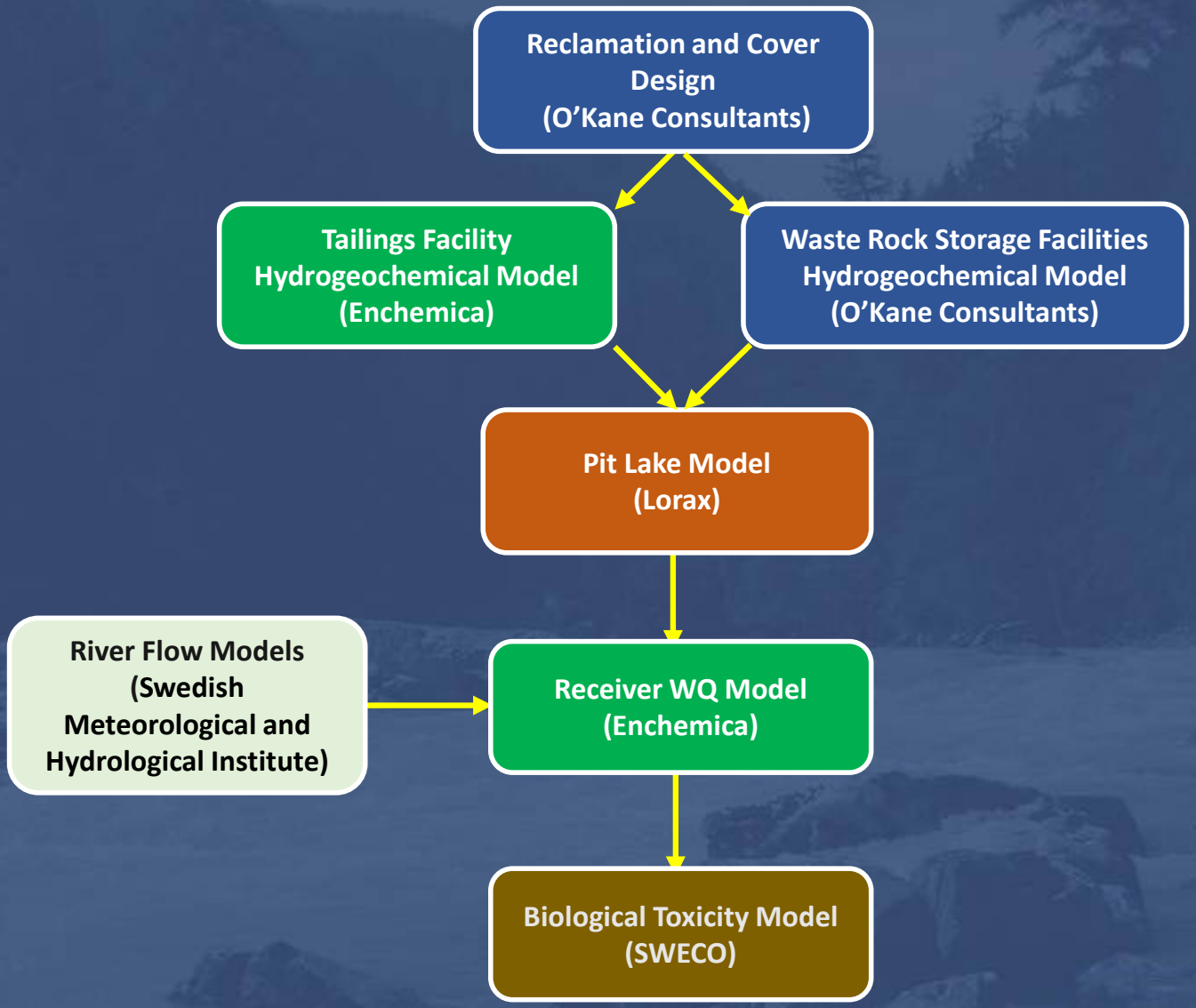
Pit Lake Modelling and Management at the Aitik Mine, Sweden

[1]Alan J. Martin, [1]Silvano Salvador, [1]Don Dunbar
[1]Colin Fraser, [2]Seth Mueller, [2]Nils Eriksson

[1]Lorax Environmental Services Ltd. (Vancouver, Canada)
[2]Boliden

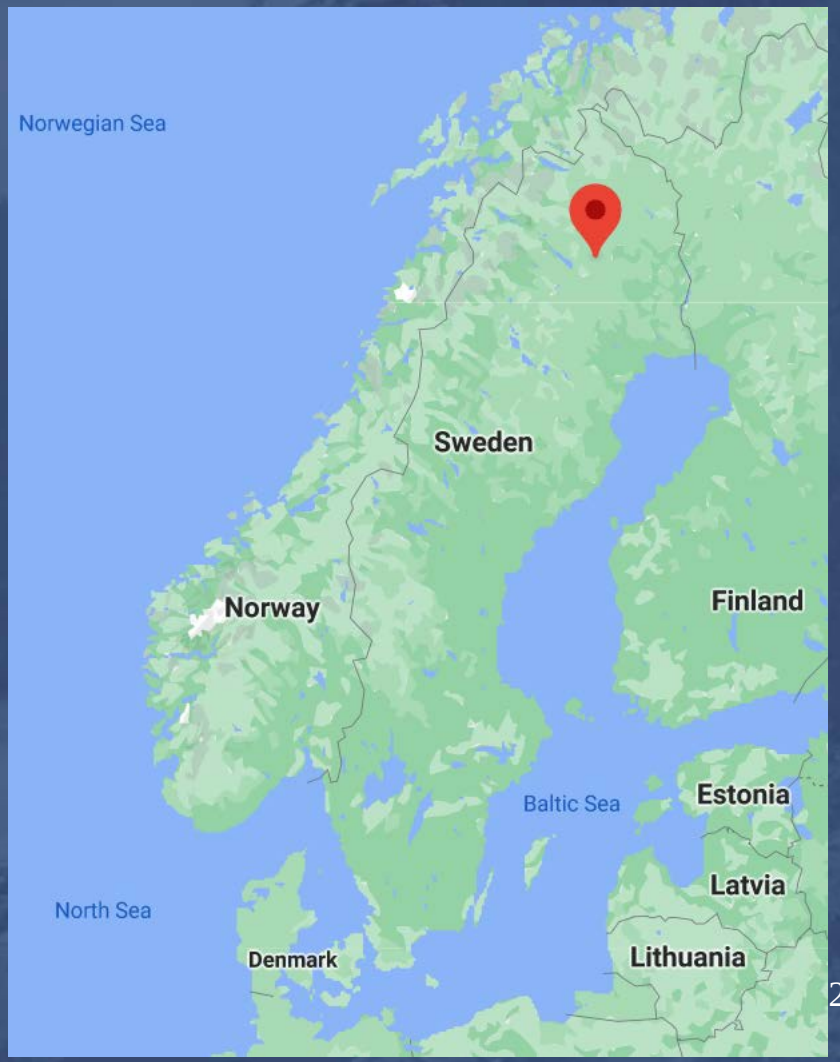
Closure Plan Linkages



O’Kane Team

Background and Site Description

- Location: 17 km southeast of Gällivare in northern Sweden.
- Largest open pit operation in Europe. Mining since 1968.
- Deposit type: metamorphosed and hydrothermally altered Cu-Au-Ag porphyry.
- Pyrite and chalcopyrite are the dominate sulphide minerals.



Site Layout

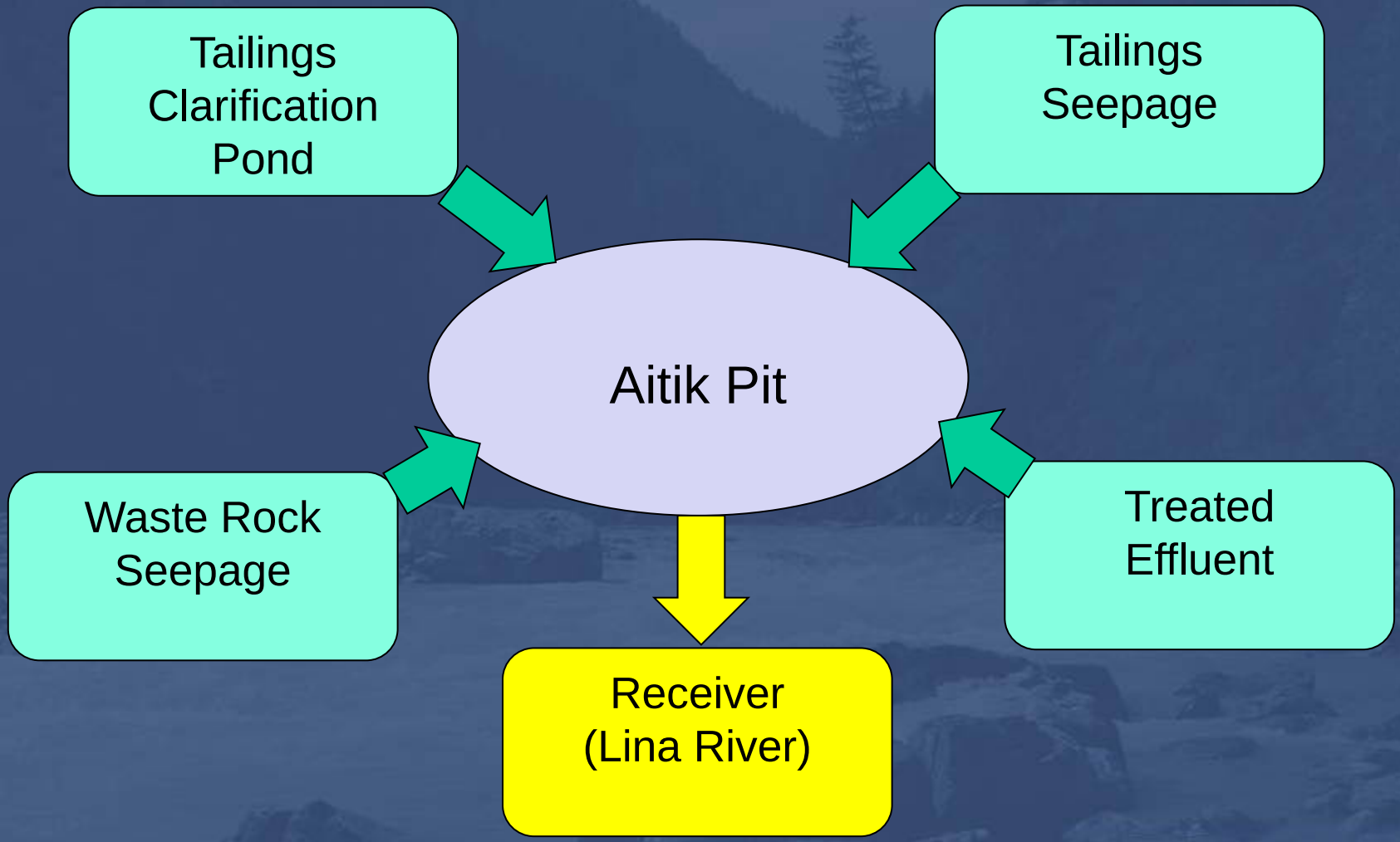

Environmental
Waste Rock
Clarification
Pond
Aitik
Pit
PAG
Waste
Rock
Tailings
Management
Facility
Salmijärvi
Pit
10 km

Aitik Mine Closure Plan

- Boliden had adopted a holistic approach to closure planning that integrates water management, waste management, reclamation design and pit lake management.

- At closure, the Aitik Pit will play a key role in water management, serving as a receptacle for mine contact flows and representing the final point of discharge to the receiving environment.

Central Role of Aitik Pit at Mine Closure



Aitik Mine Closure – Main Challenges

- Unrecoverable seepage from potentially acid generating waste rock
  - pH = 3.5, [SO_4] = >3,000 mg/L, [Cu] = 60 mg/L, [Zn] = 10 mg/L
- Unrecoverable seepage from potentially acid generating tailings
  - pH = 4.5, [SO_4] = 800 mg/L, [Cu] = 3 mg/L, [Zn] = 0.5 mg/L
- Active water treatment – goal to minimize duration
- Stringent environmental standards:
  - Receiver (Lina River) falls within the EU's Natura 2000 "network of valuable nature areas". Goal is "to protect the types of nature and species that EU member states agree are of common interest".

Pit Lake Inputs: Importance of Salinity and Water Density

- Pit lake mixing can be strongly influenced by salinity (density) gradients in the water column.
- As part of model input development, important to understand time-dependent and spatially-dependent variables that result in changes in the salinity of pit lake inputs over time.
  - Waste rock seepage
  - Tailings seepage
  - Pit wall runoff

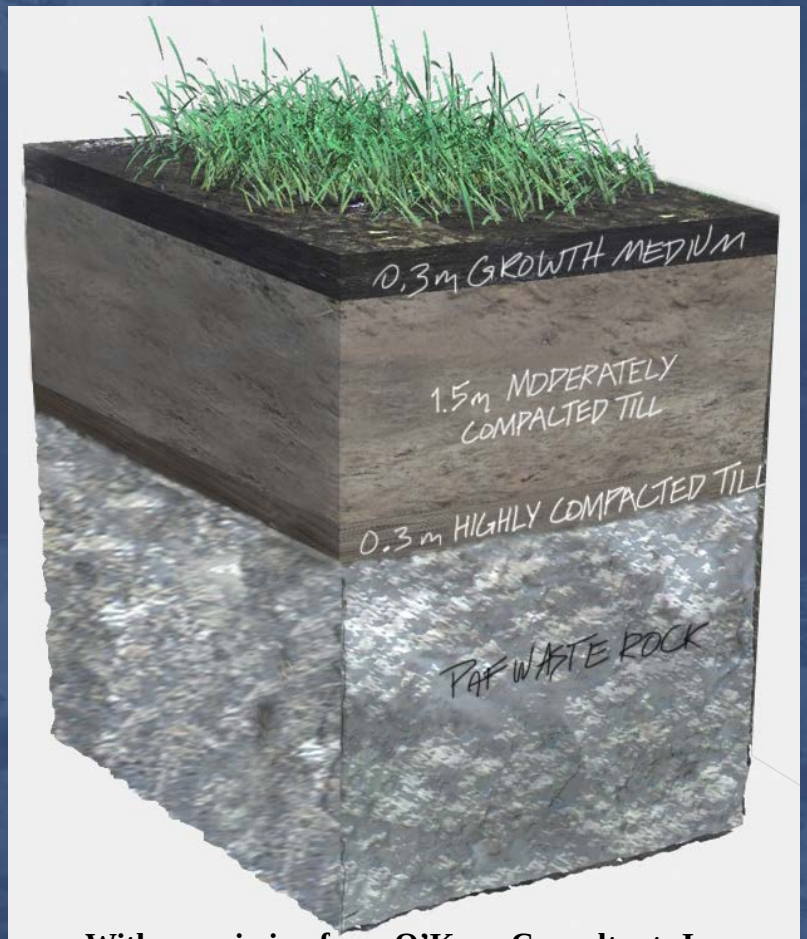
} Time Dependent Chemistries

PAG Waste Rock – Cover Design

Two closure scenarios were evaluated based on two engineered cover system options for the PAG Waste Rock Facilities, with the goal to minimize oxygen ingress and net percolation.

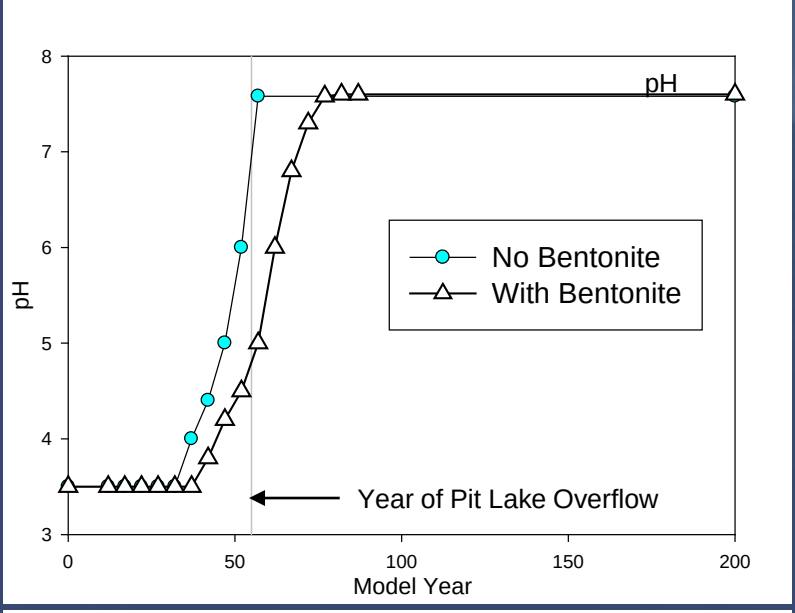
- Base Case Scenario: Engineered cover system consisting of:
  - 0.3 m vegetation growth medium
  - 1.5 m moderately compacted till
  - 0.3 m highly compacted till

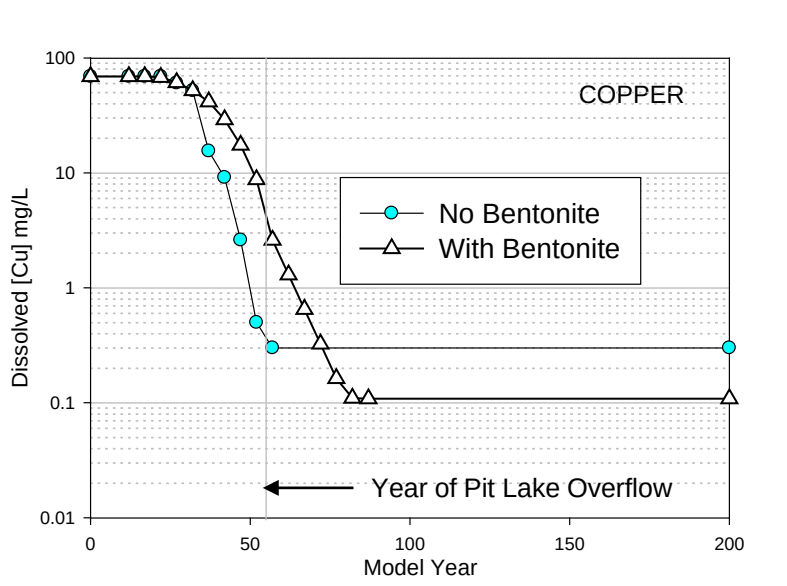
- Bentonite Scenario: Same as above, with the addition of 2-5 wt.% bentonite to the highly compacted till layer.



With permission from O'Kane Consultants Inc.

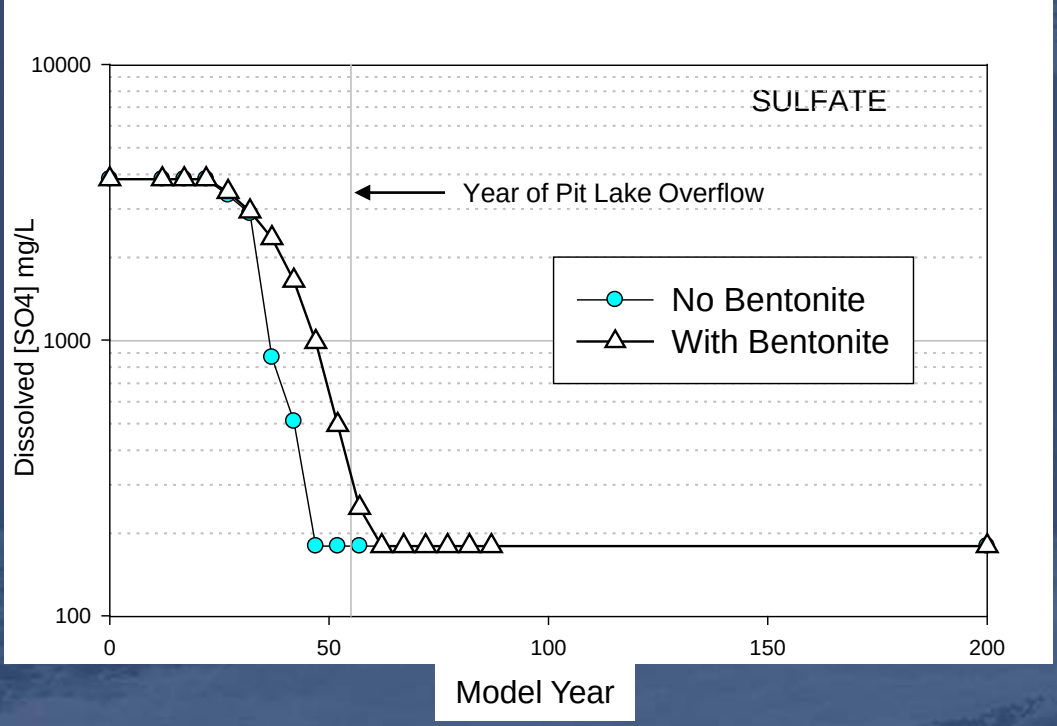
PAG Waste Rock – Drainage WQ Predictions





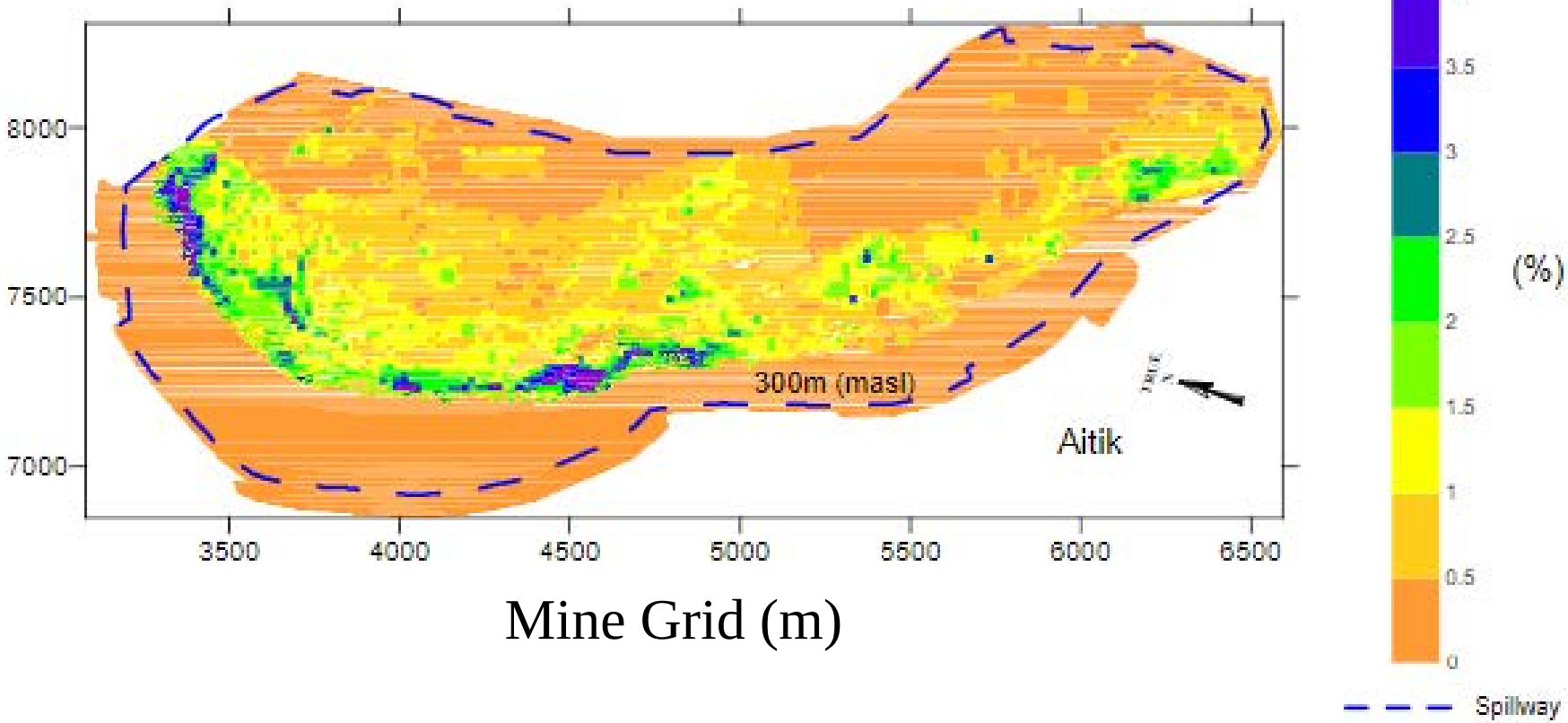
- Marked improvements in seepage quality are predicted in response to cover system placement.
- The addition of bentonite to the compacted till layer delays water quality improvements (in response to decrease in net percolation).
- However, the addition of bentonite also results in significant water quality improvements over the long term (associated with decreased oxygen ingress).

PAG Waste Rock – Drainage WQ Predictions

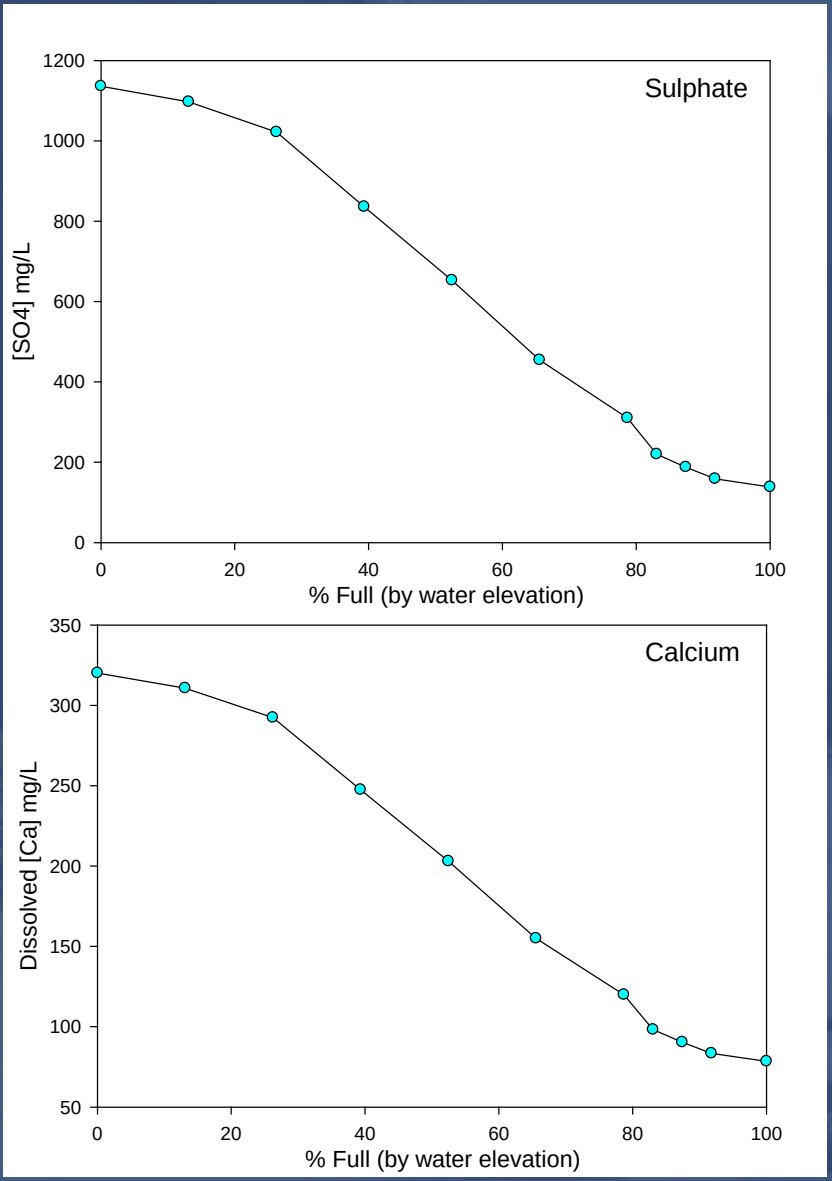


- Marked improvements in seepage quality are accompanied by pronounced decrease in salinity.
- Implications for density of pit lake inputs and mixing behaviour of pit lake water column.

Pit Wall Sulphur Content



Predicted Pit Wall Runoff Predictions



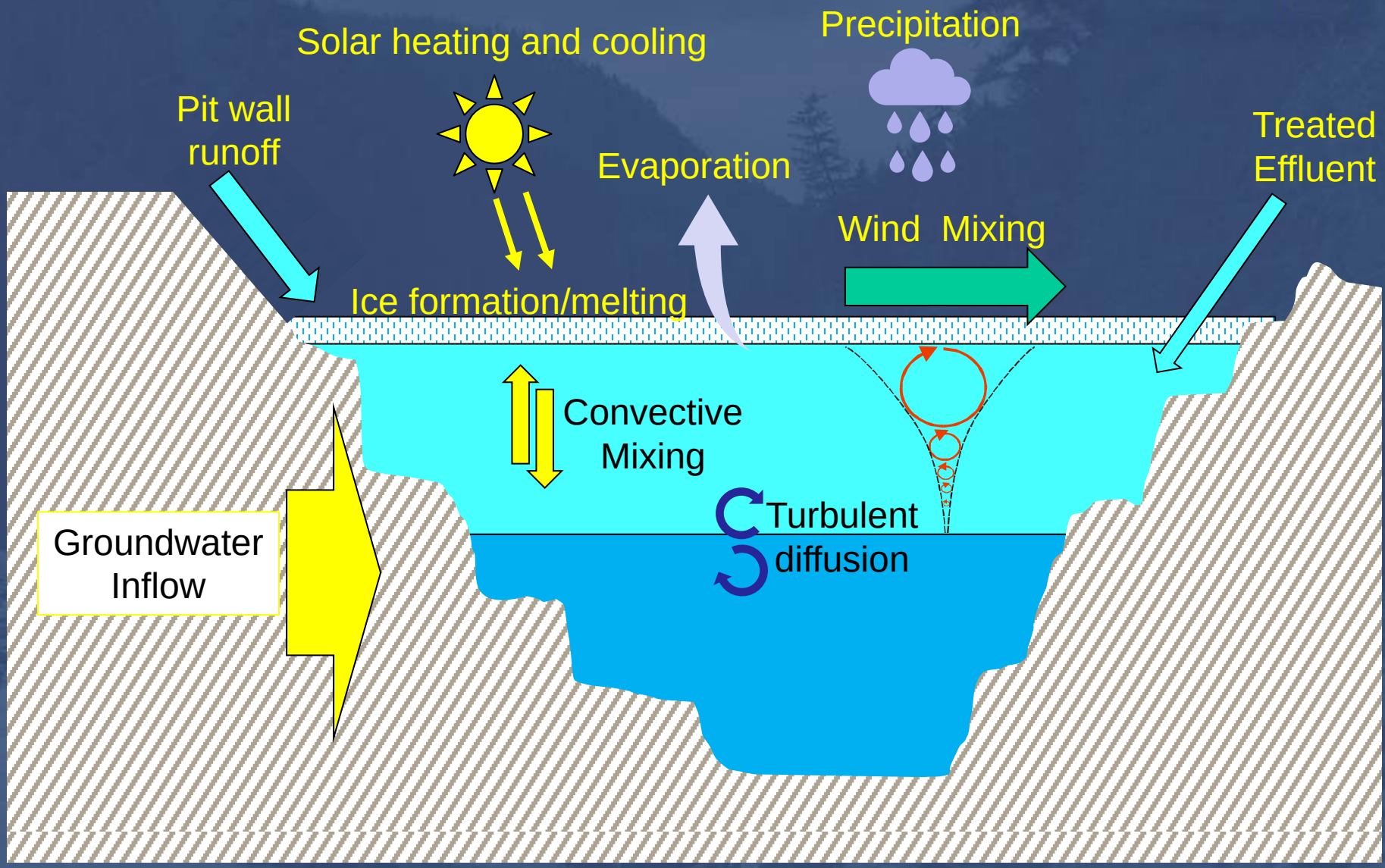
- Sulphur and metals content on pit walls increases with depth.
- Pit wall drainage chemistry improves as pit lake fills.
- Improvements in seepage quality are accompanied by pronounced decrease in salinity (and density).

Aitik Pit Lake Modelling

Model Description

- Model simulations were conducted using PitMod, a 1-dimensional numerical hydrodynamic model.
- Model assumes uniform mixing in the horizontal (no significant lateral variability in water properties).
- One-dimensional approximation is applicable to pit lakes due to their high depth to surface area ratios, and the limited barriers to horizontal mixing.
- Model has undergone rigorous validation.
- Model combines physical mixing processes in combination with biogeochemical processes (e.g., oxygen consumption).

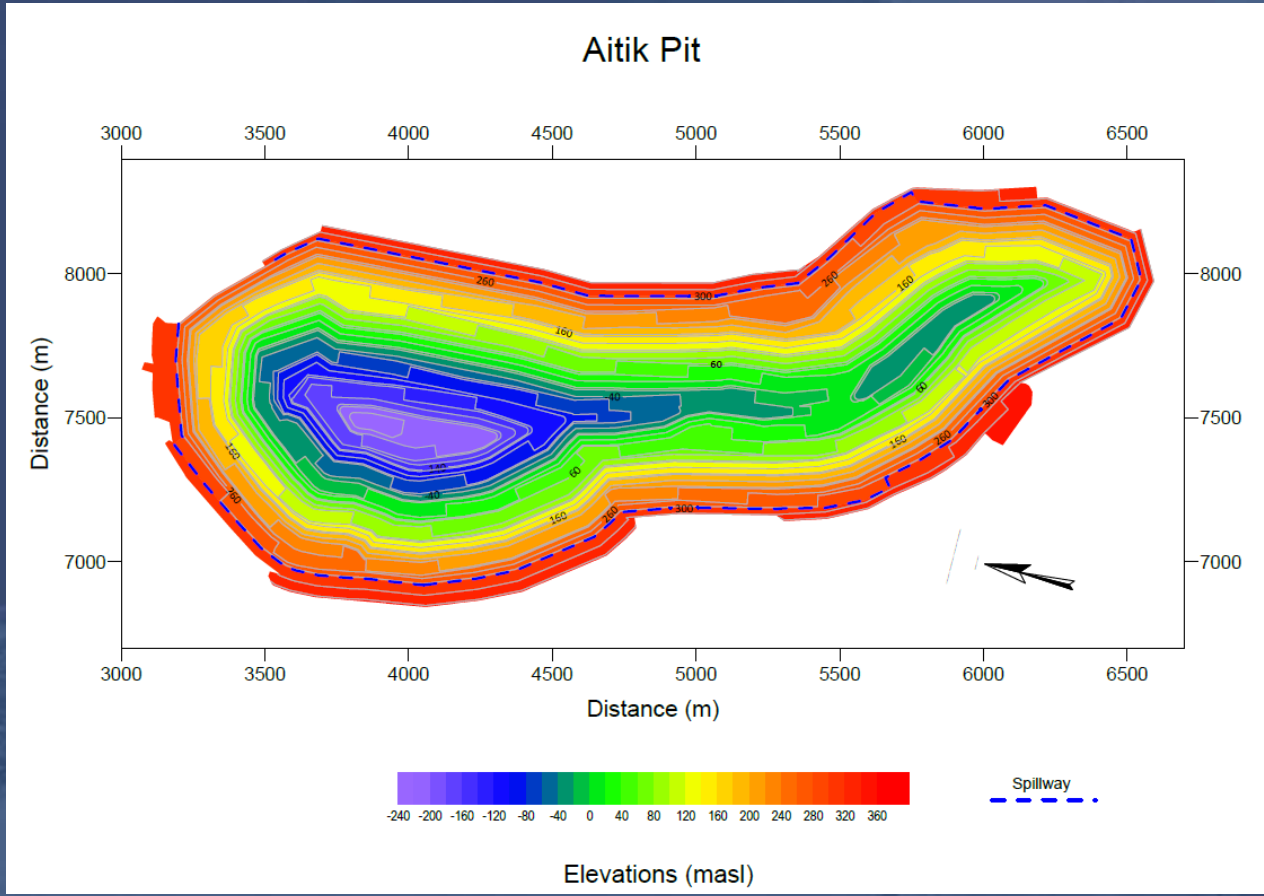
Physical Processes Simulated by PitMod



Aitik Pit Lake
Model Scenarios

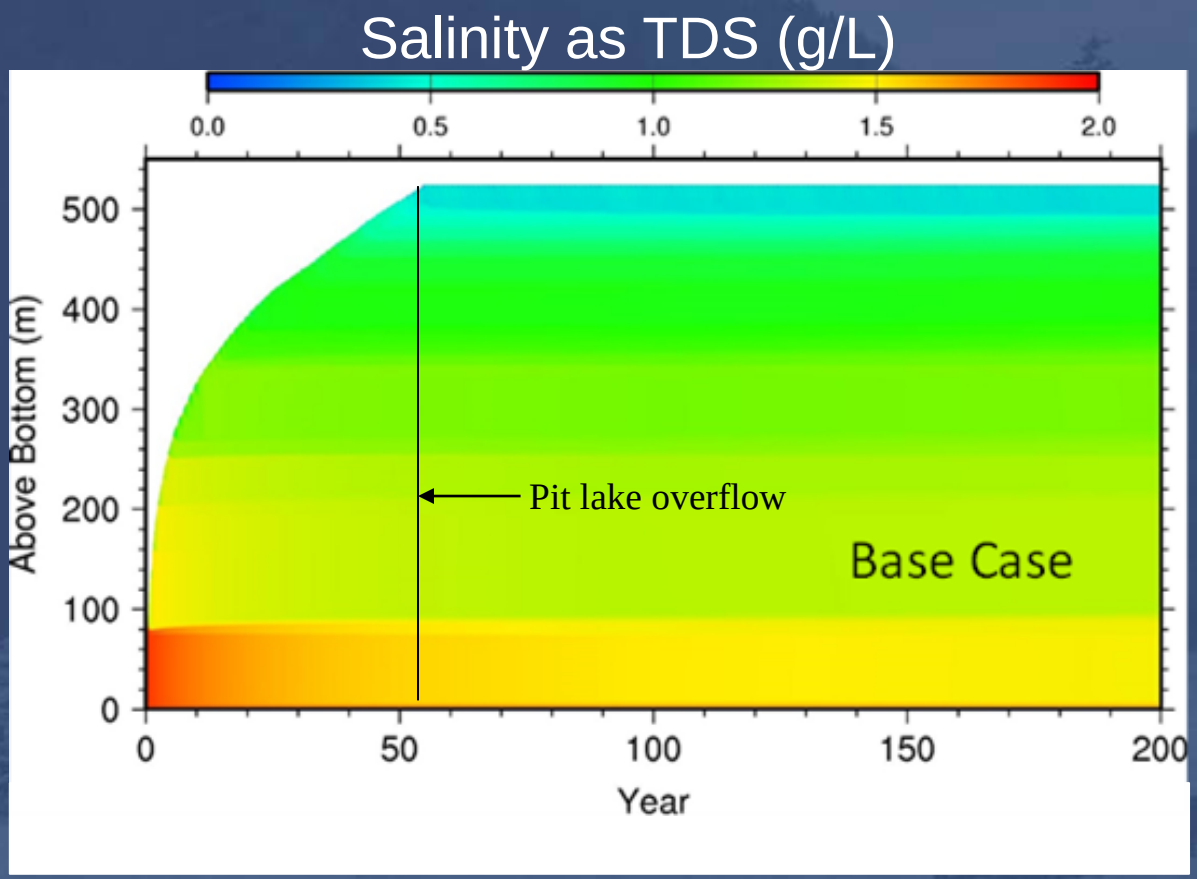
- Water quality predictions for the Aitik Pit Lake were generated for two scenarios:
  - Base Case Scenario: Treatment for a period of 55 years (filling period of pit). Lime treatment of recoverable seepages and discharge of treated effluent to pit.
  - Bentonite Scenario: Base Case scenario with inclusion of bentonite cover system.
- Model duration: 200 years

Aitik Pit Lake
Results: General Features



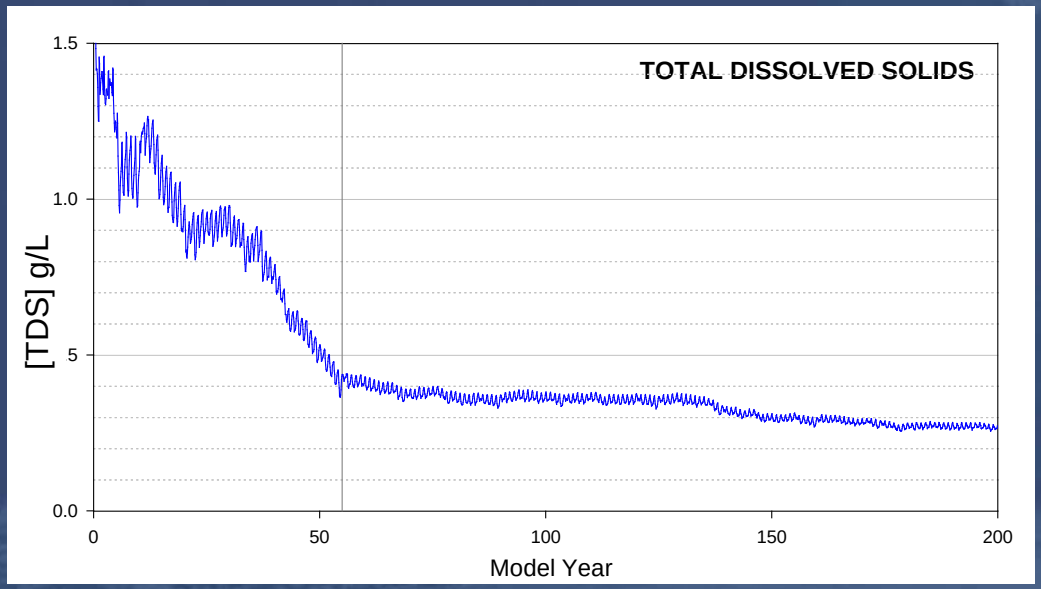
- Length = 3.4 km
- Maximum width = 1.2 km
- Maximum depth = 525 m
- Volume = 579 x 10^6 m^3
- Surface area = 279 ha
- Fill time = 55 years

Aitik Pit Base Case Predictions: Total Dissolved Solids (TDS)



- Salinity has greatest effect on water density.
- Salinity in surface layer shows gradual freshening over time.
- Salinity reduction in surface layer illustrates the development of permanent stratification in the water column (meromixis).
- Development of stratification serves to isolate concentrated water in bottom of pit.

Aitik Pit Base Case Predictions: Total Dissolved Solids in Surface Waters

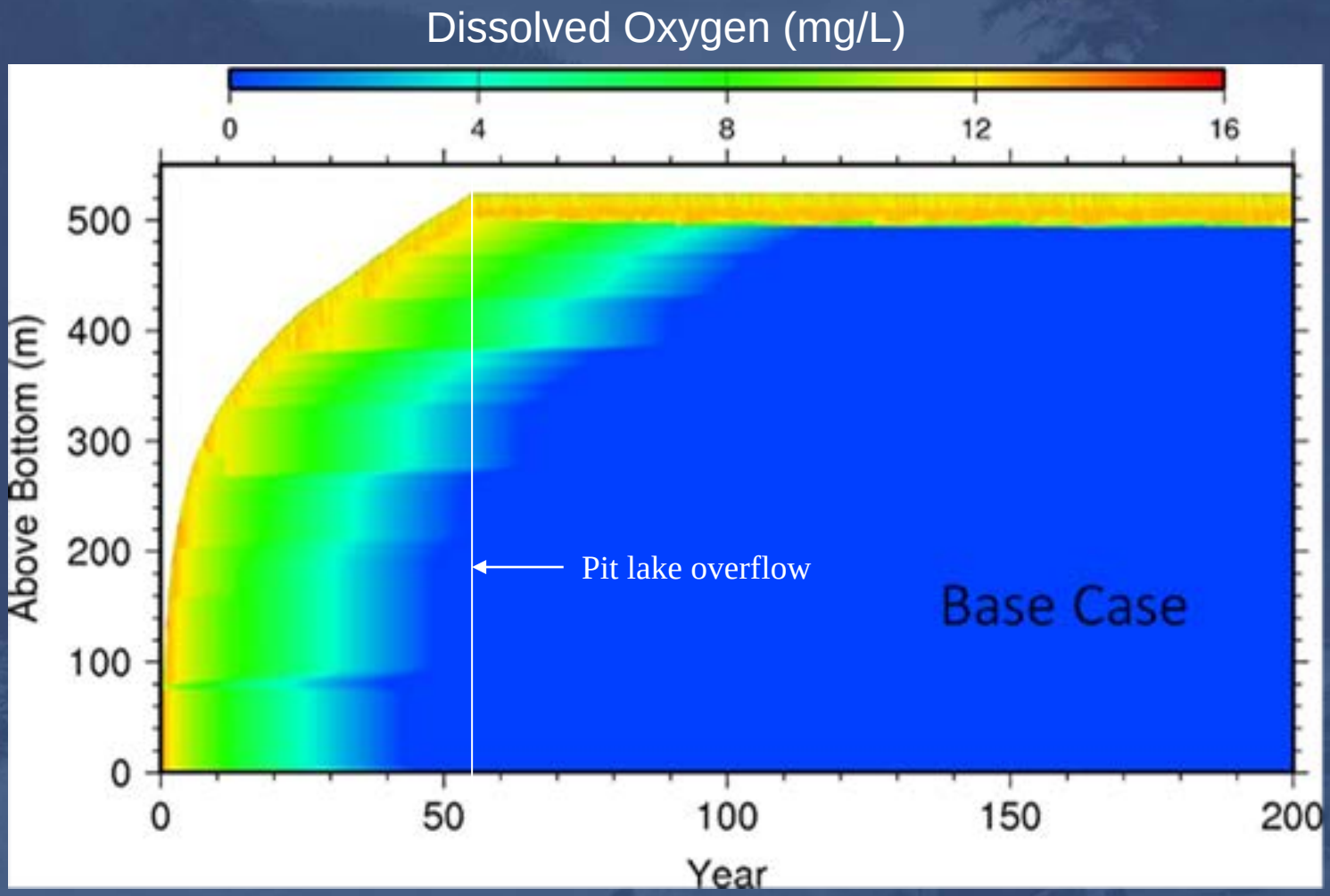


- TDS (proxy for salinity) shows initially high values in surface waters due to the input of more saline waters in the early stages of pit filling :
  - Unrecoverable PAG waste rock seepage
  - Unrecoverable TMF seepage
  - Pit wall runoff
- Notable decrease in TDS (and density) occurs during filling period.

Rationale for Surface WQ Improvements Over Time

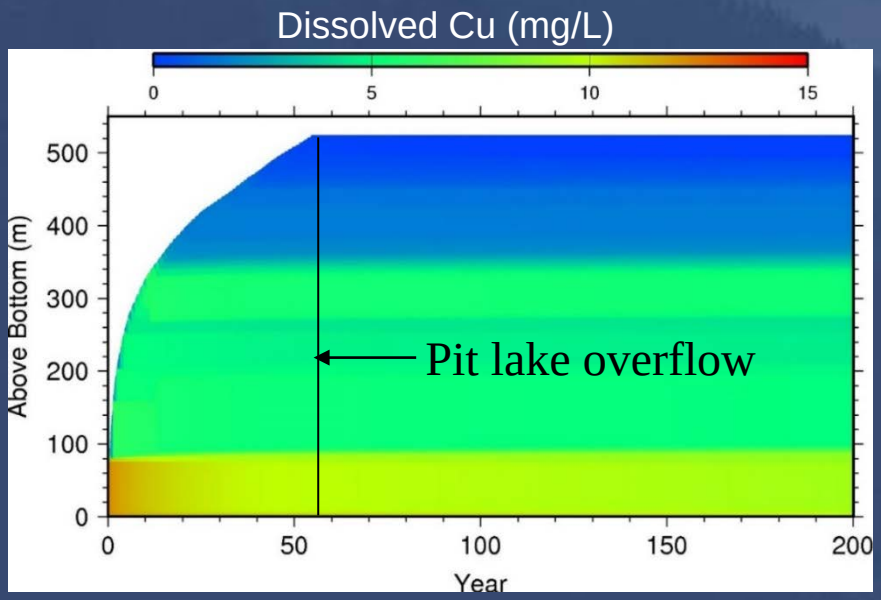
1. Decrease in loadings from PAG waste rock (covers facilitate improvements in seepage chemistry and generation of clean surface runoff).
2. Decrease in loadings from tailings seepage over time.
3. Decrease in pit wall loadings as pit fills due to: a) decreased pit wall exposure area; and b) improvement in pit wall runoff quality.
4. Increase in contribution of direct precipitation to the lake surface as lake fills.
5. Development of permanent stratification (meromixis) serves to isolate poorer water quality in pit bottom.

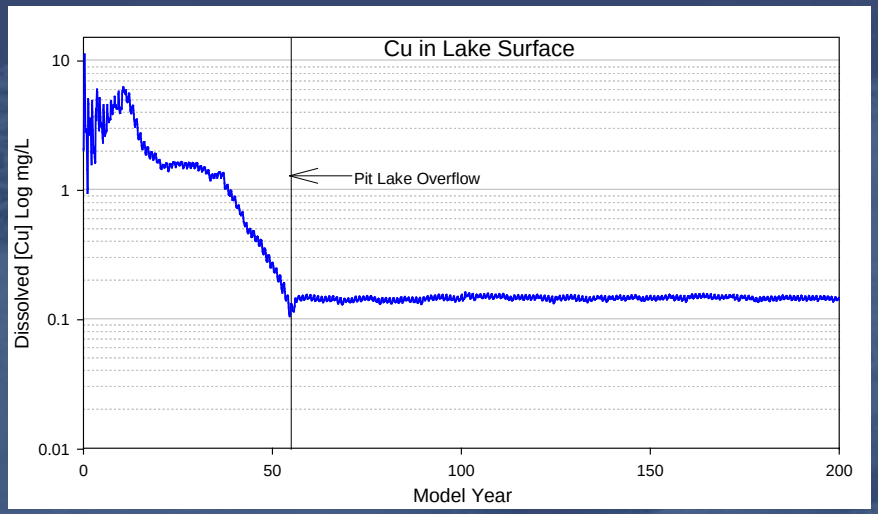
Predictions: Dissolved Oxygen



- Development of permanent stratification results in the depletion of dissolved oxygen below the surface mixed layer.

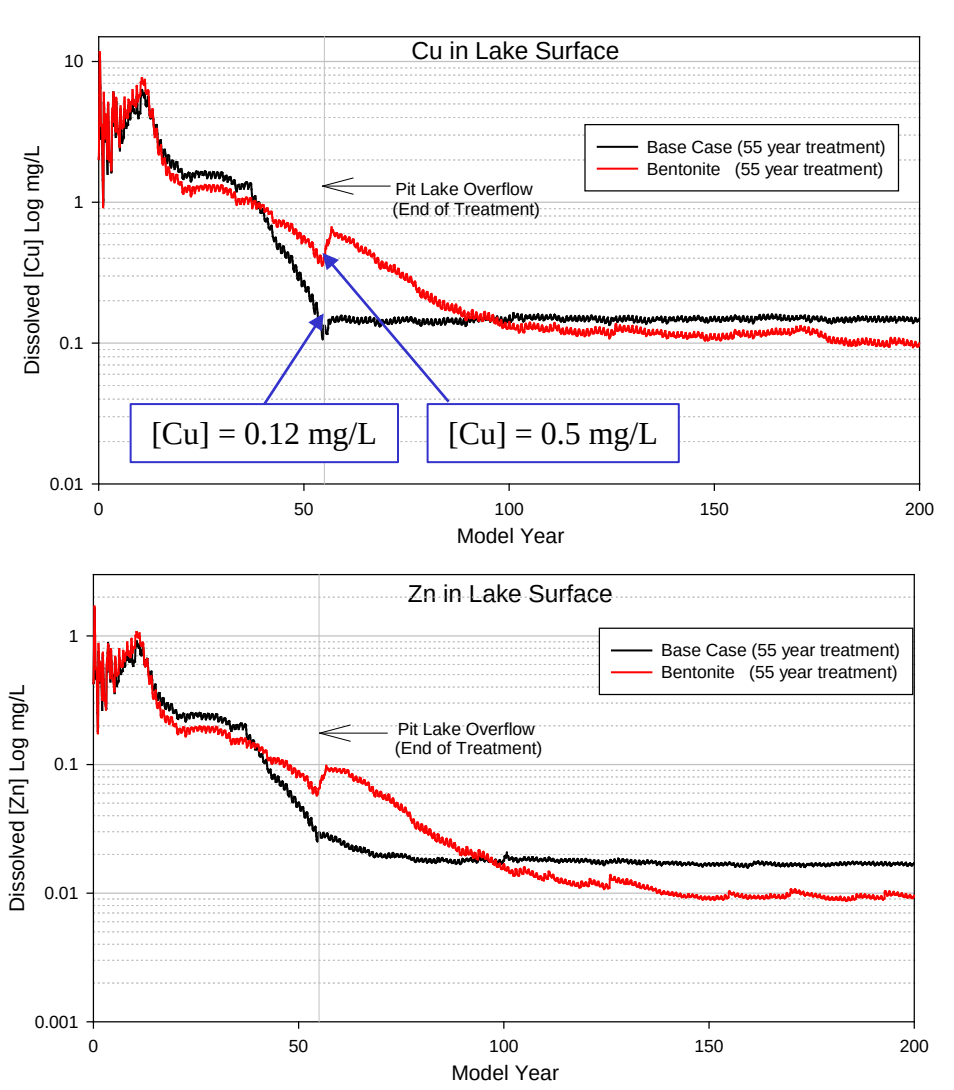
Aitik Pit Base Case Predictions: Trace Elements





- The spatial and temporal evolution of trace element concentrations closely parallel salinity.
- Trace element concentrations in surface waters improve markedly over the filling period (e.g. Cu, Ni and Zn).
- Concentrations in bottom waters remain relatively unchanged.
- Improvements in surface layer relate to decreased loadings to pit over time, as well as to development of meromixis (isolation of poor quality water in pit bottom).

Effect of Bentonite Amendment in Cover



- Bentonite Scenario: Concentrations of trace elements show significantly higher values in lake surface waters at time of pit overflow in comparison to Base case.
- For the Bentonite Scenario, stored acidity/metals from PAG waste rock are flushed out over a longer period.
- The benefits of bentonite are not realized until several decades post filling (Year 80-100).

Summary

- Evolution of Aitk pit lake chemistry is largely driven by changes in the composition of unrecoverable seepages (waste rock, tailings, pit walls).
- For the Aitik Pit lake, surface water quality improves over time in response to: 1) decrease in loadings (pit wall, tailings & waste rock); 2) increase in the contribution of direct precipitation; and 3) development of permanent stratification (isolation of poor-quality water in pit bottom).
- Water quality of lake surface waters at the time of pit lake overflow is sensitive to the timing of water quality improvements in drainage chemistry from PAG waste rock (e.g., bentonite vs. no bentonite in cover).
- The chemical evolution of pit lake inputs (changes in salinity over time) play an important role in governing water column density structure (stratification) and how loadings are stored and released from pit lakes (**emphasizes importance of development robust model inputs**).

Thank You!