depletion
- Higher EC
- pH<4

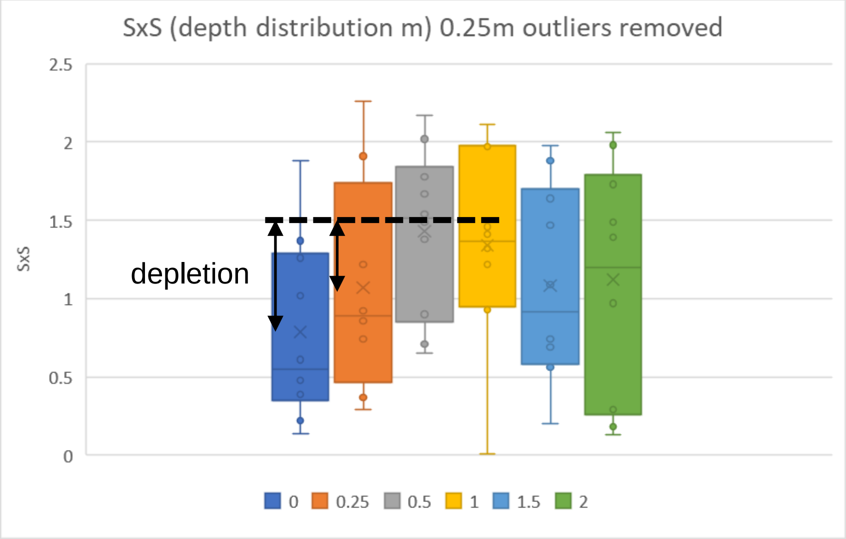
Non-oxidised zone >0.5m depth

- Little sulfide depletion
- Lower EC
- Acid seepage from shallow depth being buffered (pH>4).



Sulfide distribution with depth (10 trial pits)

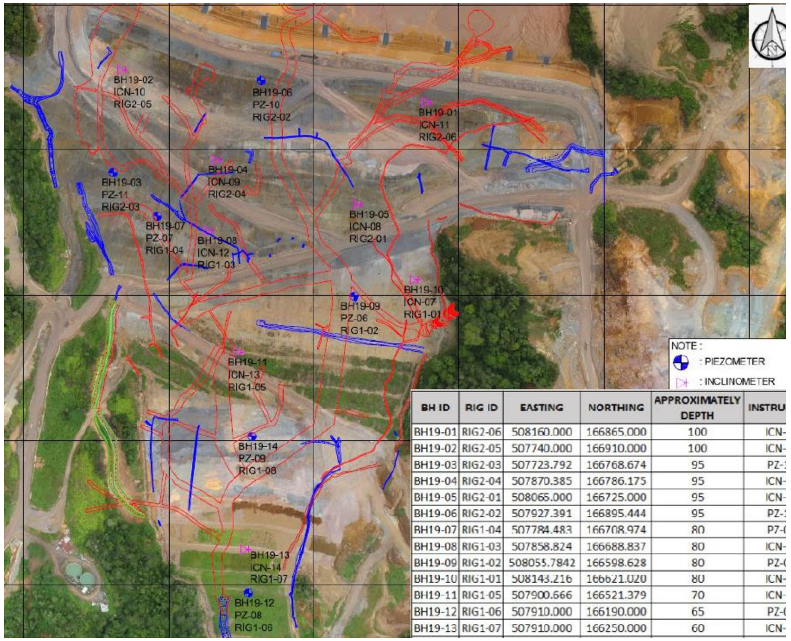




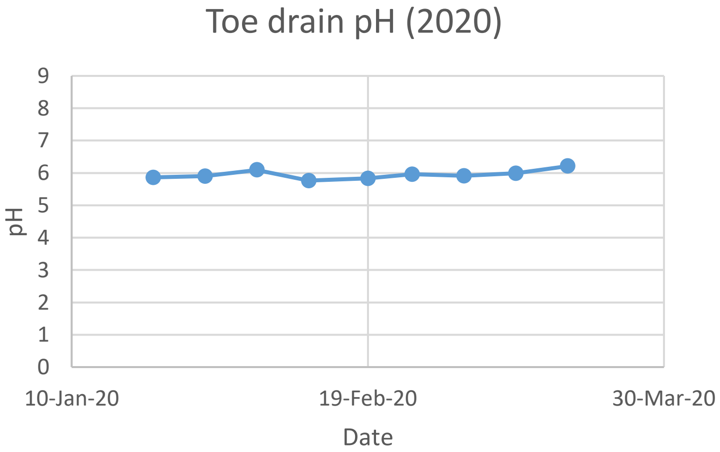
- Sulfide depth profile indicates that
  - Depletion of sulfides at shallow depth only, mostly <0.25cm depth
  - Average depletion at surface ~50% (0.75%S)
  - Average depletion at ~0.25m depth ~33% (0.5% S)
  - Apparent accumulation at 0.25m depth in some samples likely interference from sulfate minerals precipitating
  - <u>At >0.5m depth little or no depletion indicting no evidence for sulfide oxidation below 0.5m depth</u>

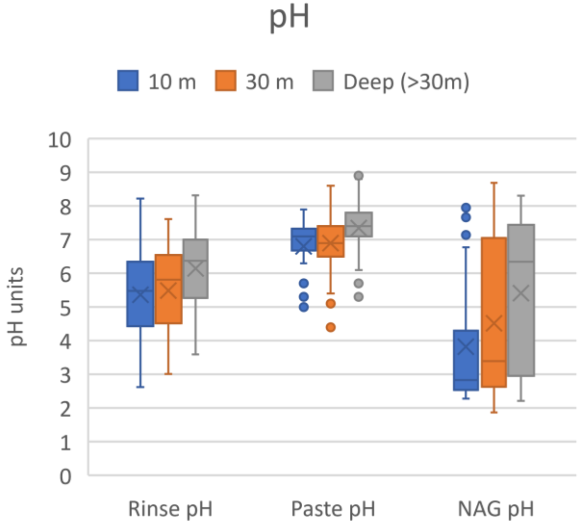
Results support oxygen ingress monitoring data which indicates that oxygen ingress is only significant in upper 0.5m depth of sealing layer

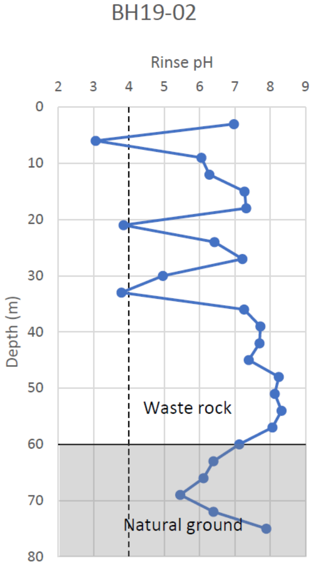
IWSF internal condition from drilling program (2019)

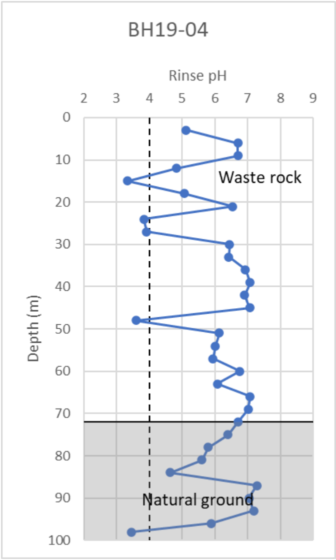


BH ID	RIG ID	EASTING	NORTHING	APPROXIMATELY DEPTH	INSTRU
BH19-01	RIG2-06	508160.000	166865.000	100	ICN-
BH19-02	RIG2-05	507740.000	166910.000	100	ICN-
BH19-03	RIG2-03	507723.792	166768.674	95	PZ-
BH19-04	RIG2-04	507870.385	166786.175	95	ICN-
BH19-05	RIG2-01	508065.000	166725.000	95	ICN-
BH19-06	RIG2-02	507927.391	166895.444	95	PZ-
BH19-07	RIG1-04	507784.483	166708.974	80	PZ-
BH19-08	RIG1-03	507858.824	166688.837	80	ICN-
BH19-09	RIG1-02	508055.7842	166598.628	80	PZ-
BH19-10	RIG1-01	508143.216	166621.020	80	ICN-
BH19-11	RIG1-05	507900.666	166521.379	70	ICN-
BH19-12	RIG1-06	507910.000	166190.000	65	PZ-
BH19-13	RIG1-07	507910.000	166250.000	60	ICN-









- Rinse pH profile in TSF indicates >75% material has pH>4.5, and ~50% has pH>5.5
- Note that ~70% of material is PAF/PAG
- pH is lower at shallow depths due to decrease in ANC at shallow depth
- Rinse pH used on site as more conservative proxy for pore water pH
- pH of toe drain ~6 indicating that acid conditions not developed in majority of seepage to date

Data does not indicate significant AMD has developed as a result of construction and supports monitoring data

Conclusion: It is possible!

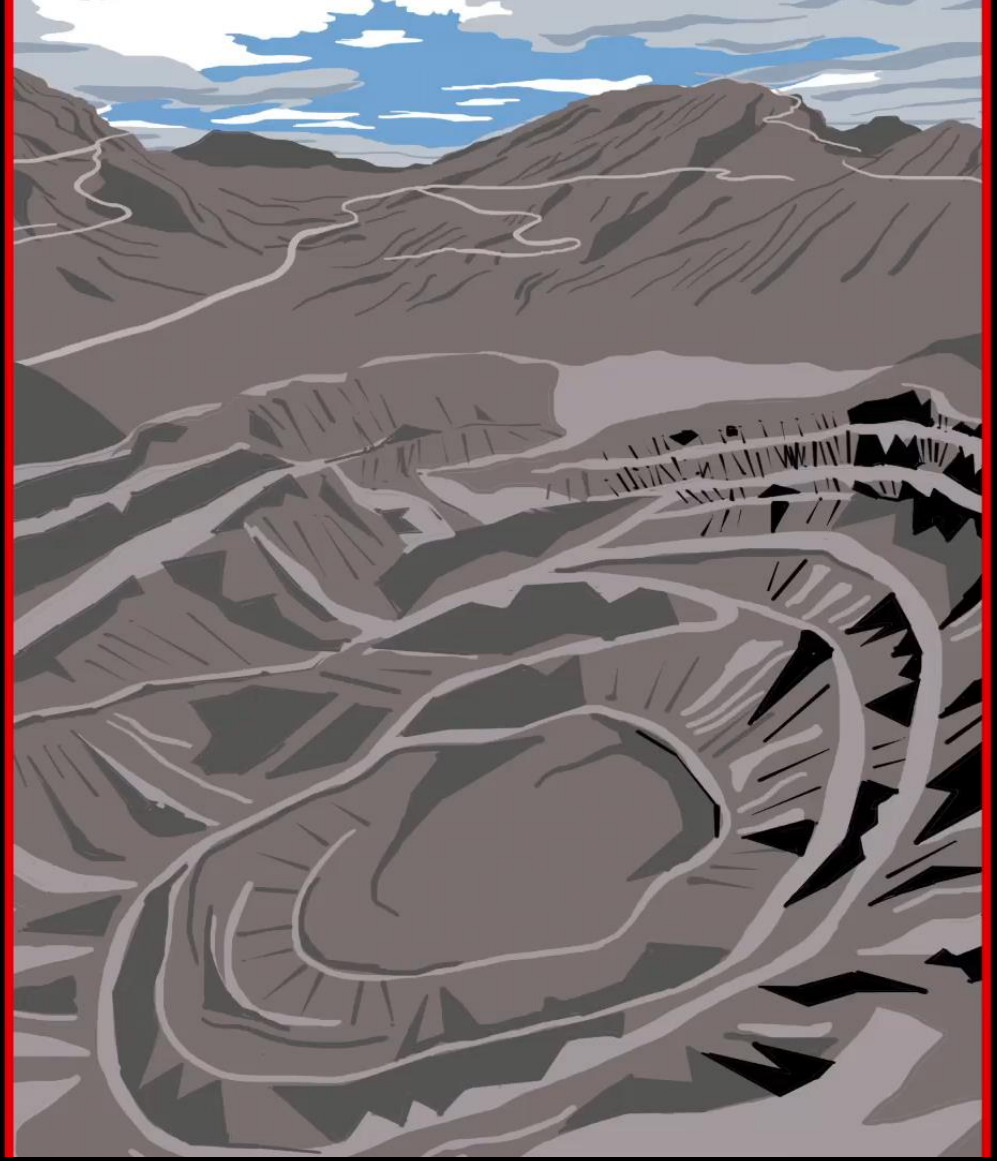
- Possible to practically achieve effectively “zero” oxygen conditions during construction of waste storage facilities

- Possible to practically integrate progressive closure planning into operational mine planning

- Possible to demonstrate “success” using <u>multiple lines of evidence</u>

Main determining factor

- <u>*The PTAR site operations team*</u>. Although this is a technical “problem” to solve “on paper” in reality success relies on the implementation, for which the site operations team is the most important factor.



Thankyou

And remember to think big!

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