PIT LAKES
LIABILITY OR LEGACY?

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PRESENTATION OUTLINE

- Introduction – Examples of Pit Lakes
- Important Questions
- Modelling Tools
- Case Study - Birla Nifty Copper Mine
    - Methodology – GoldSim and PHREEQC
    - Data Inputs
    - Pit lake volumes and recovery times
    - pH and acidity
    - Salinity
    - Metals

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MINE VOID WATER RESOURCE ISSUES IN WESTERN AUSTRALIA

Water and Rivers Commission

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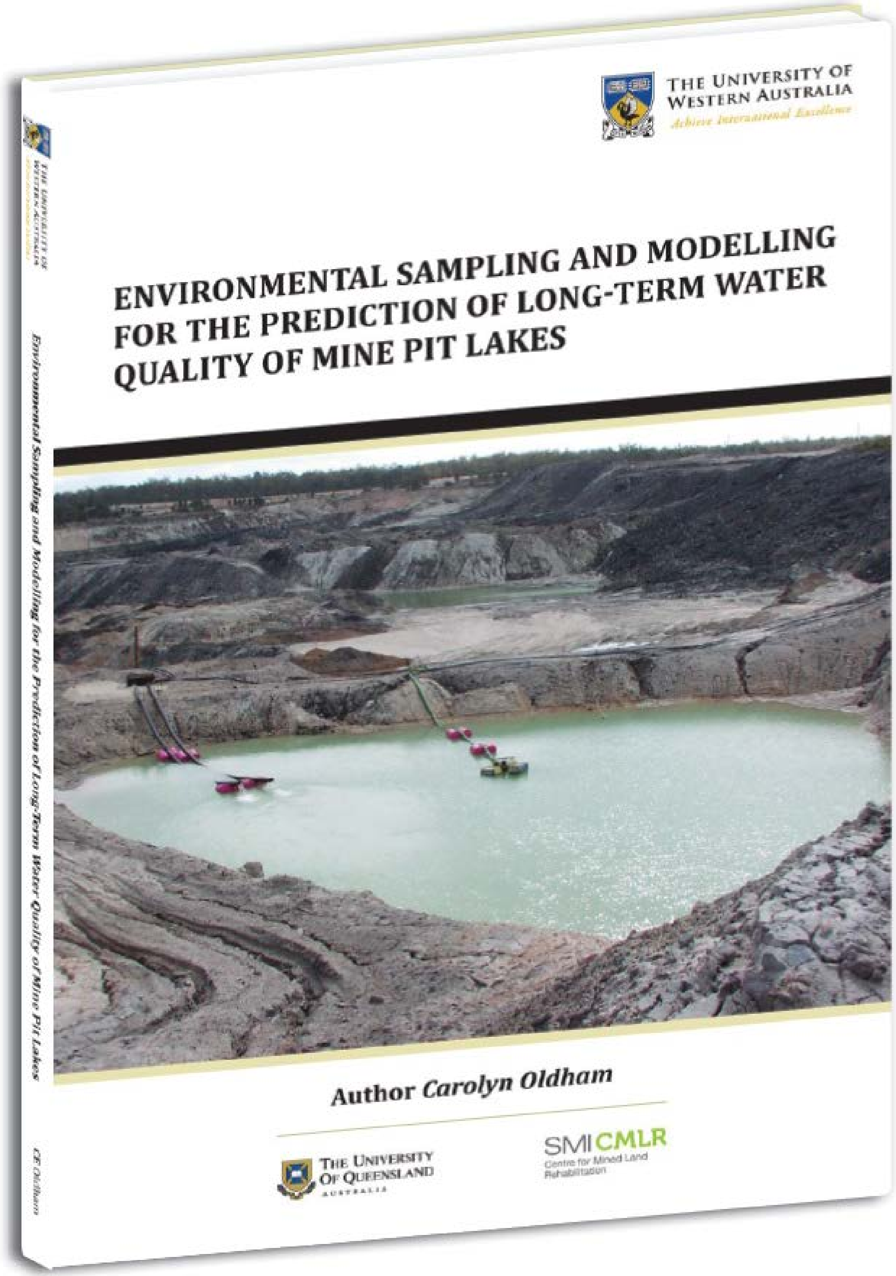

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PIT LAKES - EXAMPLES

- Acidic, saline and metalliferous
- Highly saline, circum-neutral and low metals
- Highly saline, circum-neutral, elevated arsenic
- Acidic, low salinity and slightly metalliferous
- Poorly buffered, low salinity

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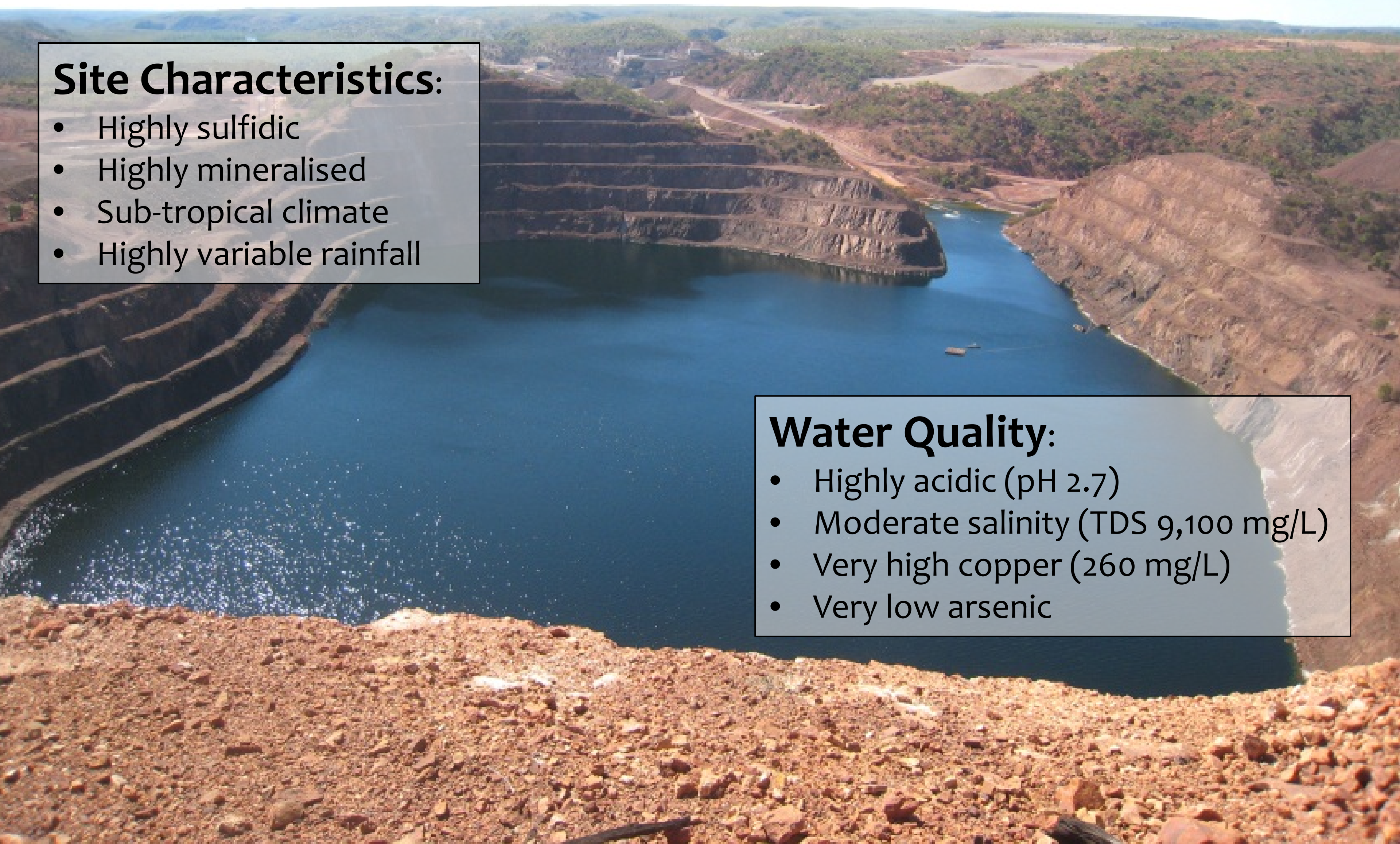
Copper Mine - Northwest Queensland



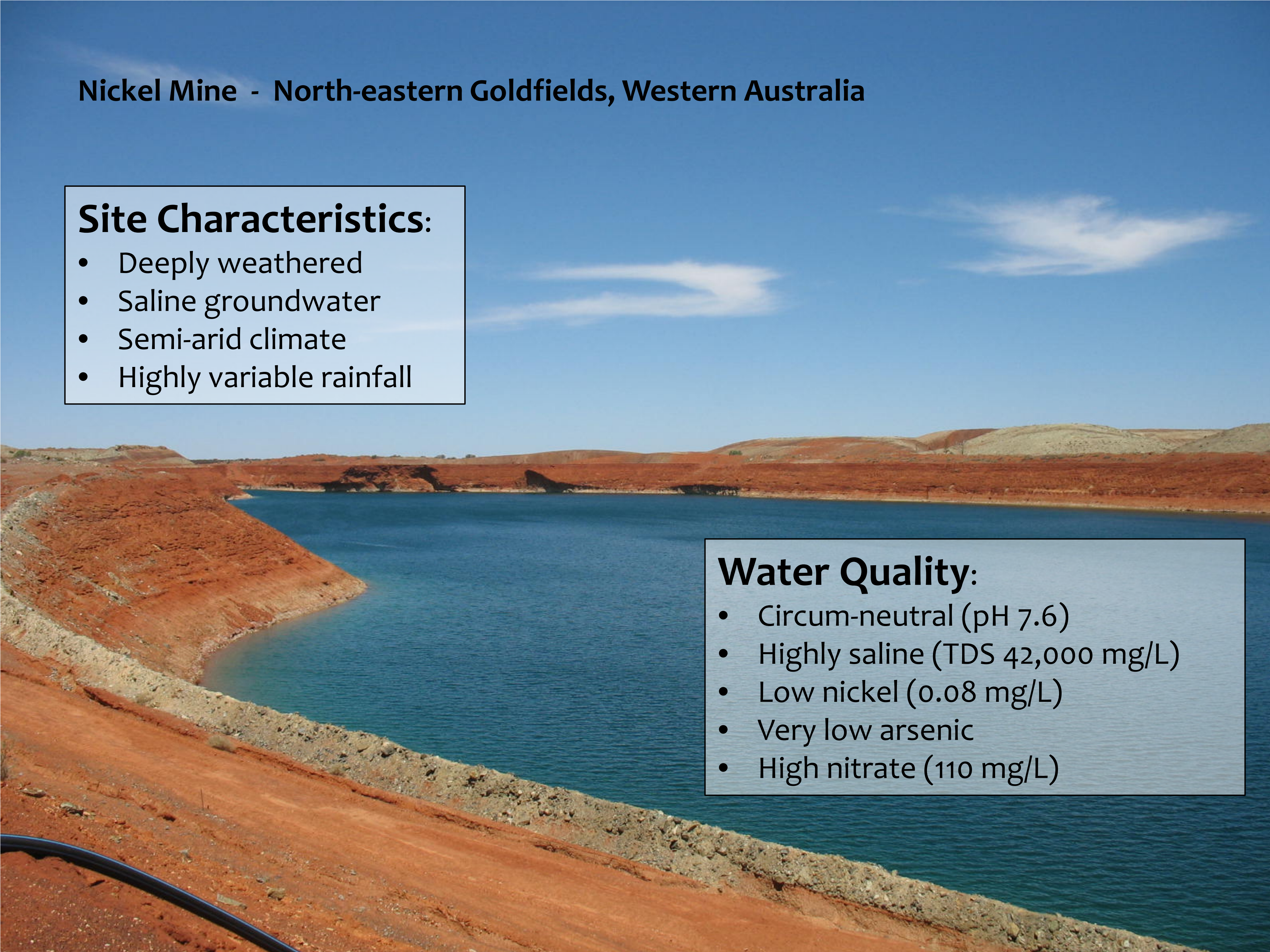
Site Characteristics:

- Highly sulfidic
- Highly mineralised
- Sub-tropical climate
- Highly variable rainfall

Water Quality:

- Highly acidic (pH 2.7)
- Moderate salinity (TDS 9,100 mg/L)
- Very high copper (260 mg/L)
- Very low arsenic

Nickel Mine - North-eastern Goldfields, Western Australia



Site Characteristics:

- Deeply weathered
- Saline groundwater
- Semi-arid climate
- Highly variable rainfall

Water Quality:

- Circum-neutral (pH 7.6)
- Highly saline (TDS 42,000 mg/L)
- Low nickel (0.08 mg/L)
- Very low arsenic
- High nitrate (110 mg/L)

Gold Mine
North-eastern Goldfields, Western Australia

Site Characteristics:

- Deeply weathered
- Saline groundwater
- Semi-arid climate
- Highly variable rainfall

Water Quality:

- Slightly alkaline (pH 8.7)
- Moderate salinity (TDS 12,000 mg/L)
- Low nickel (0.08 mg/L)
- Elevated arsenic (2.16 mg/L)

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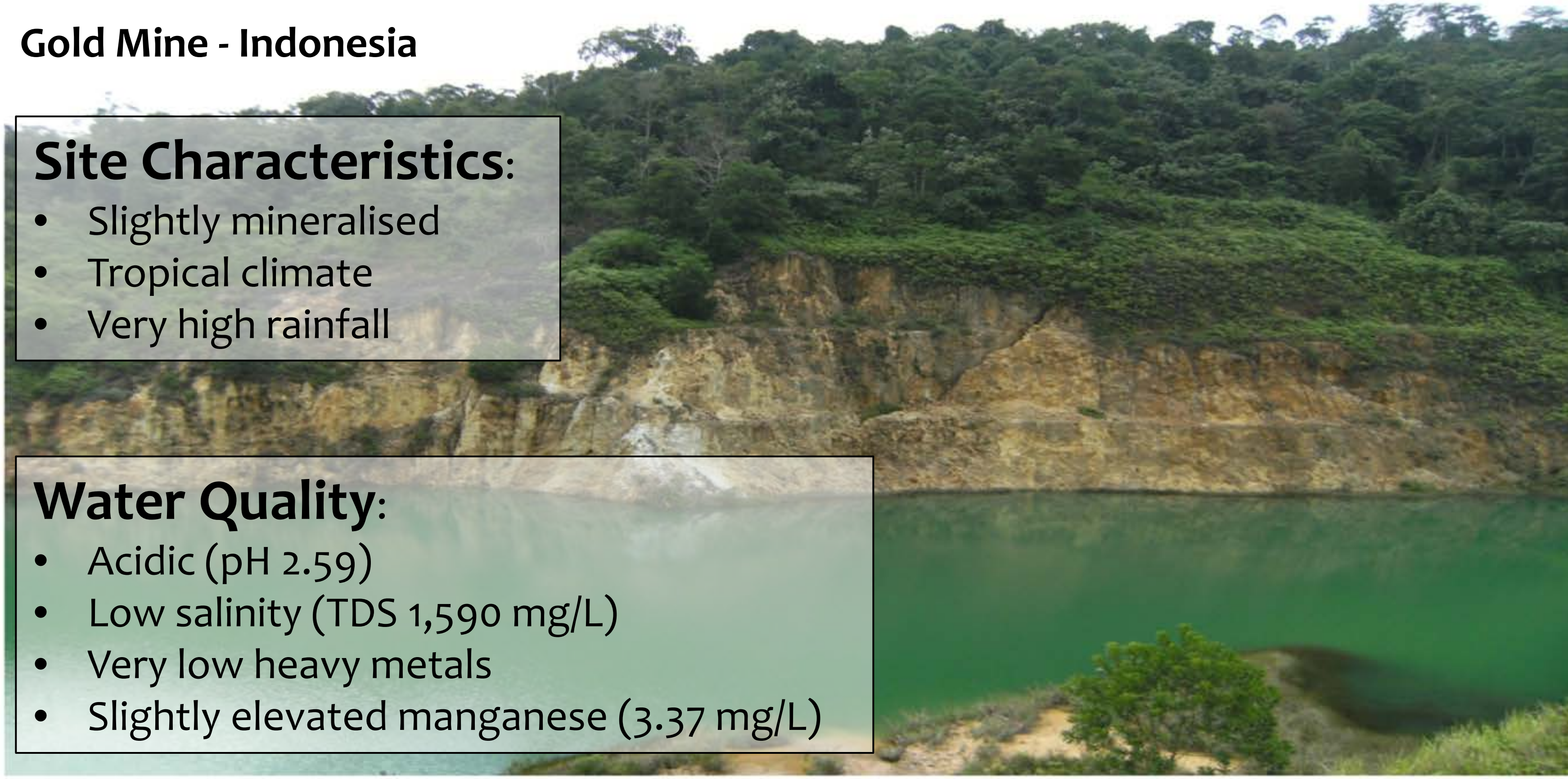
Gold Mine - Indonesia



Site Characteristics:

- Slightly mineralised
- Tropical climate
- Very high rainfall

Water Quality:

- Acidic (pH 2.59)
- Low salinity (TDS 1,590 mg/L)
- Very low heavy metals
- Slightly elevated manganese (3.37 mg/L)

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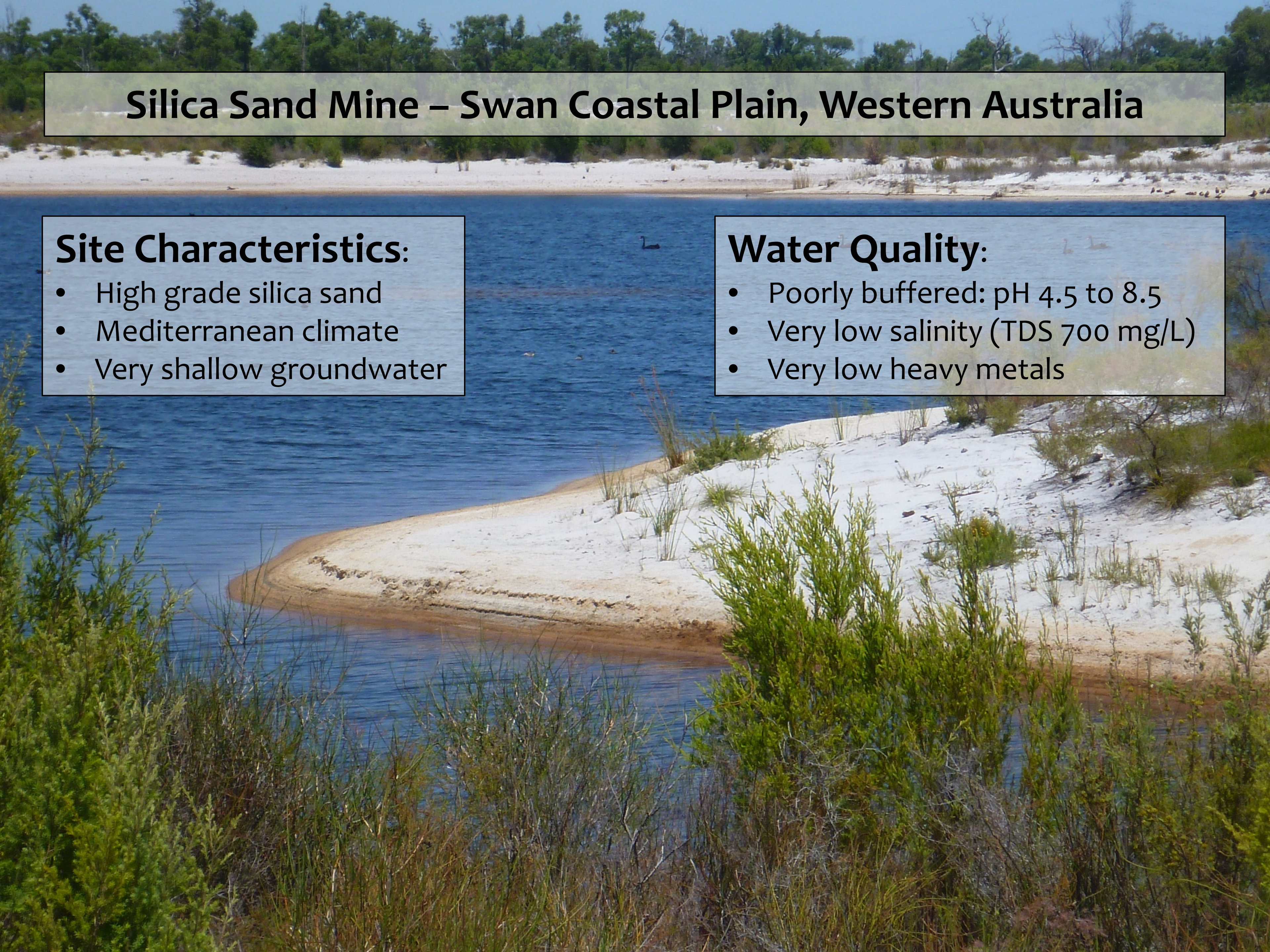
Silica Sand Mine – Swan Coastal Plain, Western Australia
Site Characteristics:
• High grade silica sand
• Mediterranean climate
• Very shallow groundwater
Water Quality:
• Poorly buffered: pH 4.5 to 8.5
• Very low salinity (TDS 700 mg/L)
• Very low heavy metals

Important Questions

- Will a pit lake form?
- What will be the final volume of the pit lake?
- Will there be sufficient freeboard to prevent overtopping or flow into surficial aquifers following extreme rainfall events?
- What will the quality of pit lake water be in terms of salinity, acidity and soluble metals and nutrients?
- If the pit lake water is of good quality, is there potential for beneficial use post closure? **legacy**
- If the pit lake water of of poor quality, what is the risk of it impacting sensitive receptors? **legacy or liability**?

Factors Affecting Pit Lake Recovery Time and Final Volume

- Rainfall
- Evaporation rates
- Pit geometry
- Hydrogeology
  - Number and types of aquifers
  - Hydraulic properties of each aquifer

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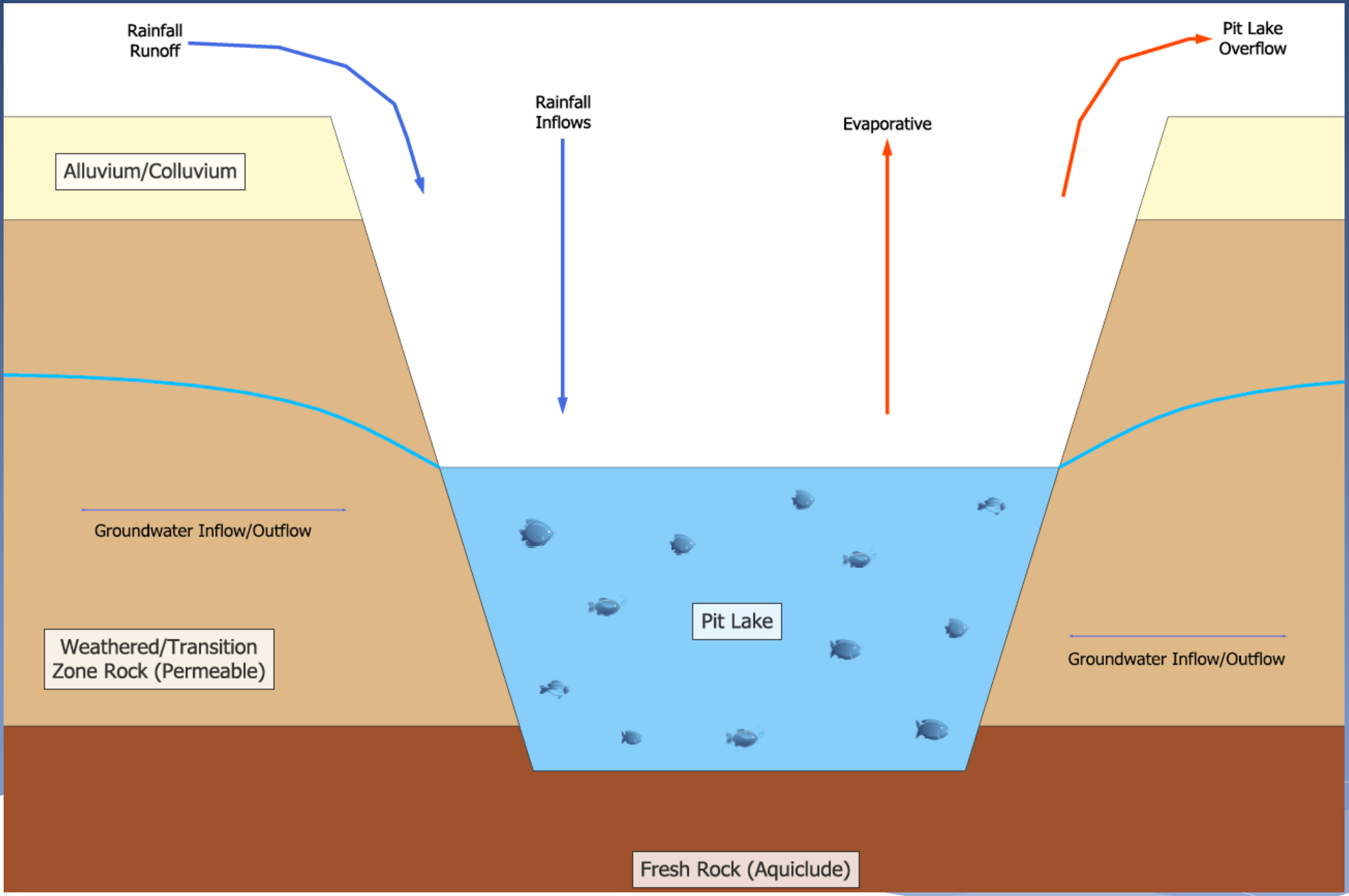
Non-Reactive Pit Walls



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Effects of AMD Inputs

Depending on relative volumes, mixing a relatively small volume of AMD with alkaline groundwater may result in:

- An acidic pit lake with high concentrations of metals
- An alkaline pit lake with very low concentrations of metals
- An alkaline pit lake with elevated concentrations of elements such as arsenic and selenium
- A circum-neutral pit lake with slightly elevated concentrations of some elements

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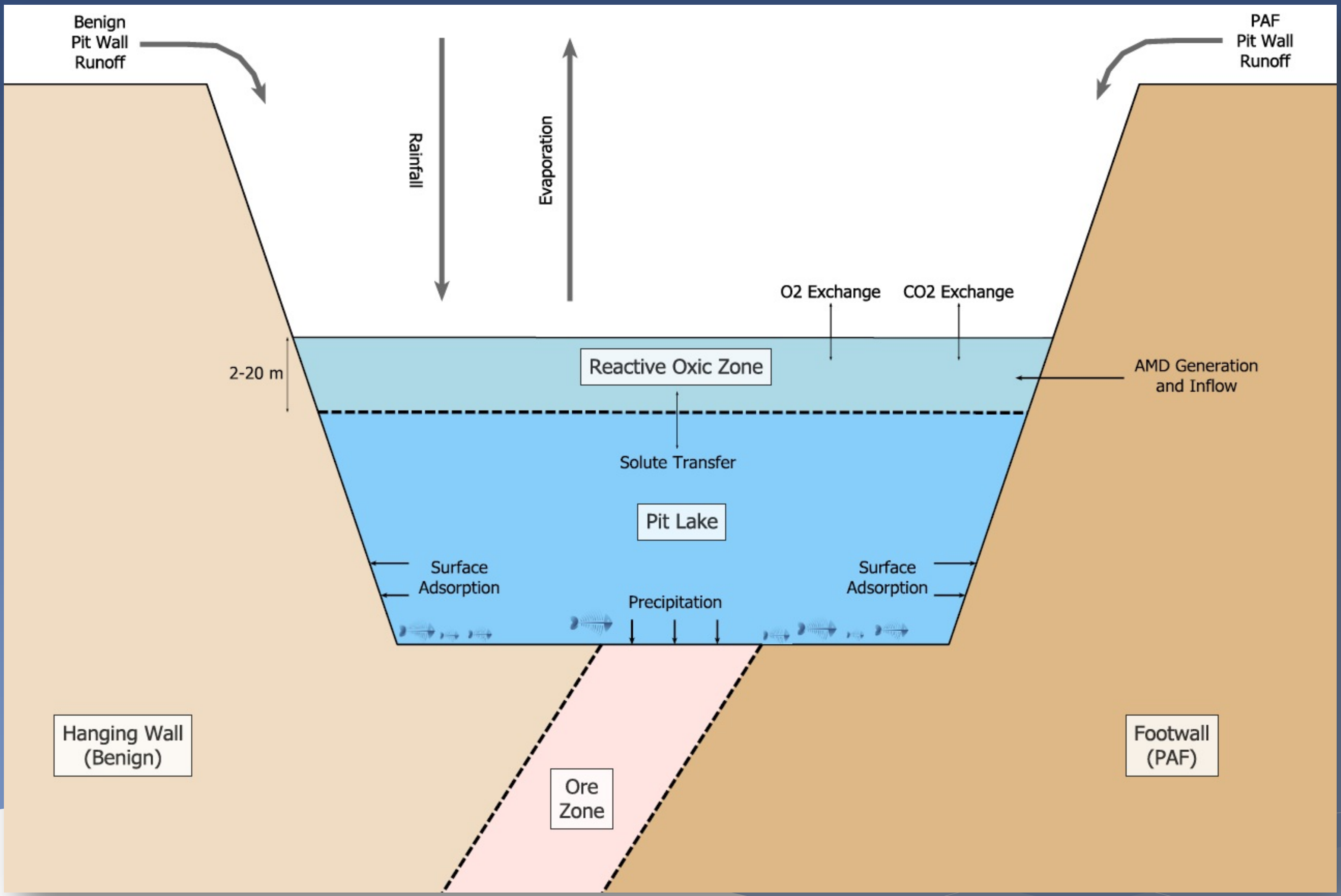
Reactive Pit Walls (AMD Inputs)



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Geochemical Modelling - PHREEQC

$$df_1 = \sum_{m}^{M_{aq}} c_{m,1} d\ln a_m + \left(-\frac{x_2}{n_1} + \frac{2a_0x_2^2 - 6a_1x_2^2 + 12a_1x_2^3}{n_1+n_2}\right)dn_1 +$$

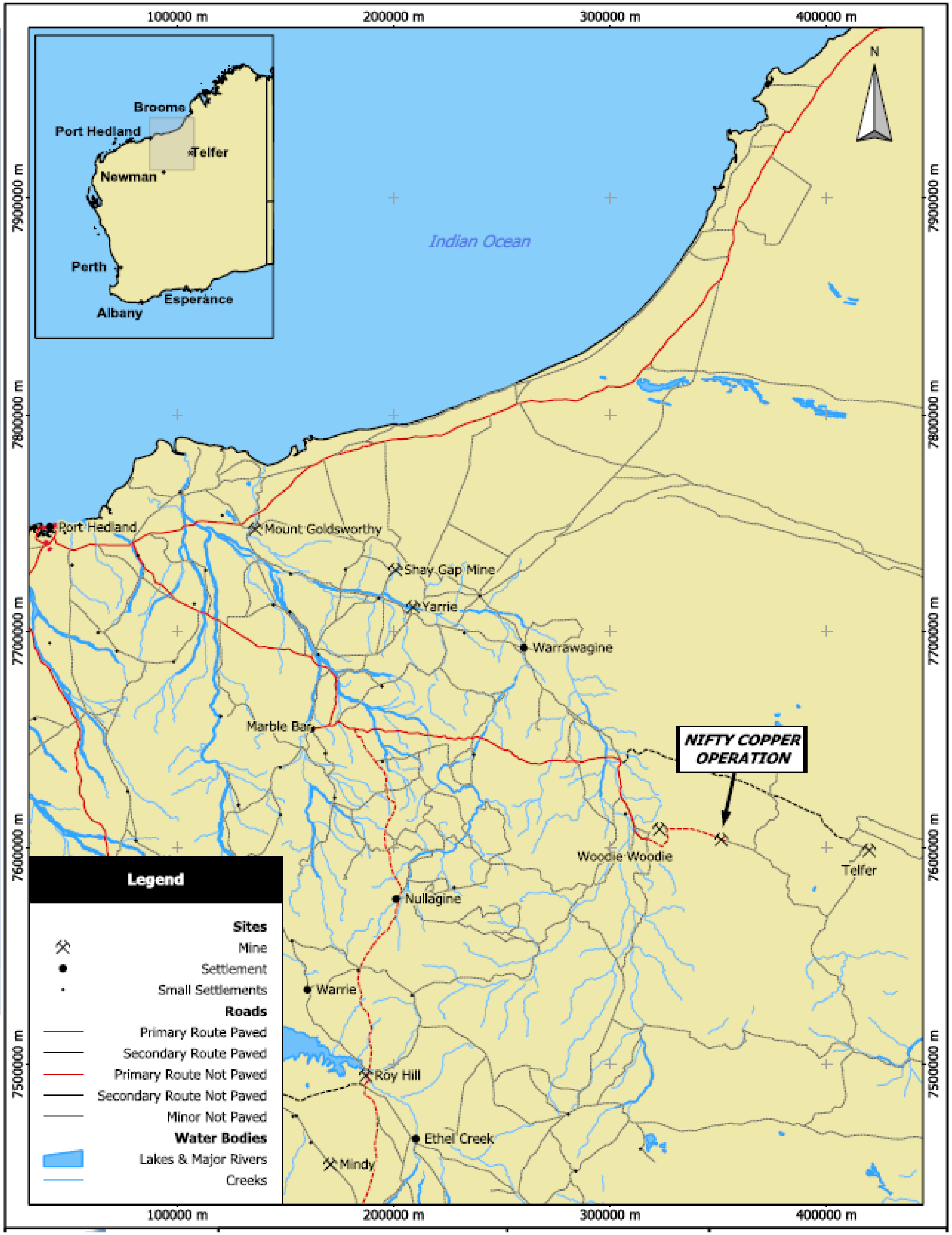
$$\frac{-2a_0x_2 + 2a_0x_2^2 + 6a_1x_2 - 18a_1x_2^2 + 12a_1x_2^3 + 1}{n_1+n_2}dn_2$$

and

$$df_2 = \sum_{m}^{M_{aq}} c_{m,2} d\ln a_m + \frac{-2a_0x_1 + 2a_0x_1^2 - 6a_1x_1 + 18a_1x_1^2 - 12a_1x_1^3 + 1}{n_1+n_2}dn_1 +$$

$$\left(-\frac{x_1}{n_2} + \frac{2a_0x_1^2 + 6a_1x_1^2 - 12a_1x_1^3}{n_1+n_2}\right)dn_2 \quad .$$

Case Study
Nifty Copper Mine



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Nifty Copper Mine – Site History

- Mining commenced in March 1993
- Construction of Heap Leach Pad 1 in August 1993
- Construction of Heap Leach Pads 2 & 3 in April 1996
- Purchased by Aditya Birla Minerals in 2003
- Commenced development for Nifty underground mine in 2004
- Completion of open pit mining in 2006
- SX-EW Plant placed on care and maintenance in February 2009

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Nifty Copper Mine – Pit Characteristics

- Average dewatering rate 5,500 m^3/day
- Maximum storage capacity 44.3 GL
- Surface level 298 m AHD
- Hydrogeological units:
  - Footwall siltstone, weathered (aquitard)
  - Nifty Carbonate Member, weathered (aquifer)
  - Hanging Wall Shale, weathered (aquitard)
  - Fresh rock (aquiclude)
- Waste rock geochemistry:
  - Highly weathered waste "oxide", highly dispersive and non acid forming (NAF)
  - Pyritic black shale, potentially acid forming (PAF)

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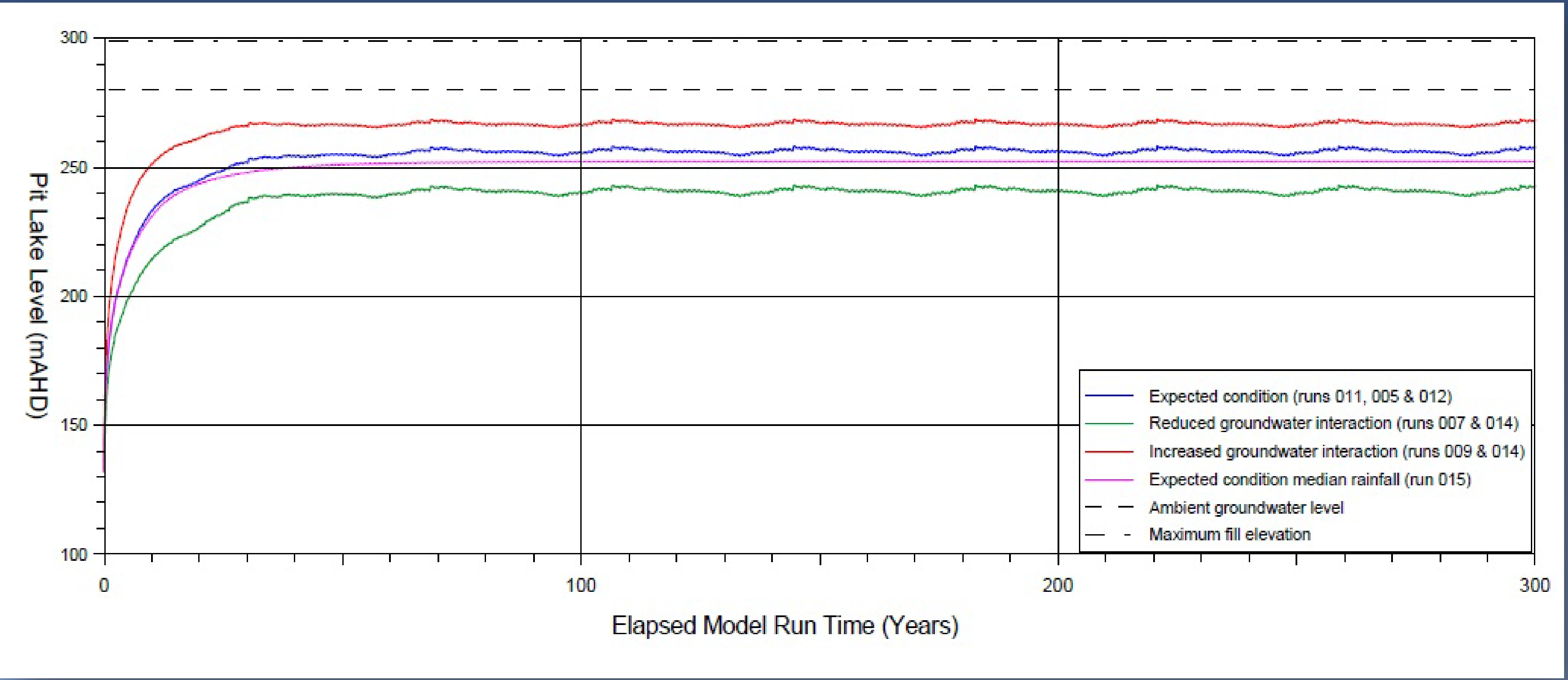
Solute and Water Balance GoldSim Runs

Run No.	Geochemistry	Groundwater Flow	Rainfall Input	Reactive Depth
1	Worst case	Expected inflow	Synthetic daily	0 metres
2	Expected	Expected inflow	Synthetic daily	0 metres
3	Expected	Expected inflow	Nil	0 metres
4	Worst case	Expected inflow	Synthetic daily	10 metres
5	Expected	Expected inflow	Synthetic daily	2 metres
6	Worst case	Low inflow	Synthetic daily	10 metres
7	Expected	Low inflow	Synthetic daily	2 metres
8	Worst case	High inflow	Synthetic daily	10 metres
9	Expected	High inflow	Synthetic daily	2 metres
10	Worst case	Expected inflow	Monthly median	10 metres
11	Expected	Expected inflow	Synthetic daily	10 metres
12	Worst case	Expected inflow	Synthetic daily	20 metres
13	Worst case	Low inflow	Synthetic daily	20 metres
14	Worst case	High inflow	Synthetic daily	20 metres
15	Worst case	Expected inflow	Monthly median	20 metres

Predicted Pit Lakes Levels and Groundwater Inflows



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Geochemical Modelling Inputs

- Rainwater composition – extremely low salinity
- Groundwater composition for three aquifers:
  - Alkaline
  - Brackish salinity
  - Very low dissolved metals
- Reactive pit wall
  - Acidic
  - Elevated sulfate
  - Elevated aluminium, copper, manganese and iron
  - Slightly elevated nickel and zinc

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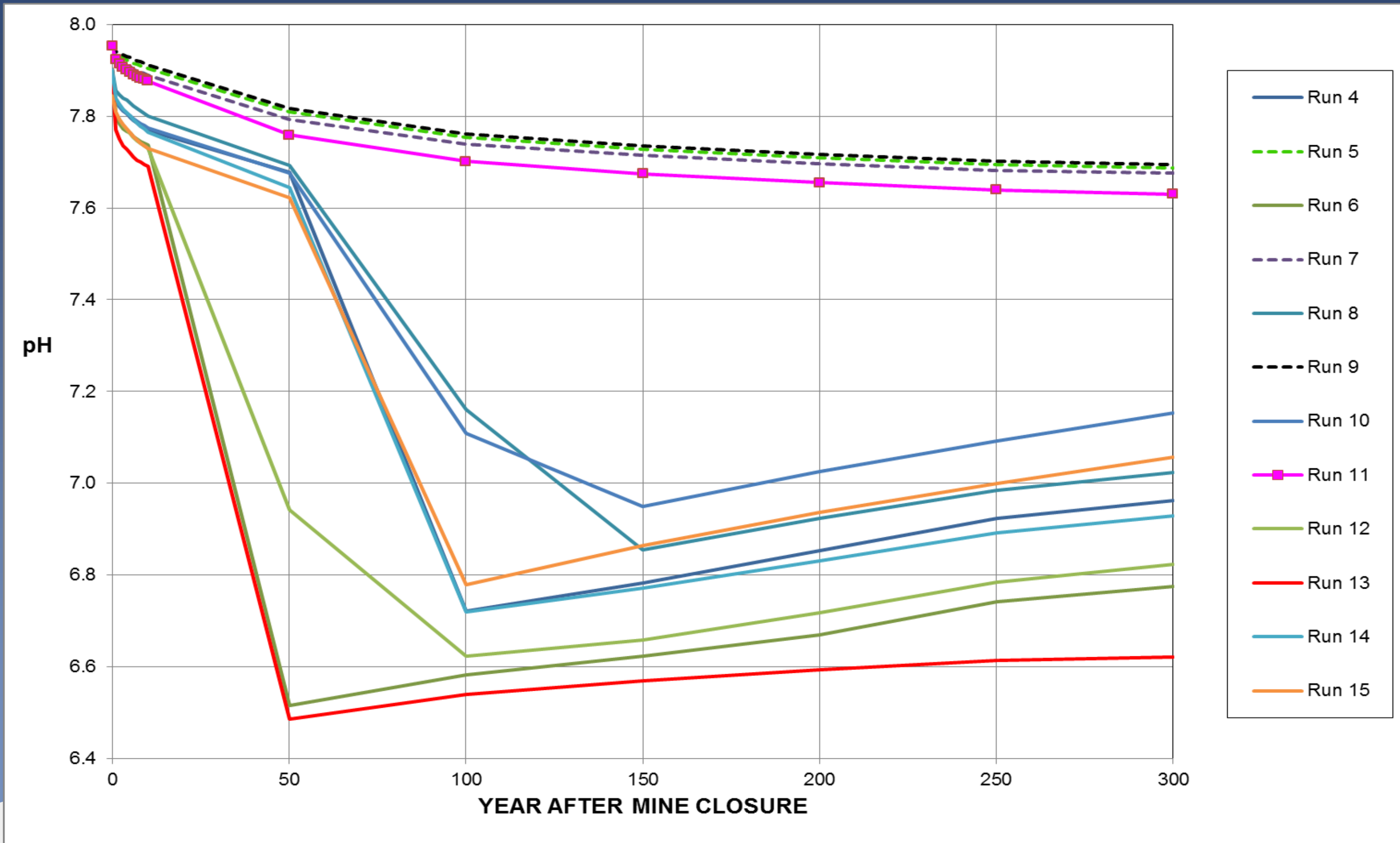
Predicted pH Values



Predicted Salinity and Metal Concentrations

Salinity	30,500 to 42,000 mg/L
Anions	Dominated by chloride and sulfate
Cations	Dominated by sodium and magnesium
Copper	0.06 to 0.91 mg/L
Manganese	87 to 178 mg/L without oxygen exchange Much lower with oxygen exchange

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Risk Assessment

Mammals	Pit water not suitable for drinking (too saline)
Birds	Pit water not suitable for drinking (too saline) Very low risk for absorption of metals through skin
Invertebrates	Unlikely to provide suitable habitat (too saline)
Aquifer contamination	Unlikely (not a flow-through system)

Significant capacity for neutralisation of AMD from waste dumps and heap leach pads

Legacy or Liability??

Legacy

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CONCLUSIONS

- Knowledge of potential pit lake volumes, recovery times and water quality is essential for effective mine closure.
- Final pit lake volumes and recovery times can be predicted accurately from good quality hydrogeological and climate data.
- Hydrogeological and climatic conditions in the arid regions of WA favour formation of highly saline pit lakes with low risk of contaminating groundwater resources and surface water ecosystems.
- Geochemical modelling tools such as PHREEQC are useful for long term predictions of pit lake water quality.
- Predicted water quality in the pit lake at the Nifty mine site suggest it will provide a post-closure legacy by its ability to provide an alkaline receptor for AMD.

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THANK YOU

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QUESTIONS?

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