Combining Field Measurements and Reactive Transport Modelling to Predict ARD

Case Study: Fault Lake Tailings, Falconbridge, ON

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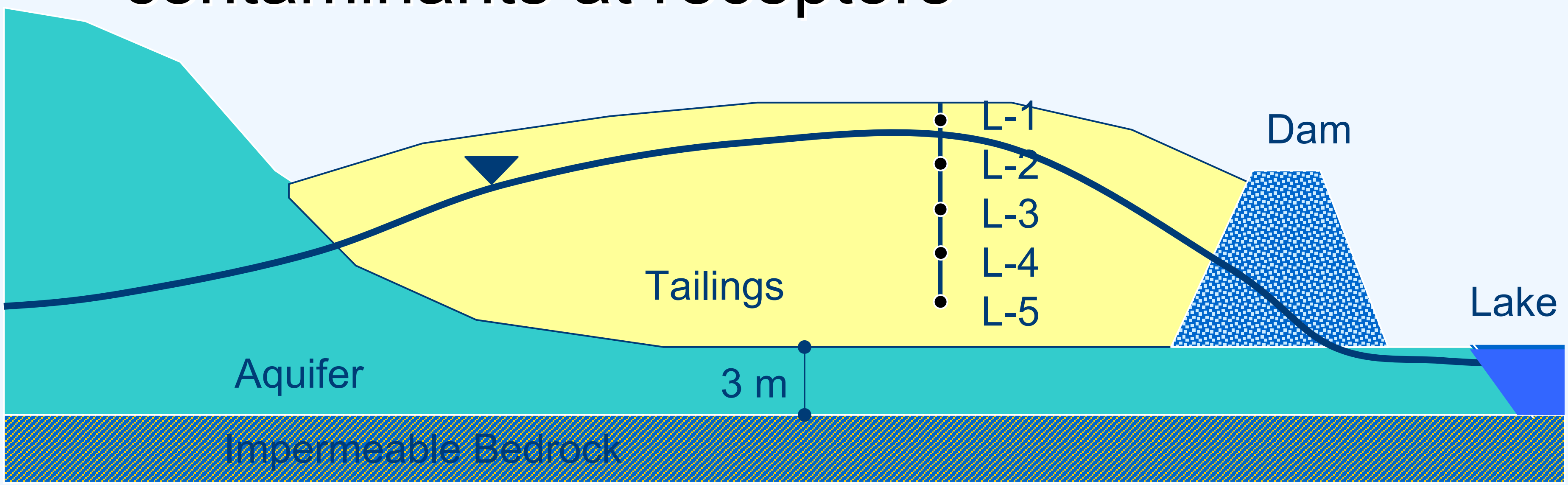
What we would like to accomplish

- Prediction of future mass loadings and maximum concentrations of target contaminants at receptors



Current Methods

- Field measurements
  - Qualitative interpretation
  - Limited quantitative interpretation
- System Complexity
  - Hydrogeology
  - Chemical Reactions
    - Sulfide oxidation and AMD release
    - pH and metal attenuation
  - Coupling between hydrogeology and geochemistry

Reactive Transport Modeling

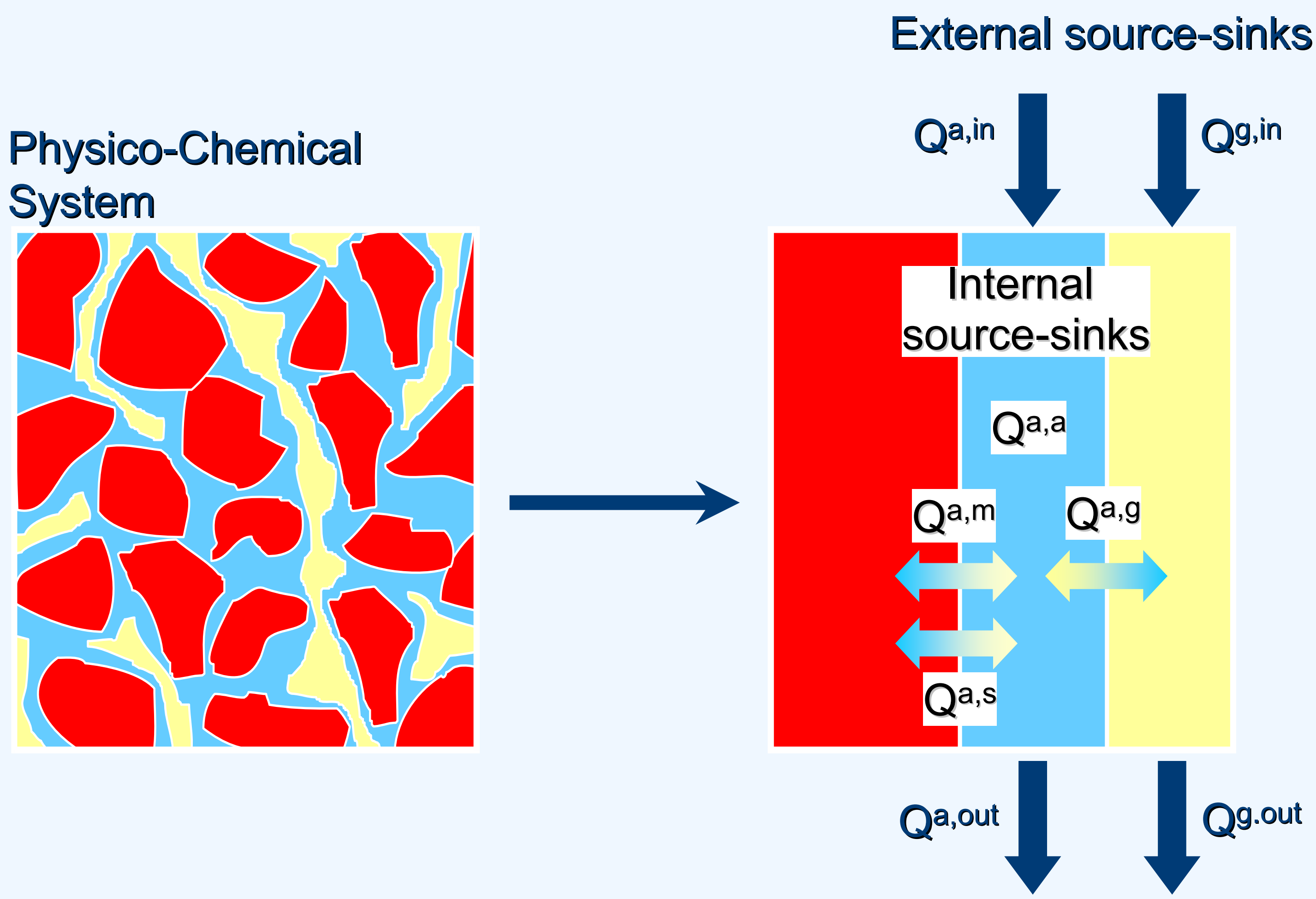
- Used as:
  - Data interpretation tool
  - What-if scenarios
  - Predictive tool

- In order to develop predictive capabilities: Model needs to be calibrated and constrained by field data

- What are the data needs?

- What can be learned, i.e. what are the strengths and limitations?

Basic Conceptual Model



Governing Equations
Reactive Transport Code MIN3P

- Simultaneous solution of transport and biogeochemical reaction processes in 1, 2 and 3 dimensions under variably saturated conditions

$$\frac{\partial}{\partial t}(S_a \phi \boldsymbol{T}_j^{\boldsymbol{a}}) + \frac{\partial}{\partial t}(S_g \phi \boldsymbol{T}_j^{\boldsymbol{g}}) + \frac{\partial}{\partial t}\boldsymbol{T}_j^{\boldsymbol{s}}$$

$$+ \nabla \cdot v\, \boldsymbol{T}_j^{\boldsymbol{a}} - \nabla \cdot D_a \nabla \boldsymbol{T}_j^{\boldsymbol{a}} - \nabla \cdot D_g \nabla \boldsymbol{T}_j^{\boldsymbol{g}}$$

$$= -(\boldsymbol{Q}_j^{\boldsymbol{a},\boldsymbol{a}} + \boldsymbol{Q}_j^{\boldsymbol{a},\boldsymbol{m}}) \qquad j = 1, N_c$$

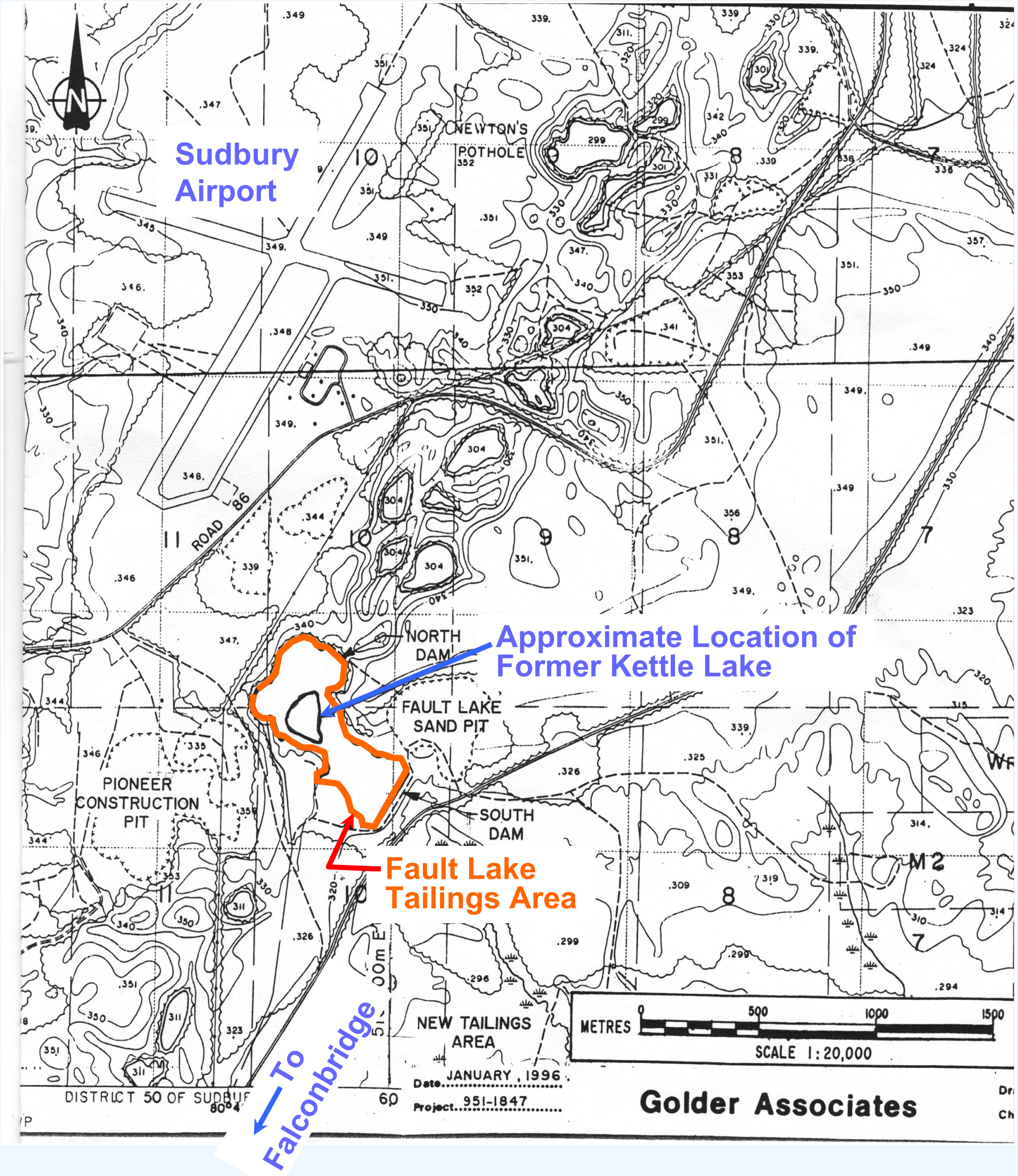
Study Site

- Fault Lake Tailings Area, Falconbridge, Ontario
- 5.7 M tonnes tailings deposited 1964-1978
- Up to 50 wt % sulfide minerals; AMD caused minor contamination downgradient
- Closure plan submitted in 1996 by Golder
- Ministry approval obtained with request for more detailed geochemical modelling
- Determine potential long term impacts to groundwater and downstream receptors
- Our approach: application of MIN3P code

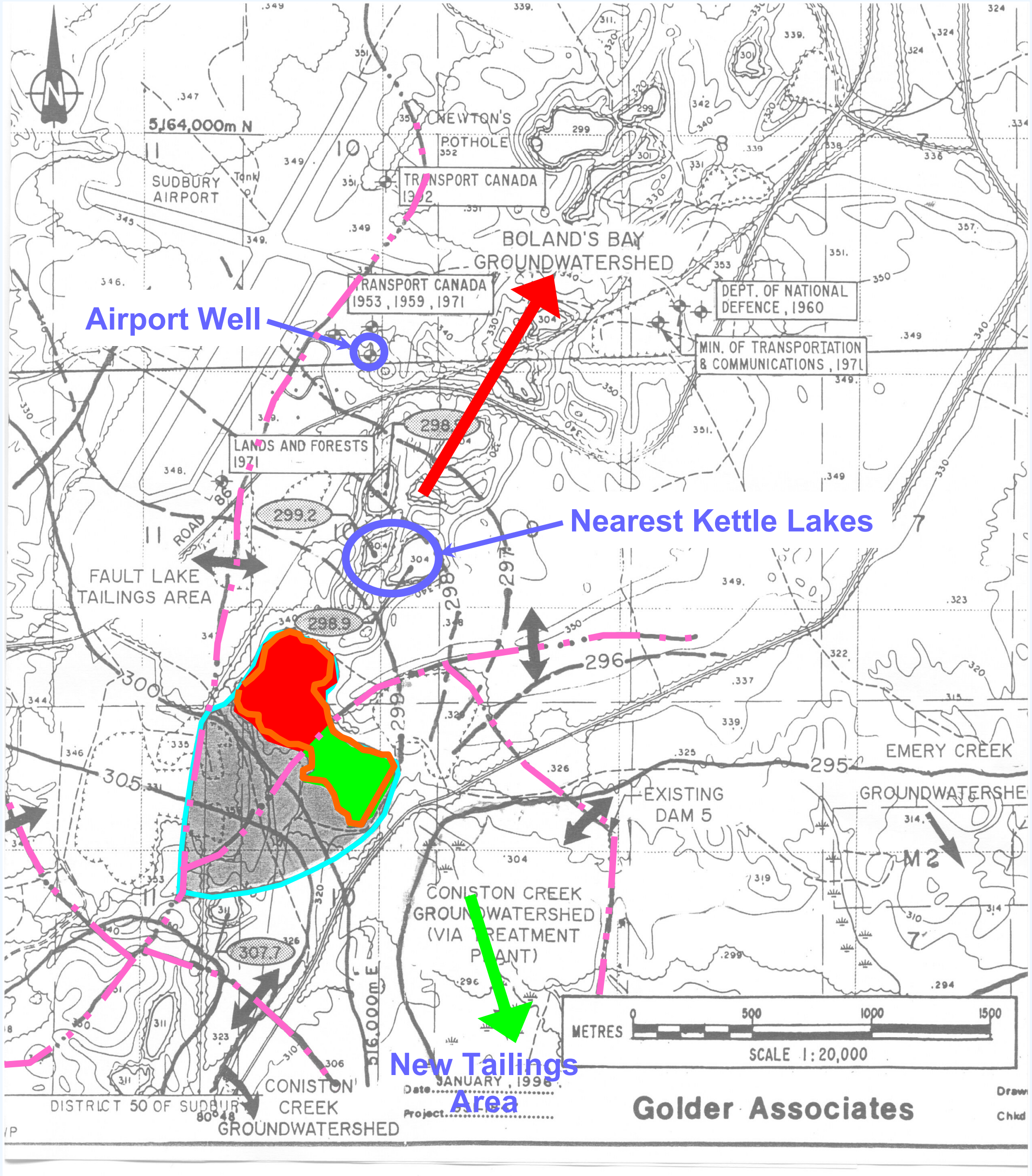
Study Objectives

- Describe geochemical conditions along groundwater flow path using existing data
- Estimate relative mobility of components of interest in groundwater
- Estimate peak concentrations/cumulative mass loading of components at sensitive receptors (i.e., airport well and nearest kettle lake)

Site Description



Groundwater Flow Regime



Conceptual Model

- Oxidation of sulfide minerals
  - Ni-bearing pyrrhotite, chalcopyrite and pentlandite
- Dissolution of pH-buffering minerals
  - Calcite, chlorite, anorthite; biotite
- Precipitation of secondary minerals
  - ferric hydroxides/hydroxysulfates (ferrihydrite, jarosite), predominantly in vadose zone
  - siderite, am Al-hydroxide, gypsum, am silica
  - Covellite (CuS), low or ND of [Cu] in tailings
- Potential re-dissolution of secondary minerals

Modelling Approach

- 1D vertical profiles through center of tailings impoundment
- 2D cross-sectional slices through tailings and aquifer to downstream receptors
- Exposed and covered tailings scenarios
- Simulation time 1000 years
- Input parameters extracted from available hydrogeological/mineralogical/chemical data from former studies by Golder and NTC

… Data Needs …

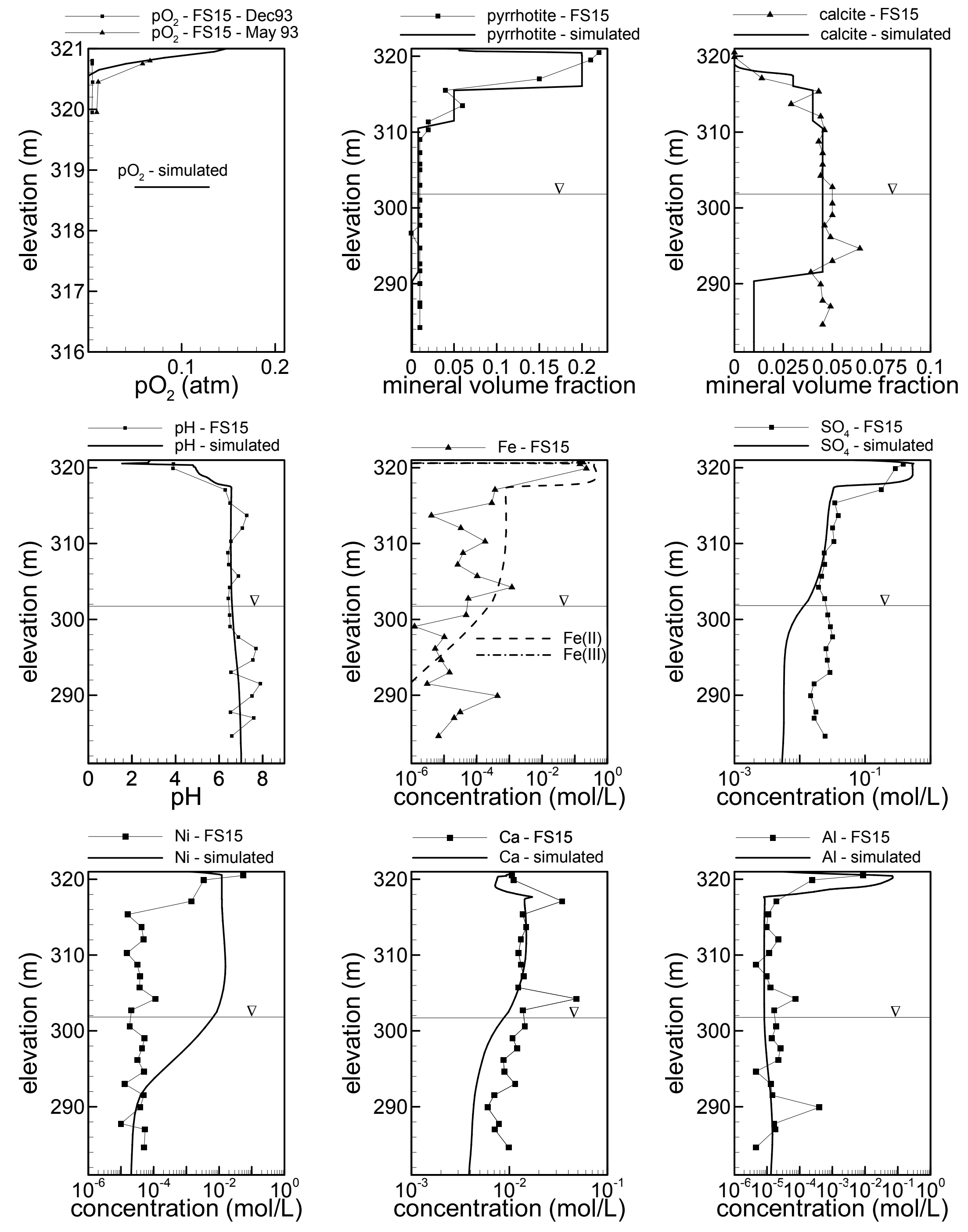
- Hydrogeology
  - Hydraulic conductivities, recharge rates
- Gas transport
  - Pore gas saturation
- Geochemistry
  - Mineralogy of tailings and aquifer, reaction rates and surface areas

Input Parameter Determination

- Hydraulic conductivities: field measurements
- Water/gas saturations: calibrated
- Mineral fractions estimated from evaluation of reported elemental analyses and qualitative XRD results of tailings
- Calcite content derived from measured neutralization potential of tailings
- Reactive surface areas for silicates derived from median grain size in tailings and assuming grains are perfectly spherical

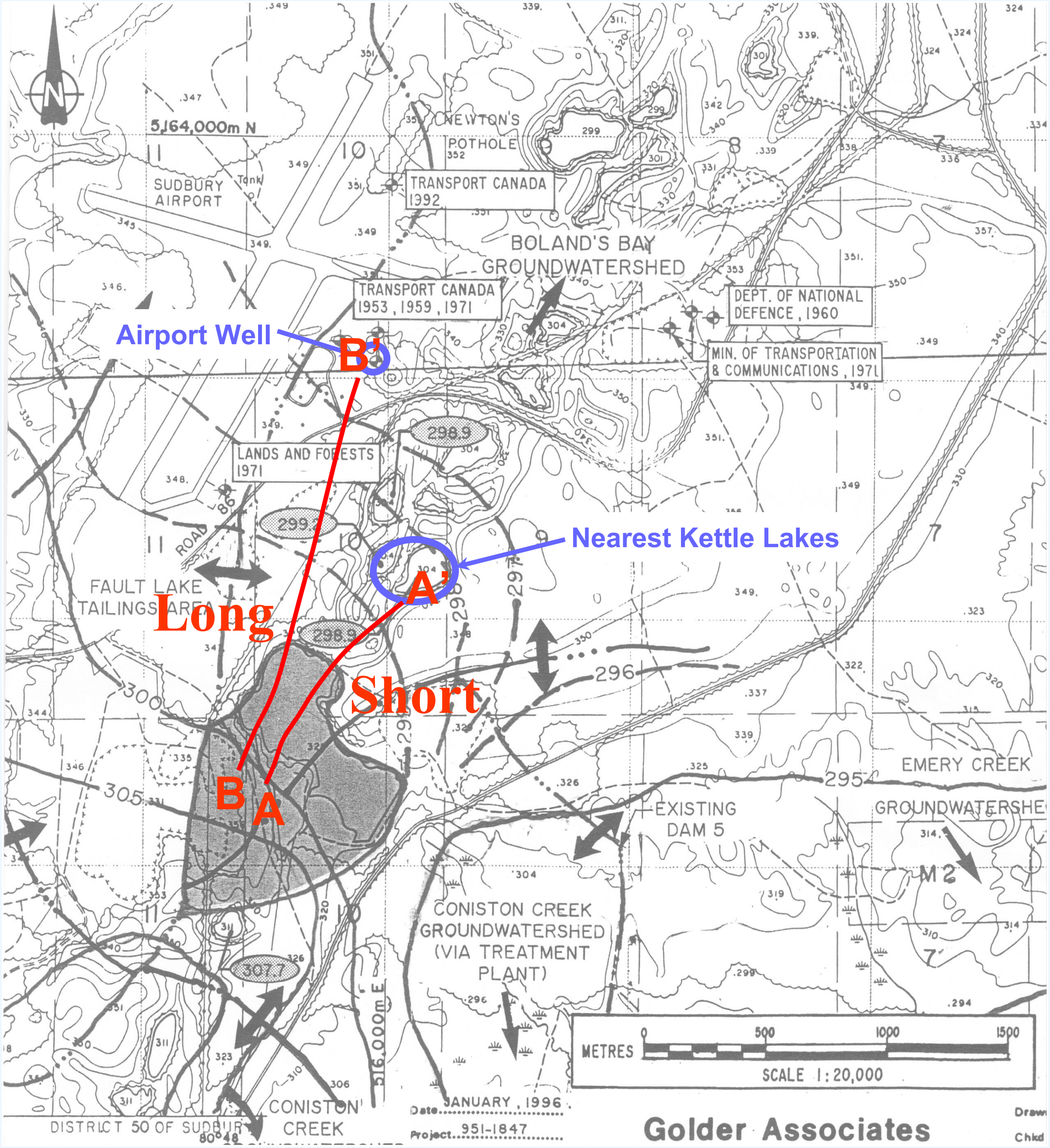
- Significant data provided, but some assumptions necessary!

1D–Simulations Model Calibration



- What could be learned?
  - Estimate of historical rates of sulfide oxidation and pH-buffer reactions
  - Coupling cross-check
  - What about Ni?

Data from NTC, 1995

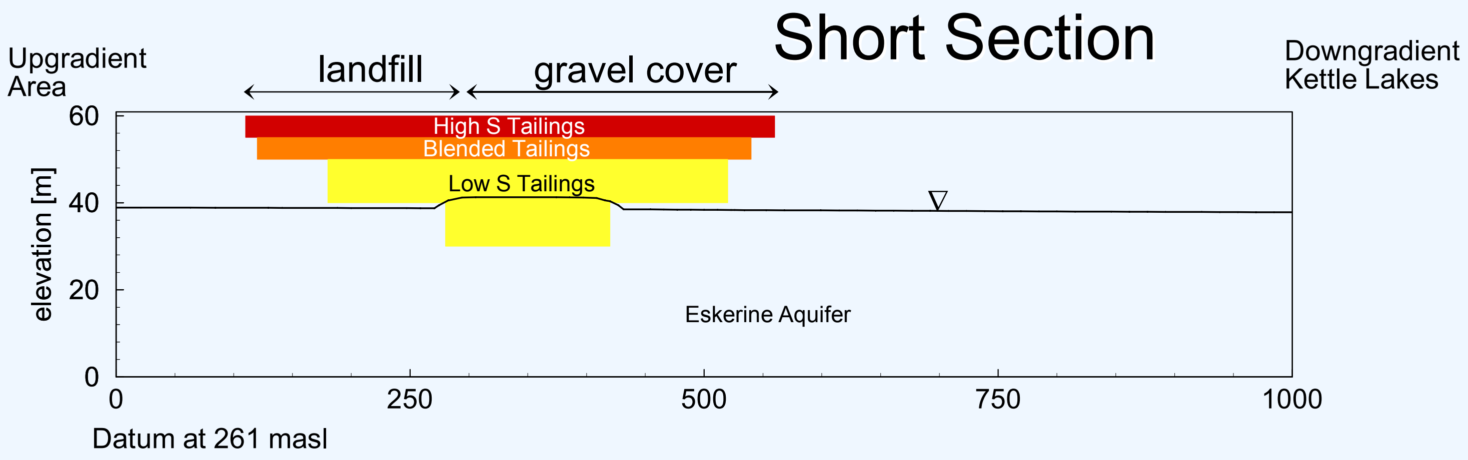


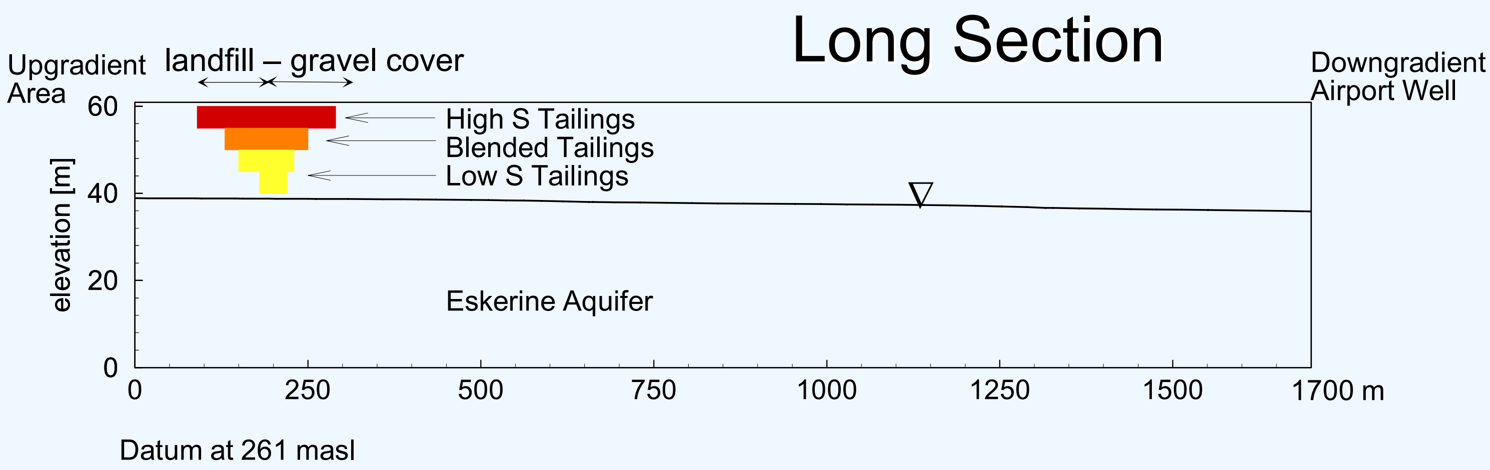
Potential Receptors

- Water supply well
- Surface water body

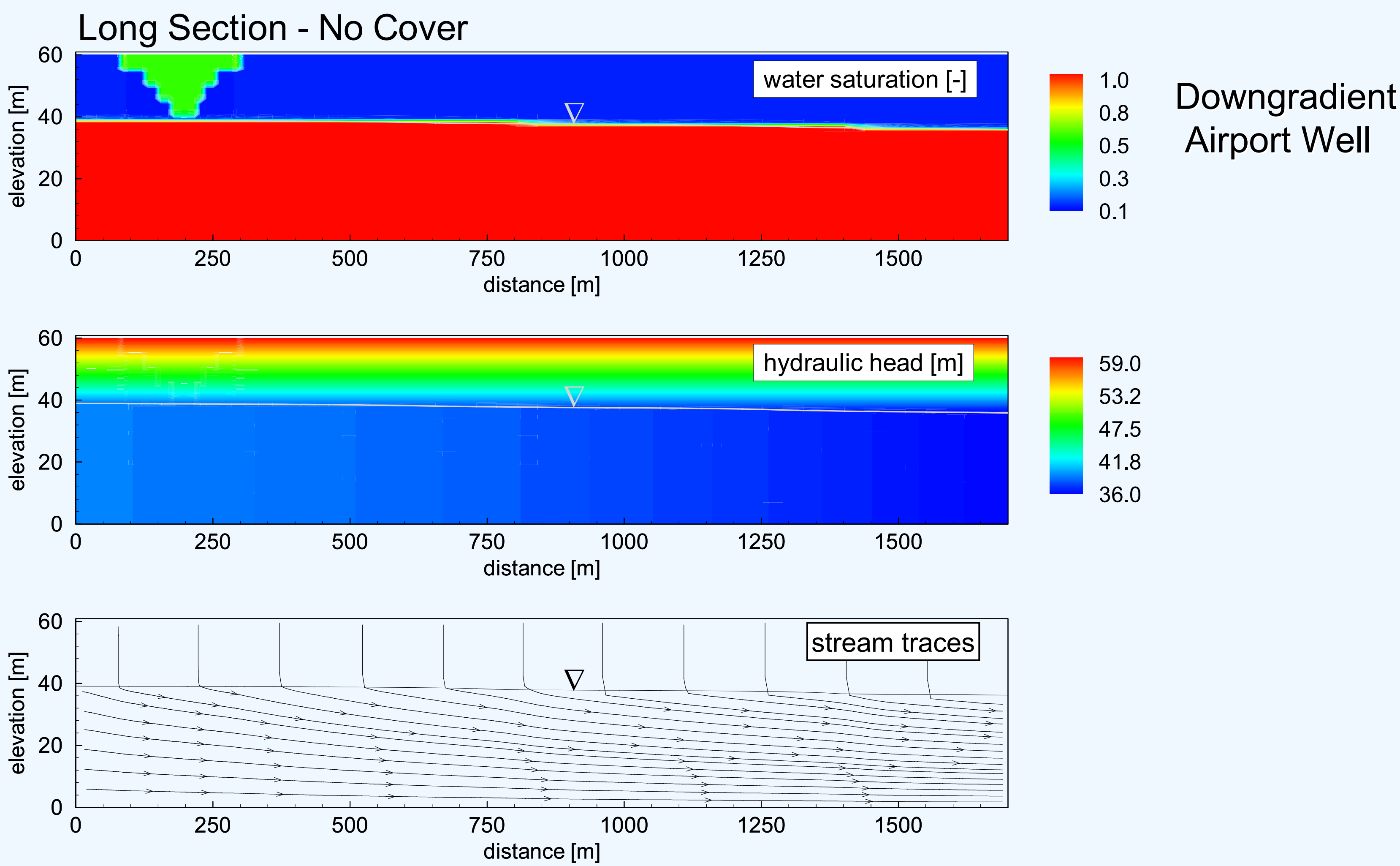
- Simulate 2D – Cross Sections

2D Simulation Domains

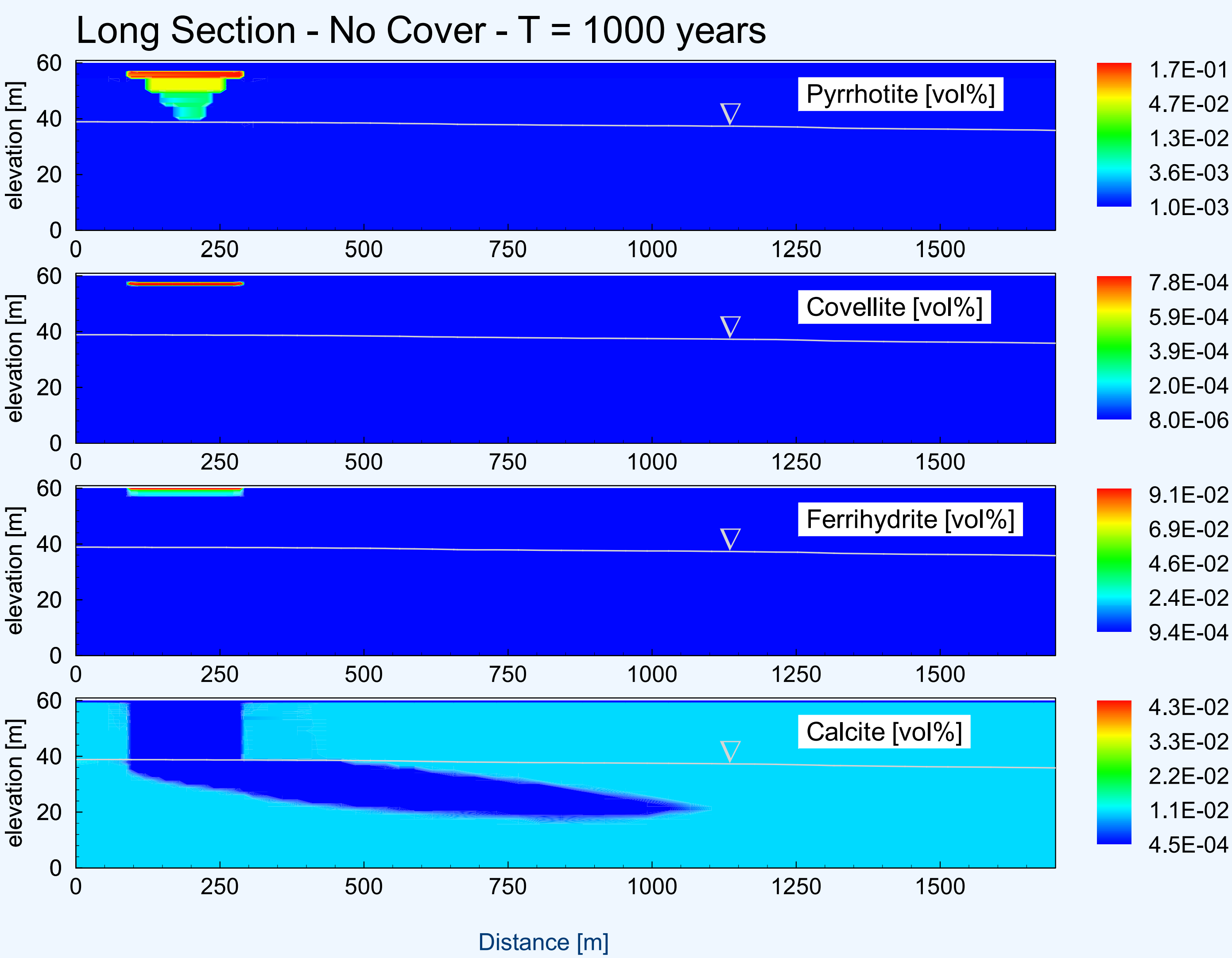




Steady State Flow Field
Long Section

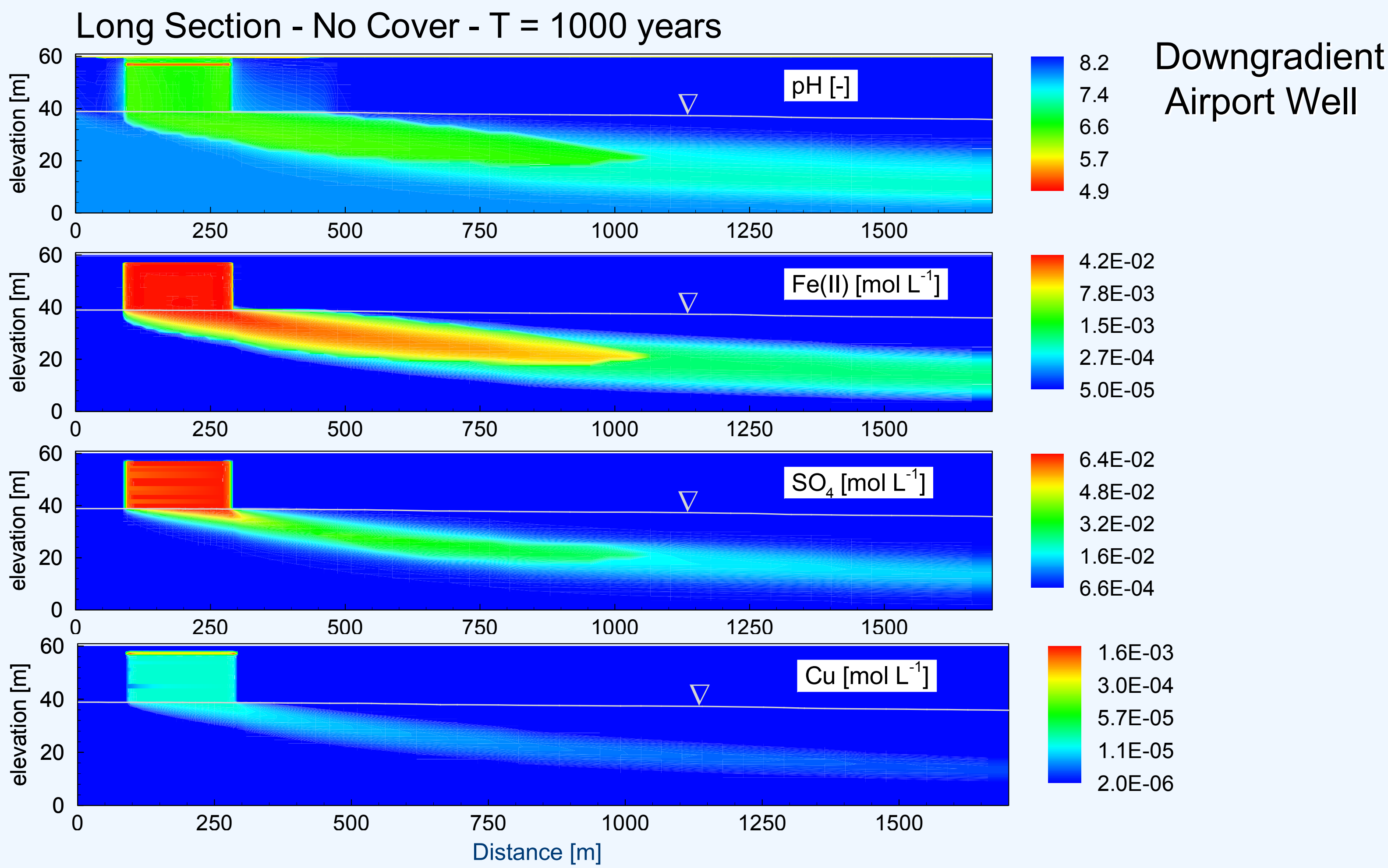


Mineral Volume Fractions Long Section

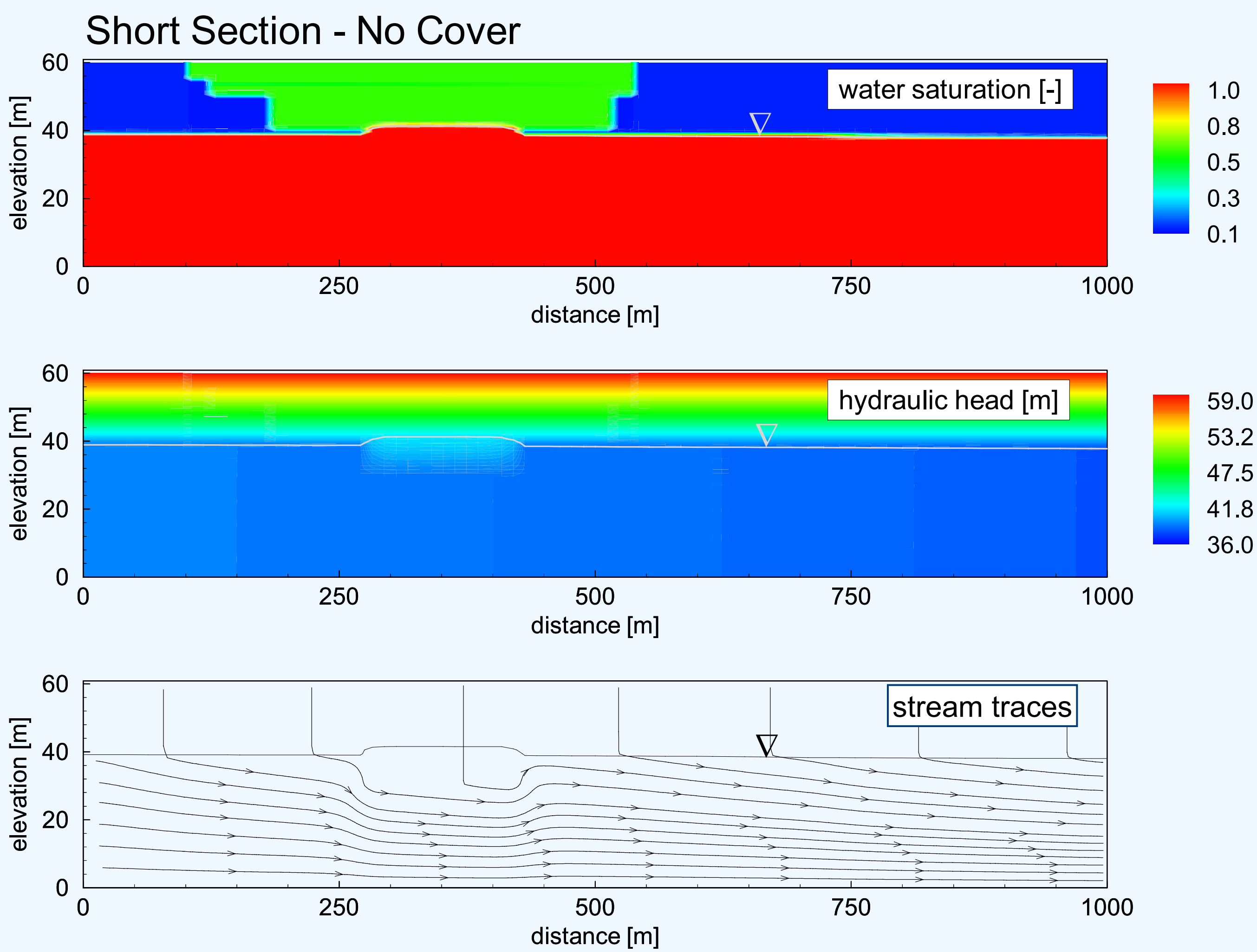


Downgradient Airport Well

Aqueous Concentrations
Key Components – Long Section

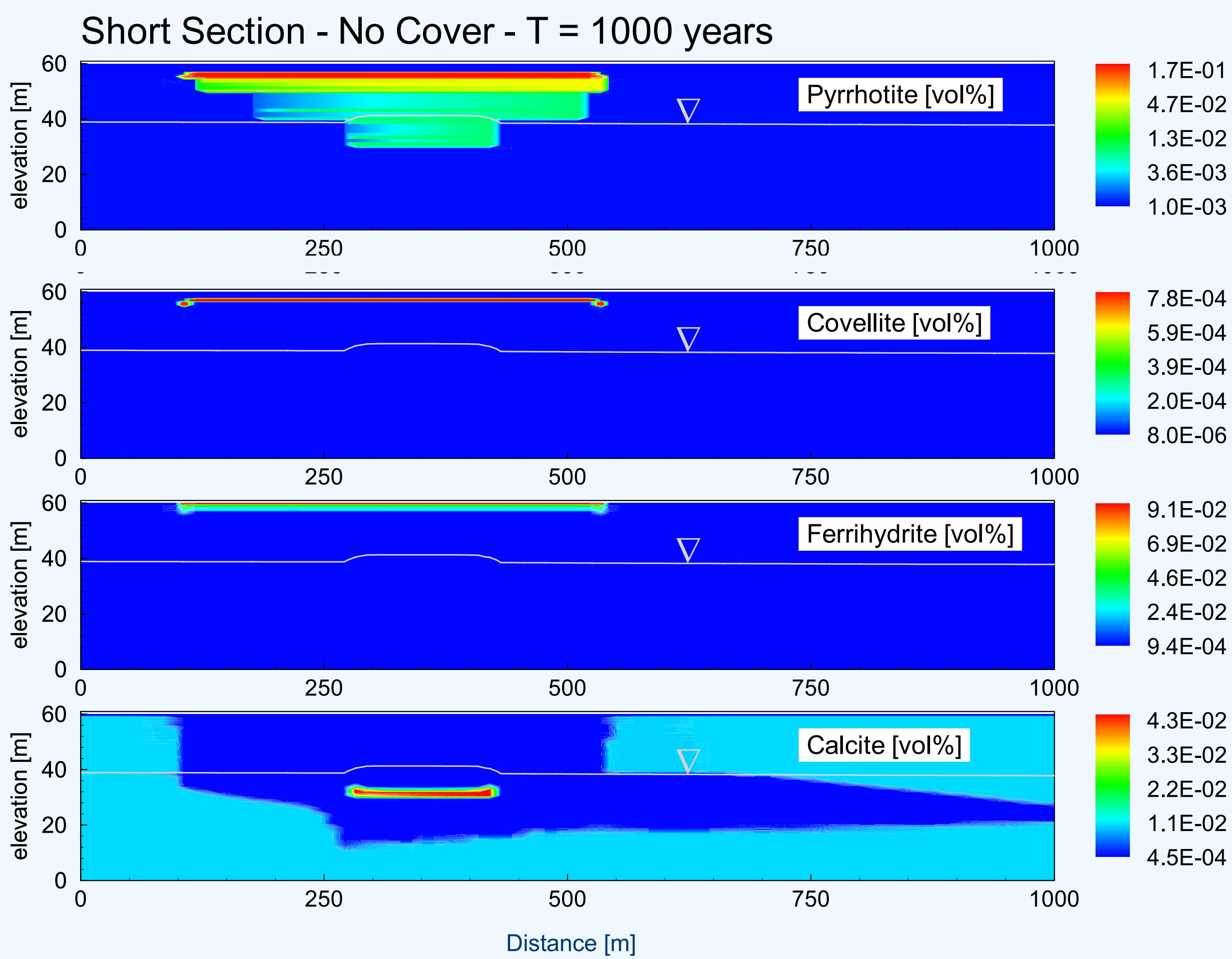


Steady State Flow Field
Short Section



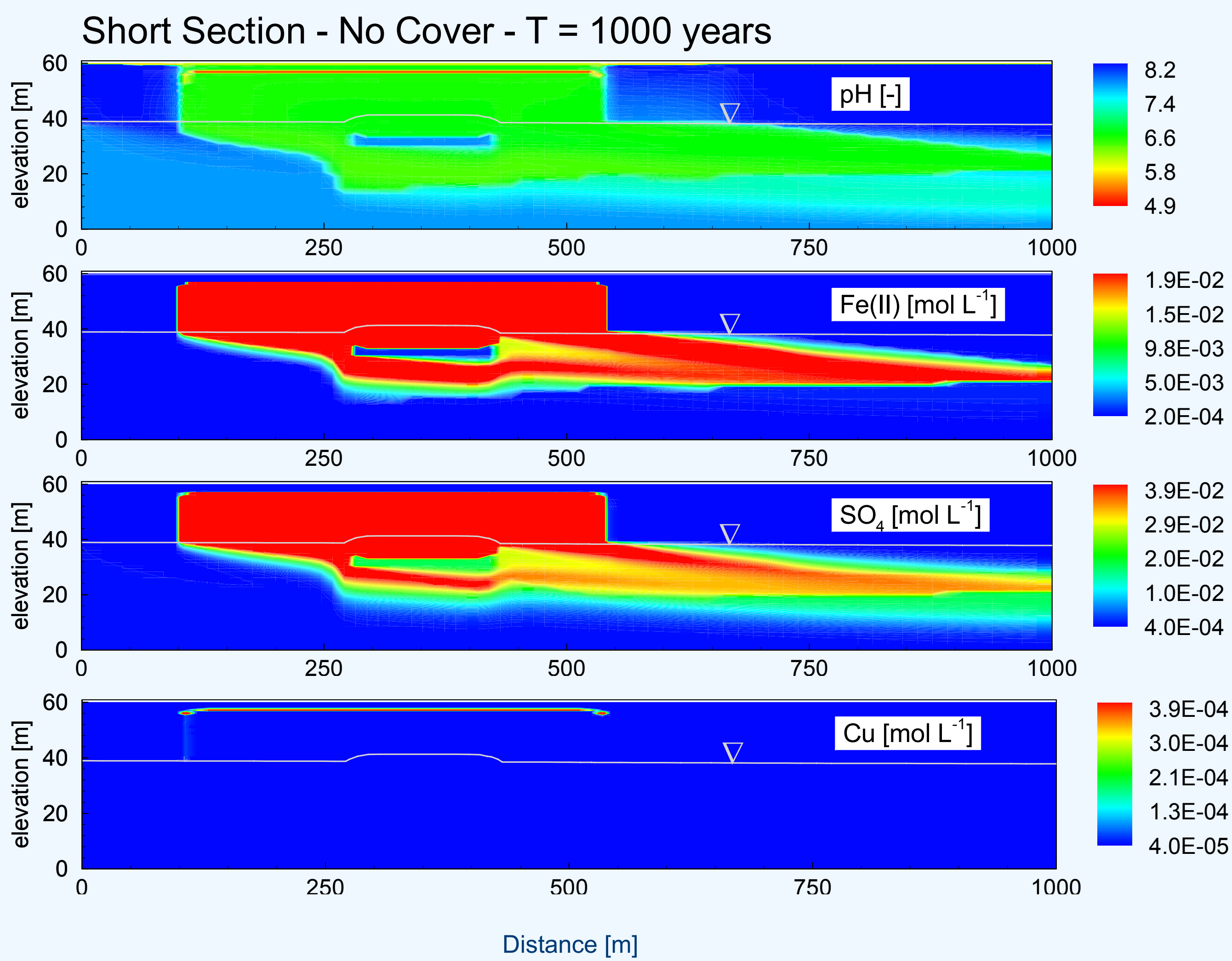
Downgradient Kettle Lakes

Mineral Volume Fractions Short Section



Downgradient Kettle Lakes

Aqueous Concentrations Key Components – Short Section



Downgradient Kettle Lakes

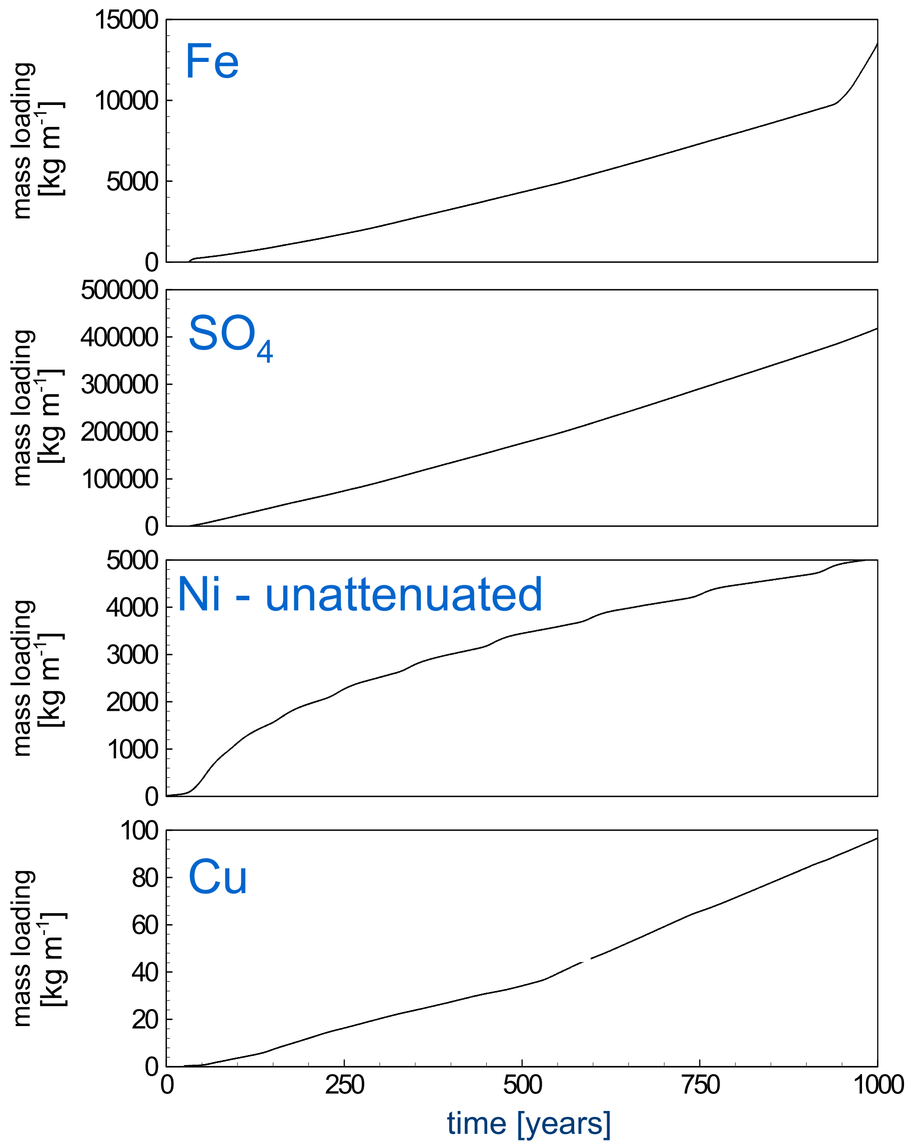
What could be learned?

- Long term release and attenuation likely
- Carbonate depletion possible in short section over 1000 year period
- Complex interactions between hydrogeology and geochemistry
  - Hydraulic exclusion of carbonate buffering minerals
  - Impact on GW first felt below fringe areas of impoundment

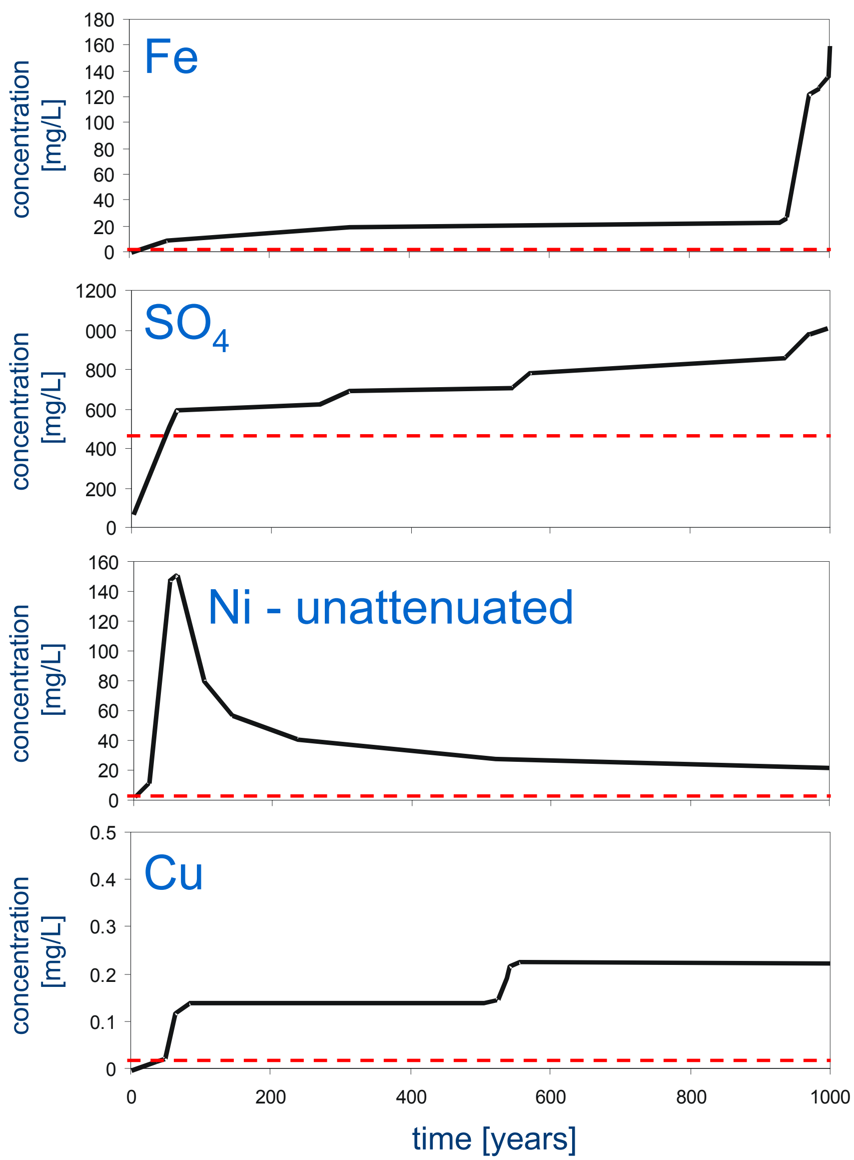
Limitations

- Long term evolution of rates?
- Hardpan formation?
- Fe attenuation by siderite?

Short Section: Mass Loading



Depth-Integrated Outflow Concentrations



Case Study Conclusions

- Simulation results suggest formation of tailings plume characterized by sub-neutral pH, elevated Fe, SO_4, (and Ni, although not representative)
- 1D simulations agreed with observed historical data
- 2D reactive transport simulations depict geochemical, spatial and temporal features
  - Time delay of breakthrough due to buffering reactions
  - AMD is preferentially generated in periphery of impoundment, where tailings are thin
  - Hydraulic exclusion of buffer capacity in saturated portion of tailings

Reactive transport modeling and field data
What we can accomplish

- Detailed data sets required
- Some gaps can be filled by history matching

- Coupling of 2D/3D hydrogeological processes and geochemical reactions can be assessed
- Major ion chemistry can be fairly well predicted

- Much more difficult for trace elements
- Long-term prediction of release rates and attenuation remains difficult

Questions?