# Model for predicting drainage quality from mine wastes

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Programme for Sustainable Growth and Jobs

Mining Waste Management Methods

Endomines

Kemira

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Centre for Economic Development, Transport and the Environment

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# Introduction

- Quantitative modelling is instrumental in effective predictions of water quality from mine wastes
- Prior understanding about the future series of events in waste settings may help performing more robust risk assessment and designing remediation measures
- Increasingly recognized not only in data interpretation but also in long-term predictions
- Received a great deal of research attention and led to the development of a variety of modelling approaches
- However, there is still a lack of attention towards utilizing predictive models at early (e.g., planning) phases of a mine

# Governing Equations

- ***Water Flow***

$$S_s S_w \frac{\partial h}{\partial t} + \theta \frac{\partial S_w}{\partial t} - \nabla \cdot \left( k_r \mathbf{K} \nabla h \right) = Q_i^w$$

- ***Solute Transport***

$$\frac{\partial}{\partial t}\left(\theta S_w C_i\right) = -\left(\mathbf{q} C_i\right) + \nabla \cdot \left(\theta S_w \mathbf{D}_i \nabla C_i\right) - \sum_{r=1}^{N_r} \upsilon_{ir} R_r - \sum_{m=1}^{N_m} \upsilon_{im} R_m - \sum_{r=1}^{N_g} \upsilon_{ig} R_g$$

- ***Gas Transport***

$$\frac{\partial}{\partial t}\left(\theta S_g C_i^g\right) = -\left(\mathbf{q}_g C_i^g\right) + \nabla \cdot \left(\theta S_g \mathbf{D}_{p,i}^g \nabla C_i^g\right) - Q_i^g$$

- ***Mineral Reactions***

$$R_j = k_j \prod \left(\gamma_j C_j\right)^{\upsilon} \left[1 - \frac{IAP_j}{K_j}\right]$$

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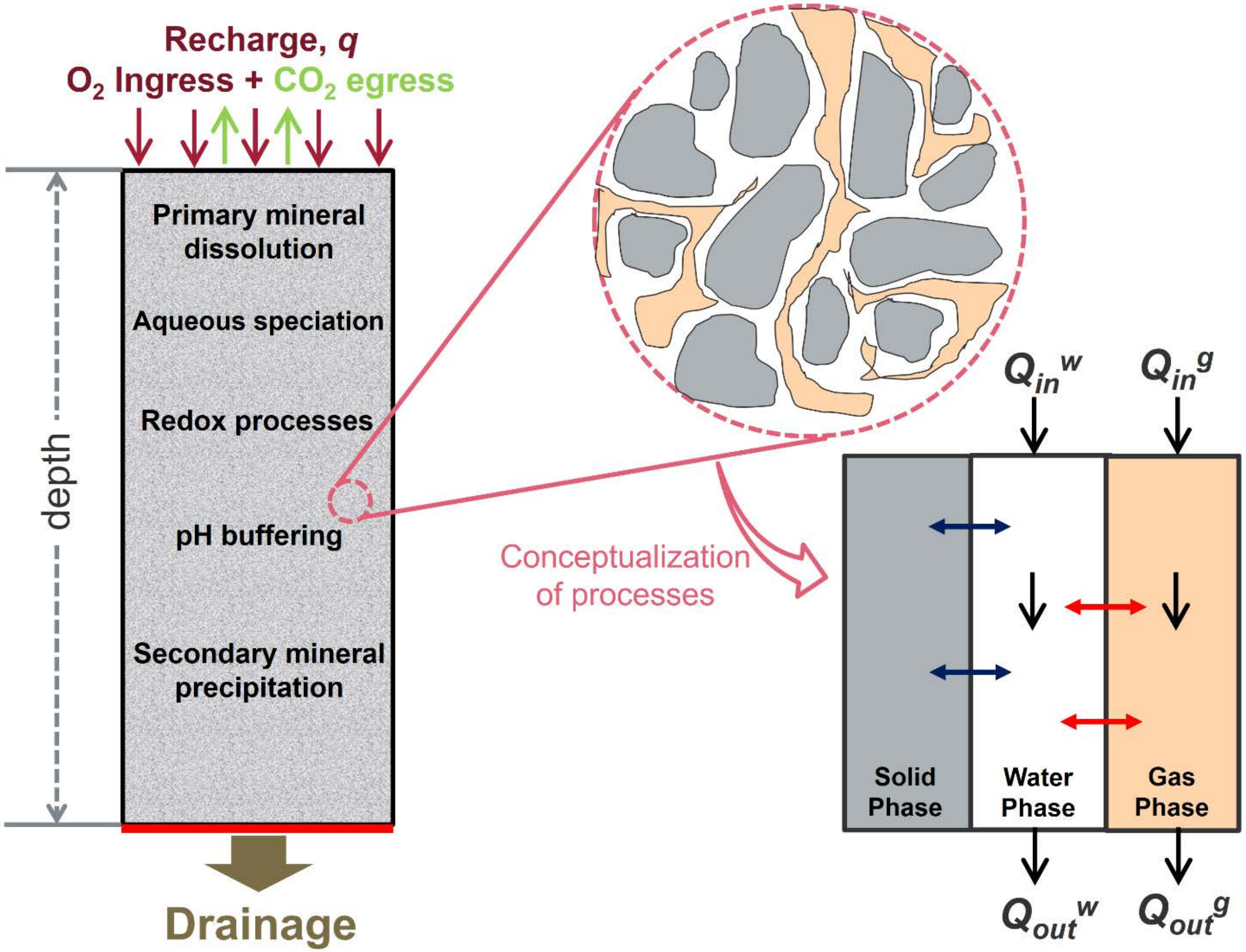
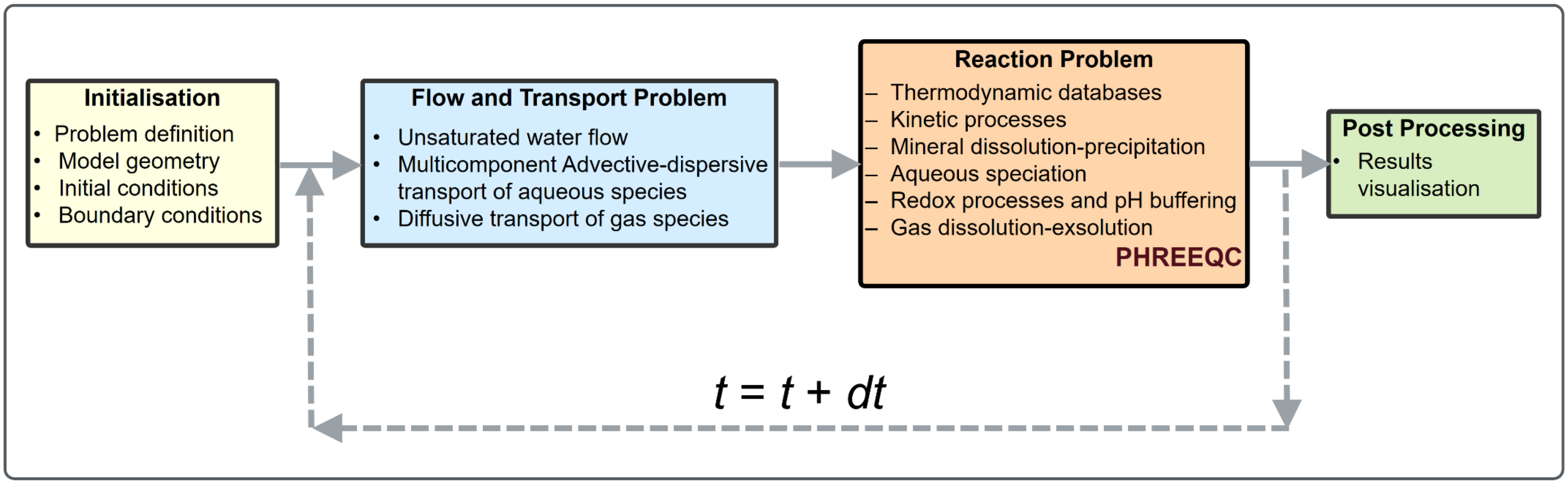
# Modelling Approach



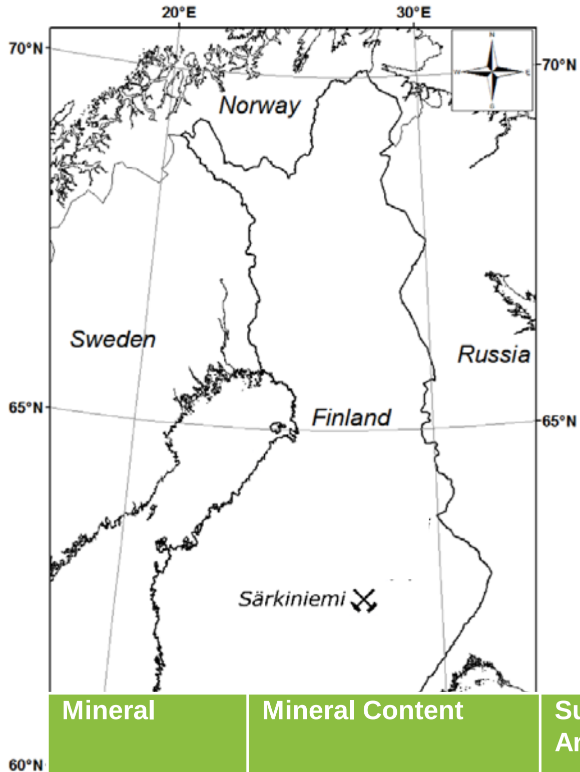
# Modelling Approach (cont'd)

## Structure of the Model




*Numerical Method:* cell-centered Finite Volume Method

# Example 1: Särkiniemi Waste Rock Pile



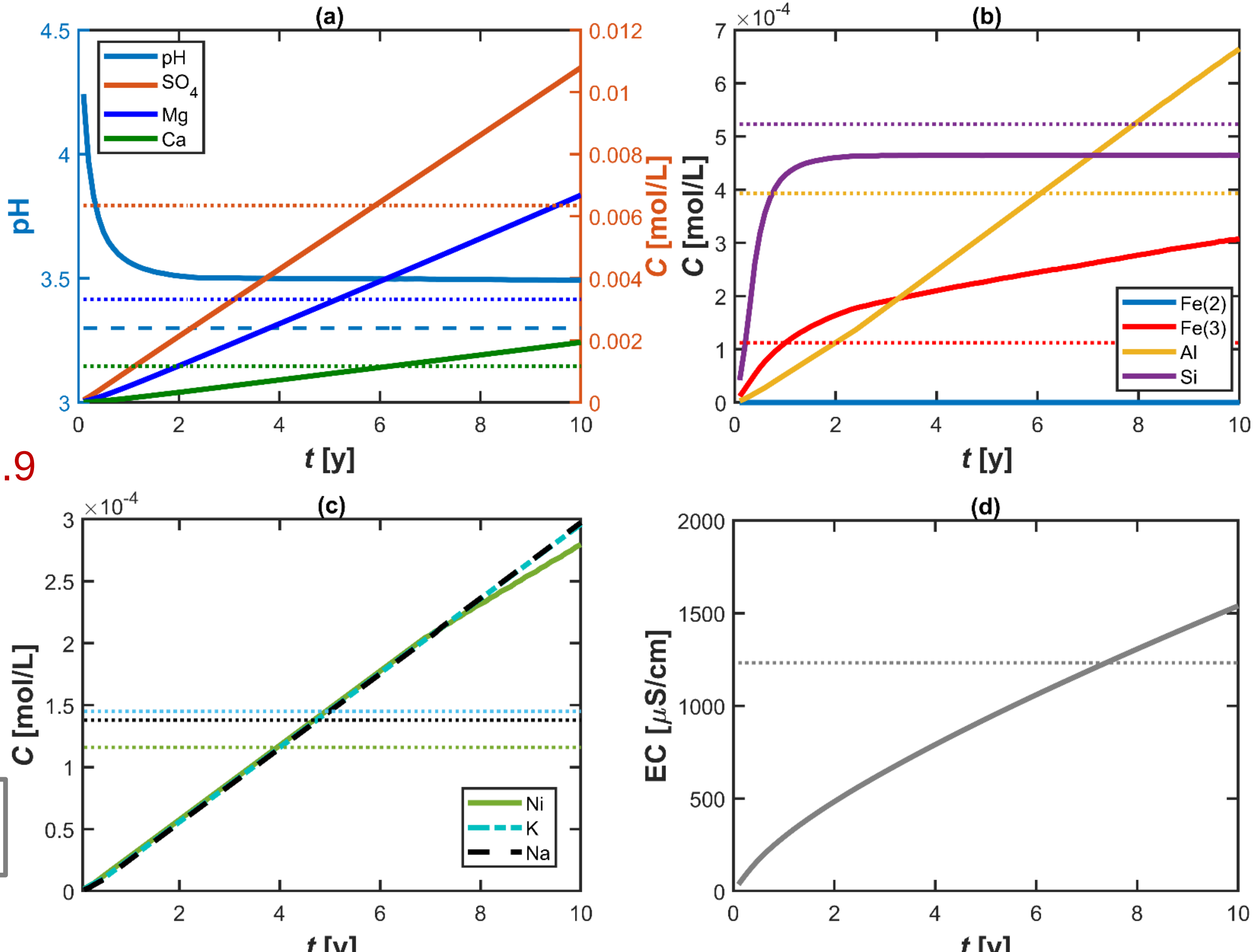


| Mineral | Mineral Content | | Surface Area, A | Rate coefficient, k | Reference |
|---|---|---|---|---|---|
| | [wt%] | [mol $L_w^{-1}$][a] | [$m^2$ $L_w^{-1}$] | [mol $m^{-2}$ $s^{-1}$] | |
| **Biotite** | 33.56 | 2.12 | 0.65 | $10^{-10.97}$ | Nagy (1995) |
| **Hornblende** | 6.07 | 0.58 | 0.05 | $10^{-8.10}$ | Palandri & Kharaka (2004) |
| **Serpentine** | 3.52 | 0.33 | 0.05 | $10^{-9.08}$ | Declercq & Oelkers (2014) |
| **Albite** | 1.45 | 0.15 | 0.60 | $10^{-10.16}$ | Palandri & Kharaka (2004) |
| **Chlorite** | 1.35 | 0.06 | 0.50 | $10^{-11.11}$ | Palandri & Kharaka (2004) |
| **Pyrrhotite** | 1.52 | 0.50 | 0.30 | $10^{-8.19}$ | Williamson & Rimdstidt (1994) |
| **Anthophyllite** | 0.45 | $1.53\times10^{-2}$ | 0.50 | $10^{-11.94}$ | Palandri & Kharaka (2004) |
| **Pentlandite** | 0.03 | $1.03\times10^{-3}$ | 0.70 | $10^{-8.19}$ | Williamson & Rimdstidt (1994) |
| **Pyrite** | 0.02 | $4.42\times10^{-3}$ | 0.30 | $10^{-8.19}$ | Williamson & Rimdstidt (1994) |
| **$SiO_2$(a)** | - | - | - | $10^{-10.5}$ | Rimstidt & Barnes (1980) |

# Example 1: Särkiniemi Waste Rock Pile (cont'd)

Drainage Chemistry:

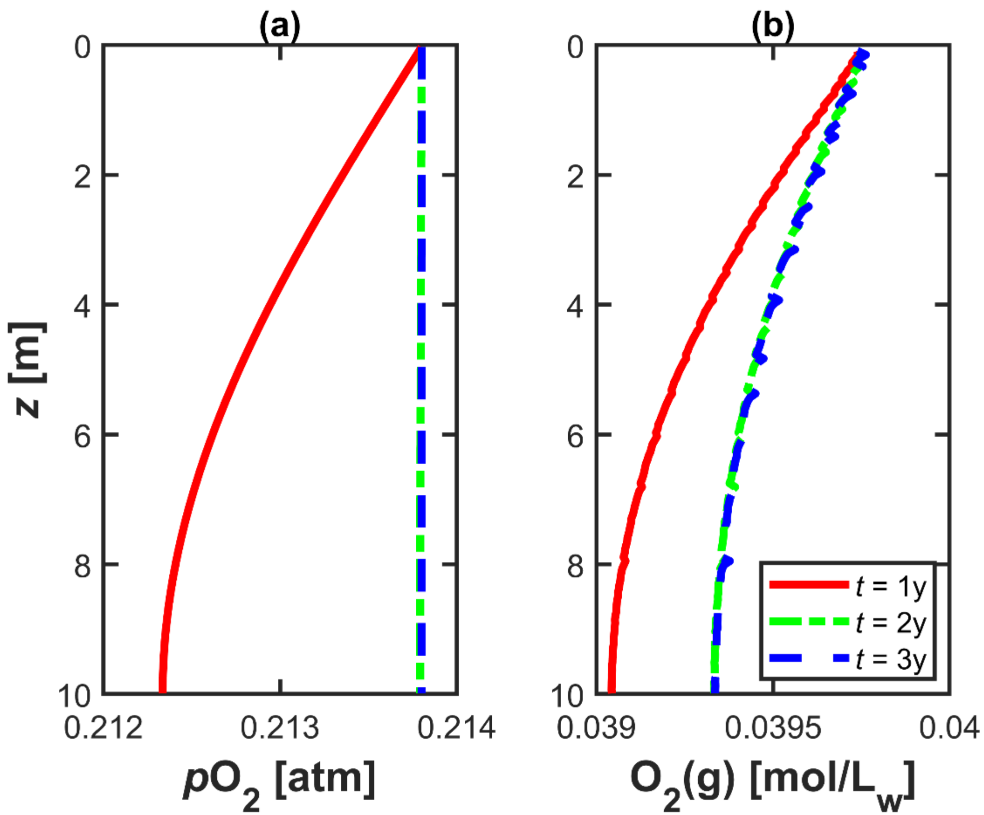
NPR = 0.2 – 0.4
NAG pH = 2.7 – 2.9




Solid Lines – Model
Dashed Lines - Data

# Example 1: Särkiniemi Waste Rock Pile (cont'd)

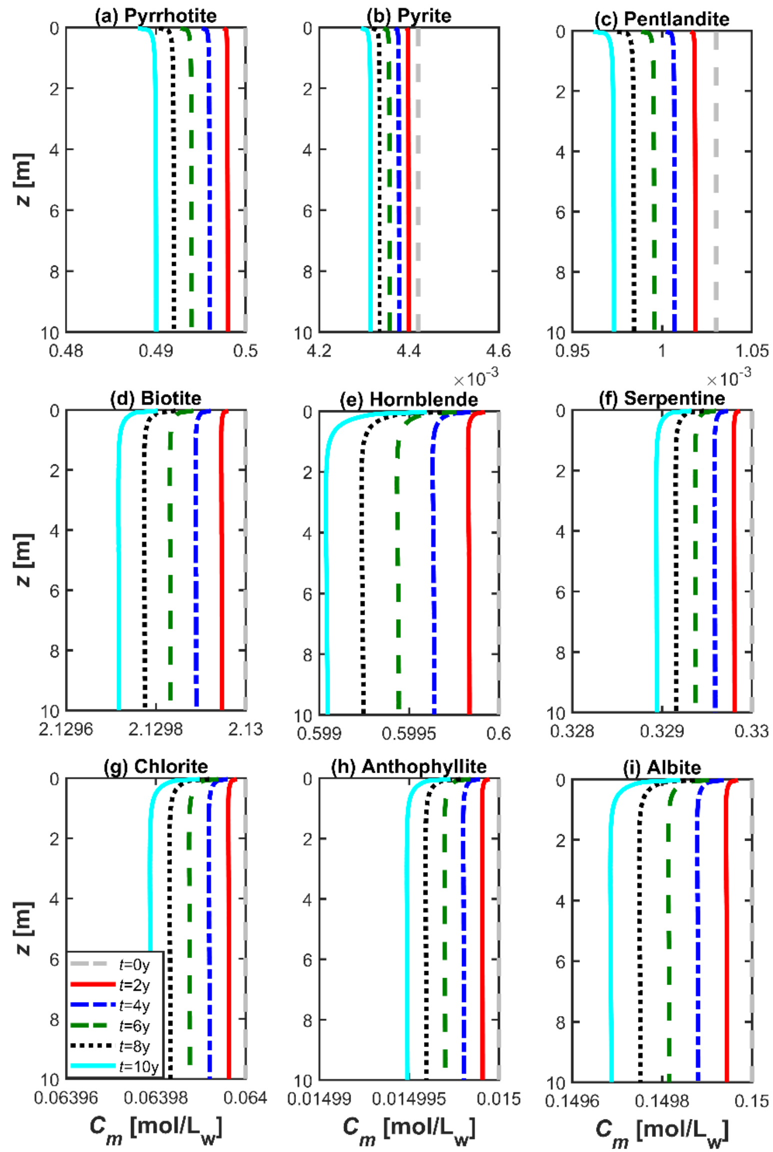
Transport of oxygen:



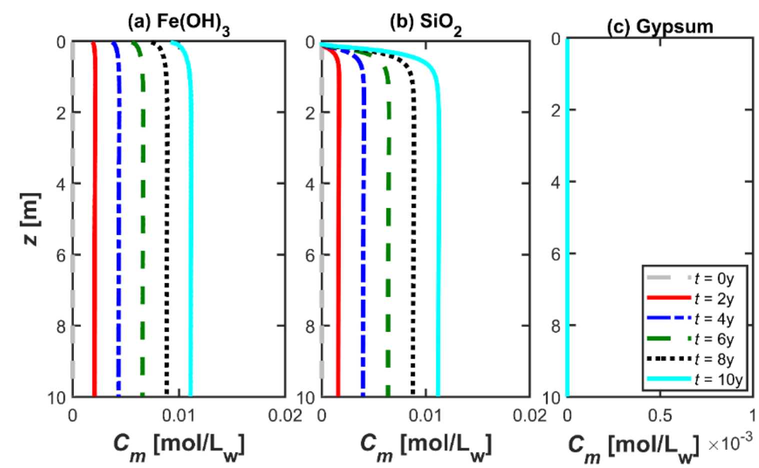
# Example 1: Särkiniemi Waste Rock Pile (cont'd)

Evolution of minerals:

**Primary minerals**




**Secondary minerals**

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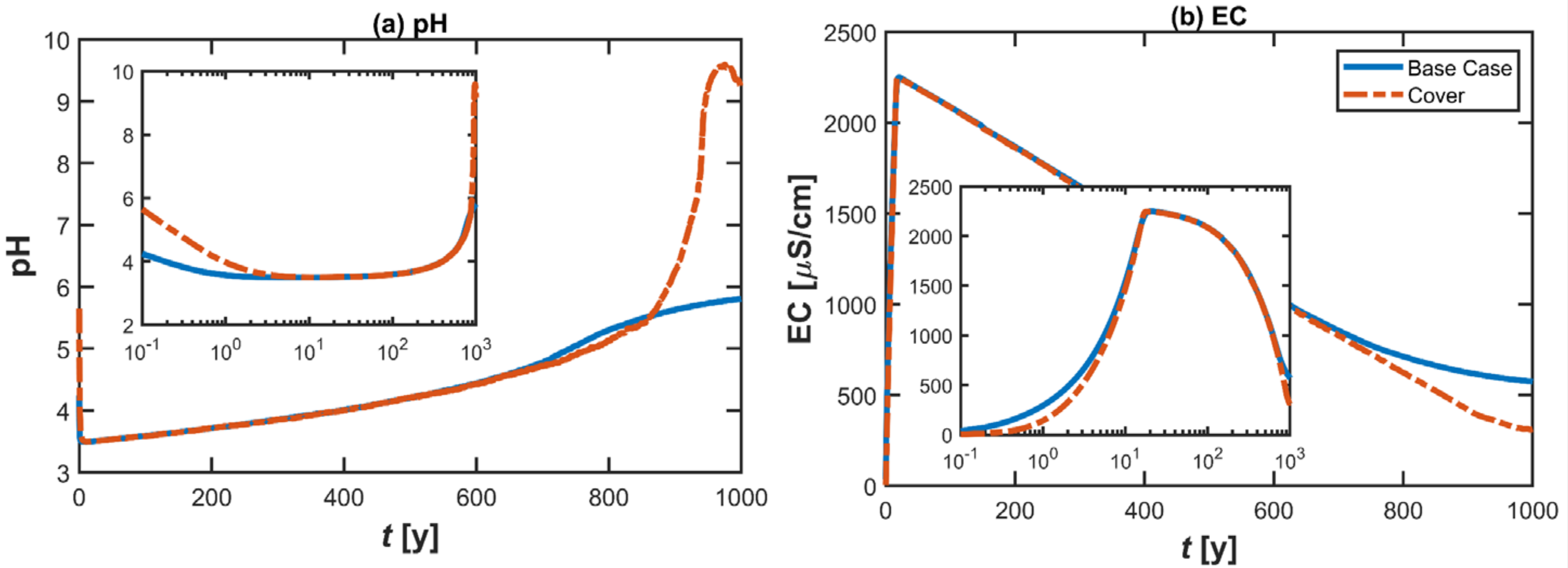
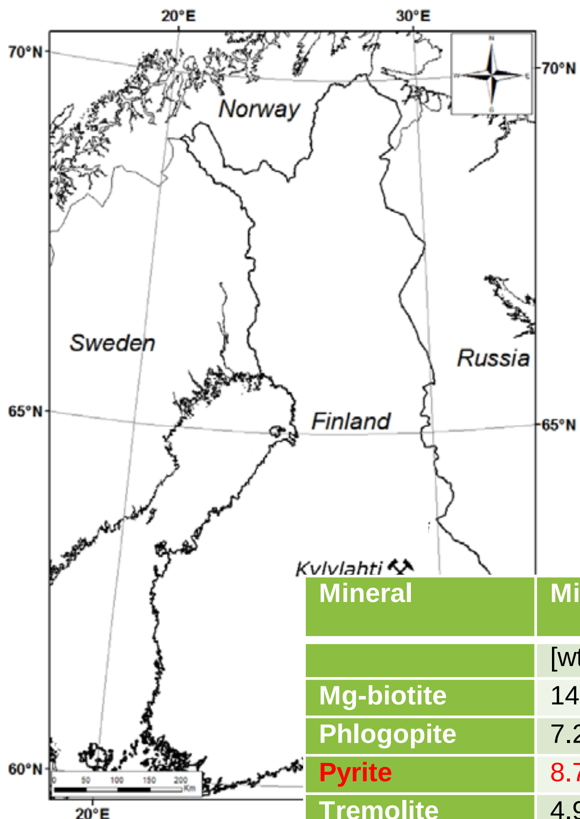
# Example 1: Särkiniemi Waste Rock Pile (cont'd)

Long-term predictions and cover scenario:




# Example 2: Kylylahti Waste Rock Pile



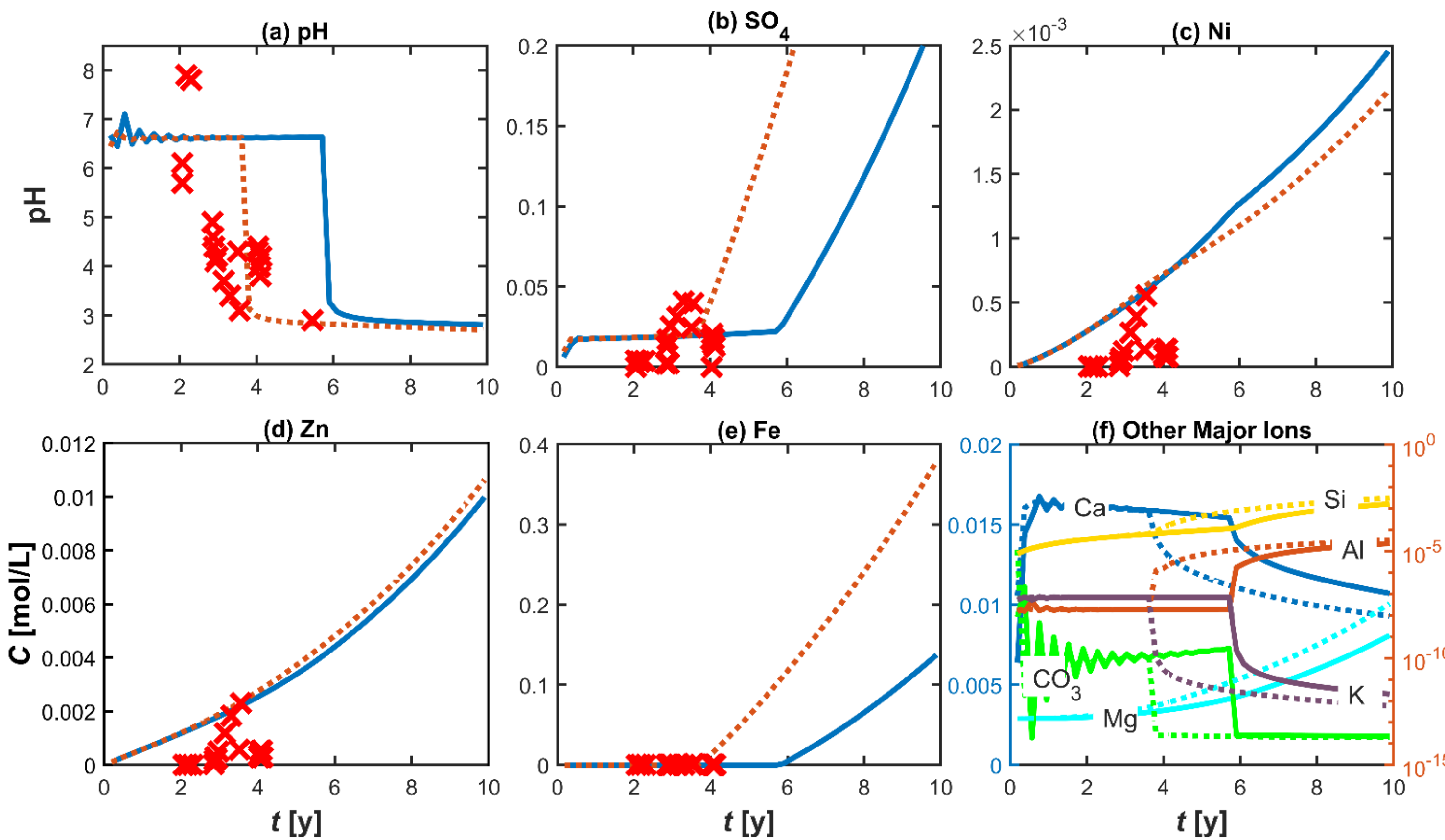


| Mineral | Mineral Content | | Surface Area, A | Rate Coefficient, k | Reference |
|---|---|---|---|---|---|
| | [wt%] | [mol $L_w^{-1}$][b] | [$m^2 L_w^{-1}$] | [mol $m^{-2}s^{-1}$] | |
| Mg-biotite | 14.49 | 0.92 | 0.05 | $10^{-10.97}$ | Nagy (1995) |
| Phlogopite | 7.25 | 0.46 | 0.05 | $10^{-10.97}$ | Nagy (1995) |
| Pyrite | 8.79 | 1.94 | 1.43[c] | $10^{-10.19}$ | Williamson & Rimdstidt |
| Tremolite | 4.92 | 0.16 | 0.05 | $10^{-8.40}$ ($k_1$)<br>$10^{-11.98}$ ($k_2$) | Palandri & Kharaka (2004) |
| Albite | 3.83 | 0.39 | 0.06 | $10^{-10.16}$ | Palandri & Kharaka (2004) |
| Calcite | 1.89 | 0.50 | 5[d] | $10^{-1.29}$ ($k_1$)<br>$10^{-4.46}$ ($k_2$)<br>$10^{-6.92}$ ($k_3$) | Plummer et al. (1978) |
| Pyrrhotite | 0.61 | 0.20 | 1.43[c] | $10^{-10.19}$ | Williamson & Rimstidt (1994) |
| Sphalerite | 0.08 | $2.17\times10^{-2}$ | 1.43[c] | $10^{-9.22}$ | Domenech et al. (2002) |
| Pentlandite | 0.05 | $1.72\times10^{-3}$ | 1.43[c] | $10^{-10.19}$ | Williamson & Rimdstidt (1994) |
| Dolomite | 0.02 | $2.87\times10^{-3}$ | 5[d] | $10^{-3.19}$ ($k_1$)<br>$10^{-5.11}$ ($k_2$)<br>$10^{-7.53}$ ($k_3$) | Plummer et al. (1978) |

# Example 2: Kylylahti Waste Rock Pile (cont'd)

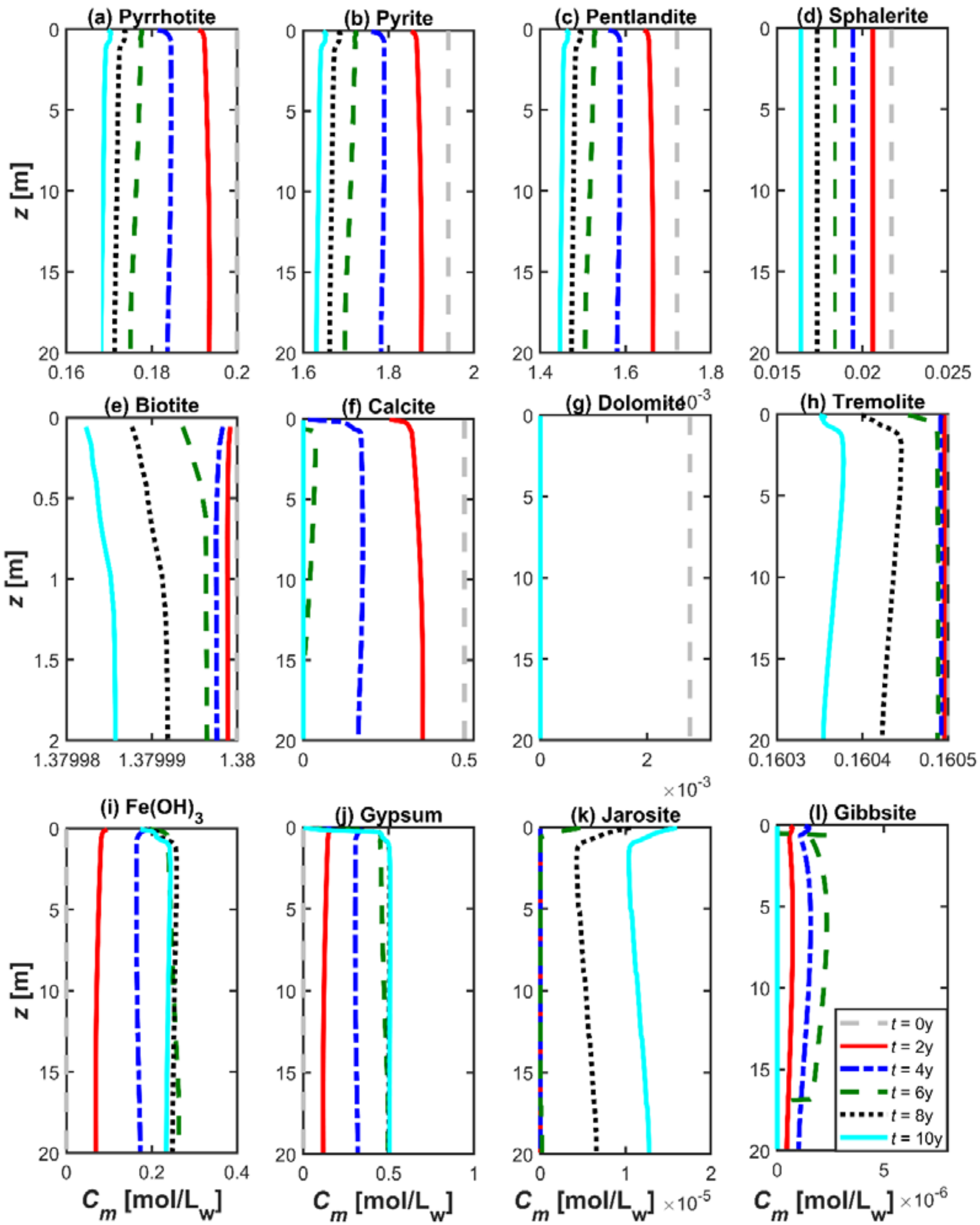
Evolution of Drainage Chemistry:

**Blue Lines** – lower oxidation rate
**Orange Lines** – higher oxidation rate

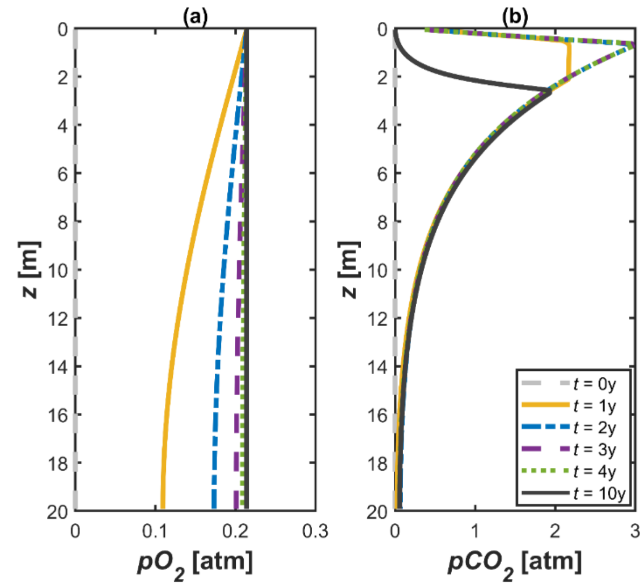


# Example 2: Kylylahti Waste Rock Pile (cont'd)

Evolution of minerals




## Gas transport

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# Example 2: Kylylahti Waste Rock Pile (cont'd)

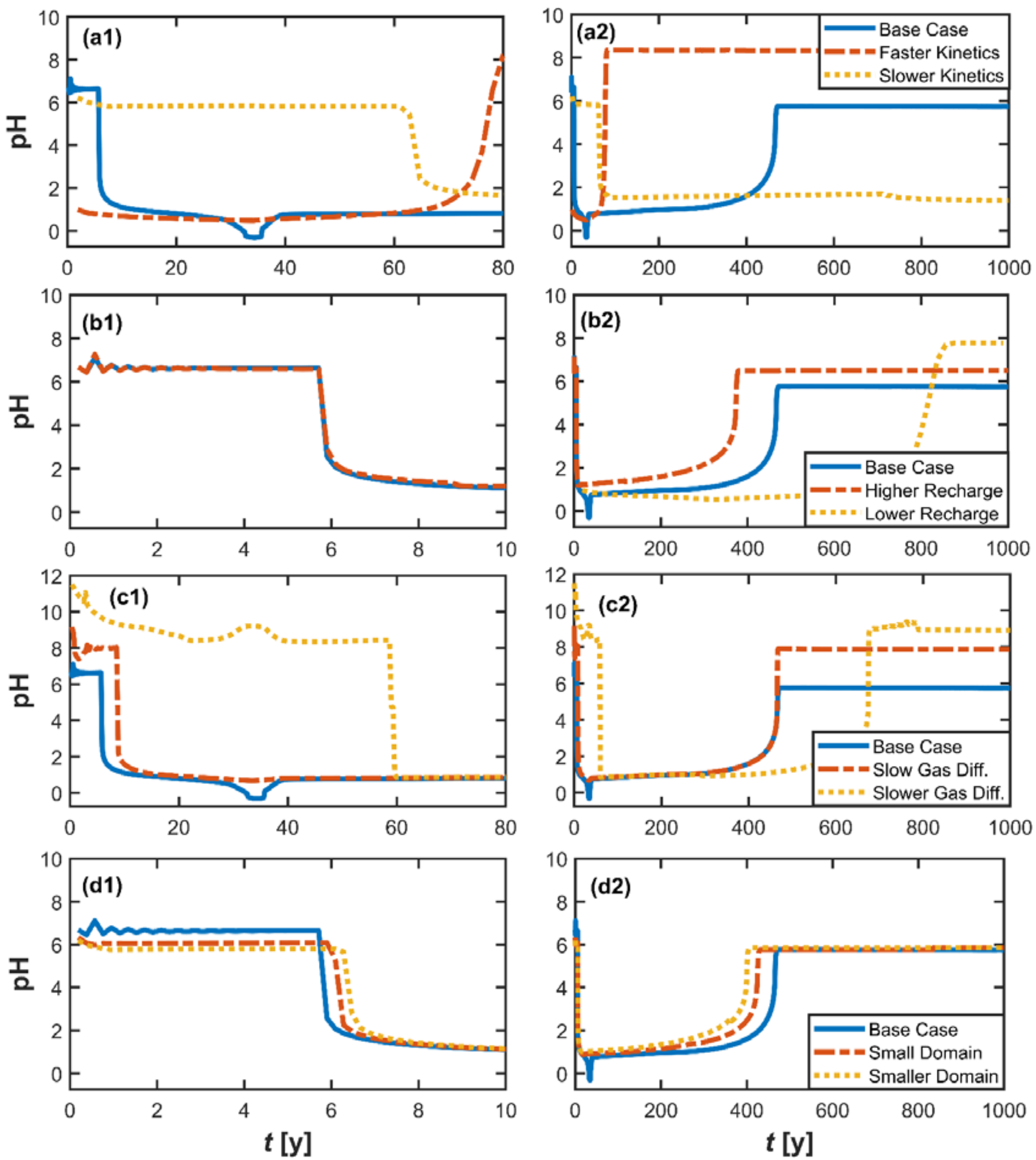
**Sensitivity Analysis:**

Reaction rate

Recharge rate

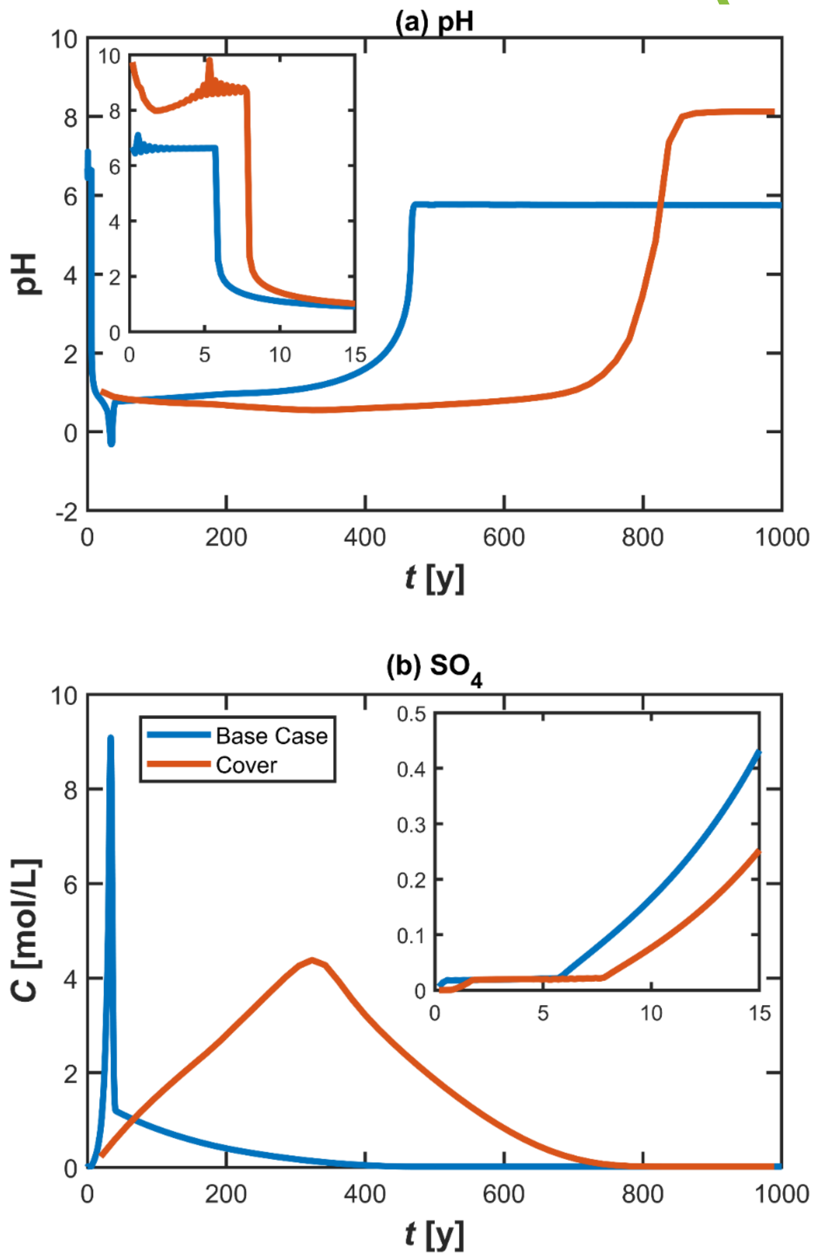
Gas diffusion

Domain size

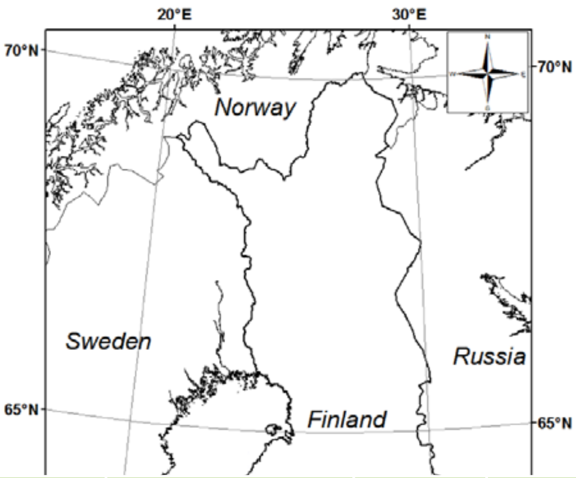


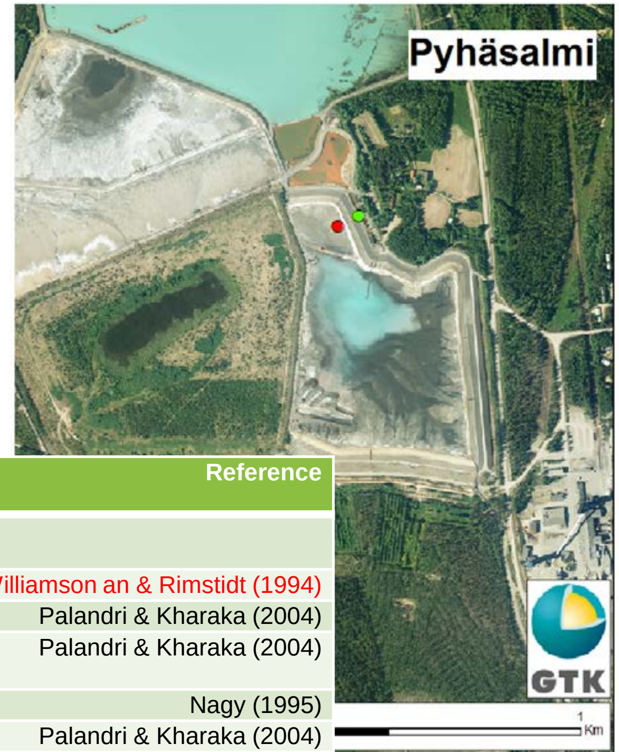
# Example 2: Kylylahti Waste Rock Pile (cont'd)

**Long-term simulation and cover scenario:**



# Example 3: Pyhäsalmi Tailings Facility



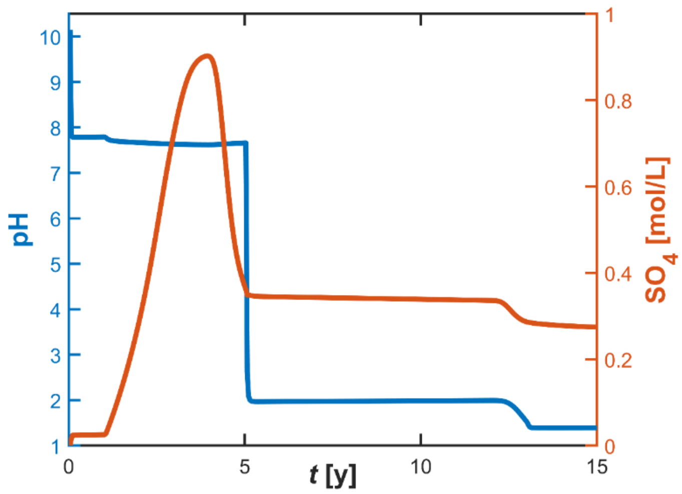

Drainage sample

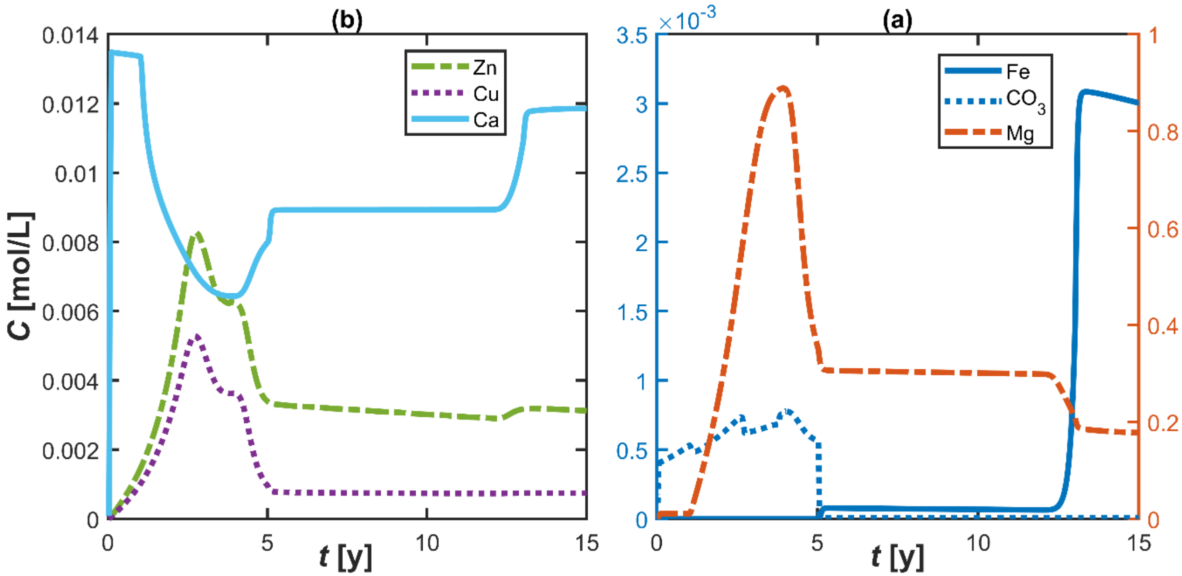
| Mineral | Mineral Content | | Surface Area, A | Rate Coefficient, k | Reference |
|---|---|---|---|---|---|
| | [wt%] | [mol $L_w^{-1}$][b] | [$m^2 L_w^{-1}$] | [mol $L_w^{-1}$ $s^{-1}$] | |
| Pyrite | 29.9 | 9.82 | 1.43[c] | $10^{-8.19}$ | Williamson an & Rimstidt (1994) |
| Hornblende | 9.2 | 1.42 | 0.50 | $10^{-8.11}$ | Palandri & Kharaka (2004) |
| Tremolite | 5.0 | 0.24 | 0.50 | $10^{-8.4}$ ($k_1$)<br>$10^{-11.98}$ ($k_2$) | Palandri & Kharaka (2004) |
| Biotite | 3.0 | 0.29 | 0.30 | $10^{-10.97}$ | Nagy (1995) |
| Albite | 1.9 | 0.29 | 0.50 | $10^{-10.16}$ | Palandri & Kharaka (2004) |
| Serpentine | 1.8 | 0.25 | 0.05 | $10^{-7.08}$ | Declercq & Oelkers (2014) |
| K-feldspar | 1.7 | 0.25 | 0.50 | $10^{-10.06}$ | Palandri & Kharaka (2004) |
| Dolomite | 1.7 | 0.36 | 5[d] | $10^{-3.19}$ ($k_1$)<br>$10^{-5.11}$ ($k_2$)<br>$10^{-7.53}$ ($k_3$) | Plummer et al. (1978) |
| Chlorite | 1.4 | 0.10 | 0.50 | $10^{-11.11}$ | Palandri & Kharaka (2004) |
| Calcite | 1.1 | 0.42 | 5[c] | $10^{-1.29}$ ($k_1$)<br>$10^{-4.46}$ ($k_2$)<br>$10^{-6.92}$ ($k_3$) | Plummer et al. (1978) |
| Anthophyllite | 0.9 | 0.05 | 0.50 | $10^{-11.94}$ | Palandri & Kharaka (2004) |
| Phlogopite | 0.8 | 0.07 | 0.30 | $10^{-10.97}$ | Nagy (1995) |
| Pyrrhotite | 1.0 | 0.50 | 1.43[c] | $10^{-8.19}$ | Williamson an & Rimstidt (1994) |
| Chalcopyrite | 0.2 | 0.04 | 1.43[c] | $10^{-8.19}$ | Williamson an & Rimstidt (1994) |
| Sphalerite | 0.1 | 0.05 | 1.43[c] | $10^{-9.22}$ | Domenech et al. (2002) |

# Example 3: Pyhäsalmi Tailings Facility (cont’d)

**Predicted Drainage Quality:**

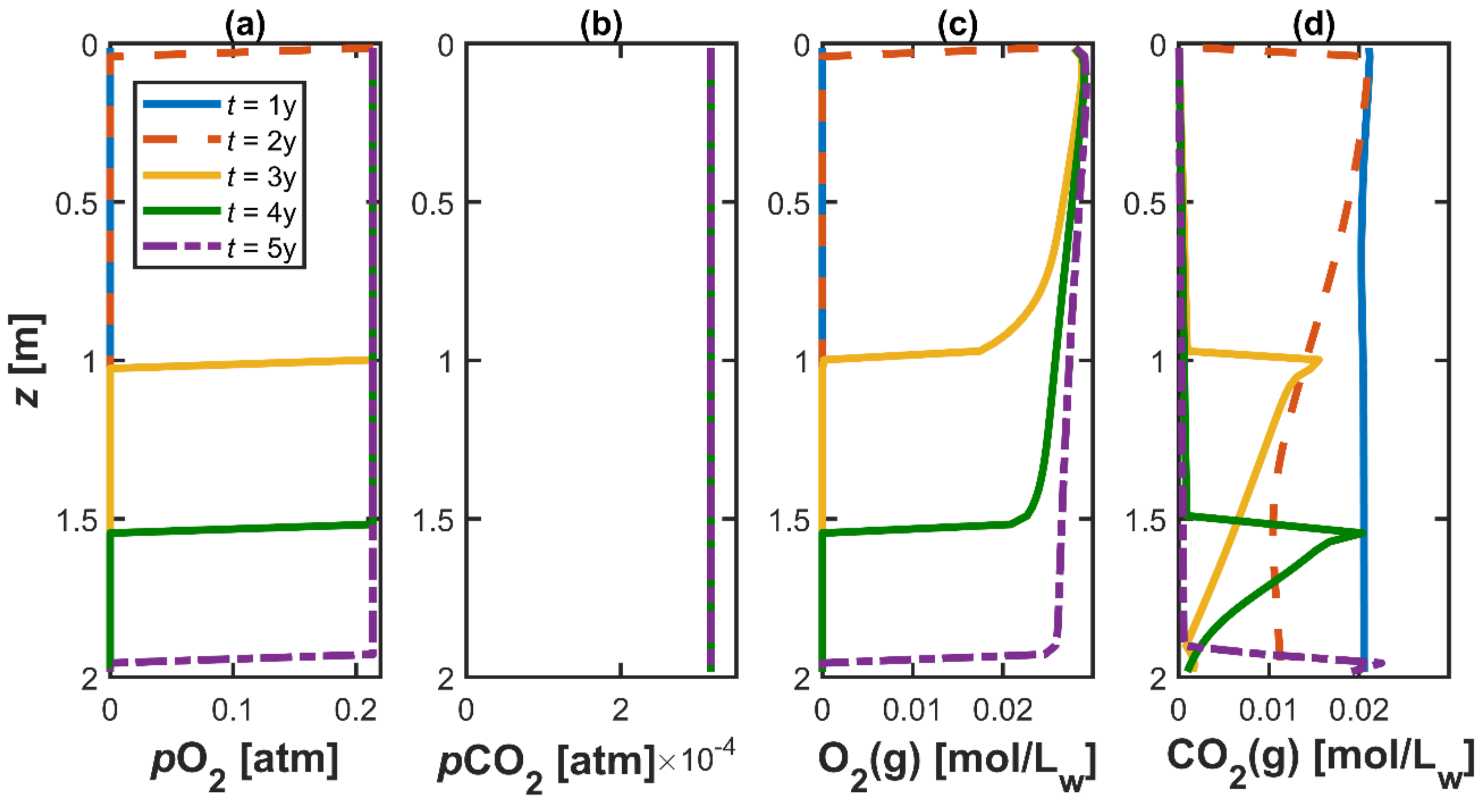
measured seepage water pH = 2.87
NAG pH = 2.14



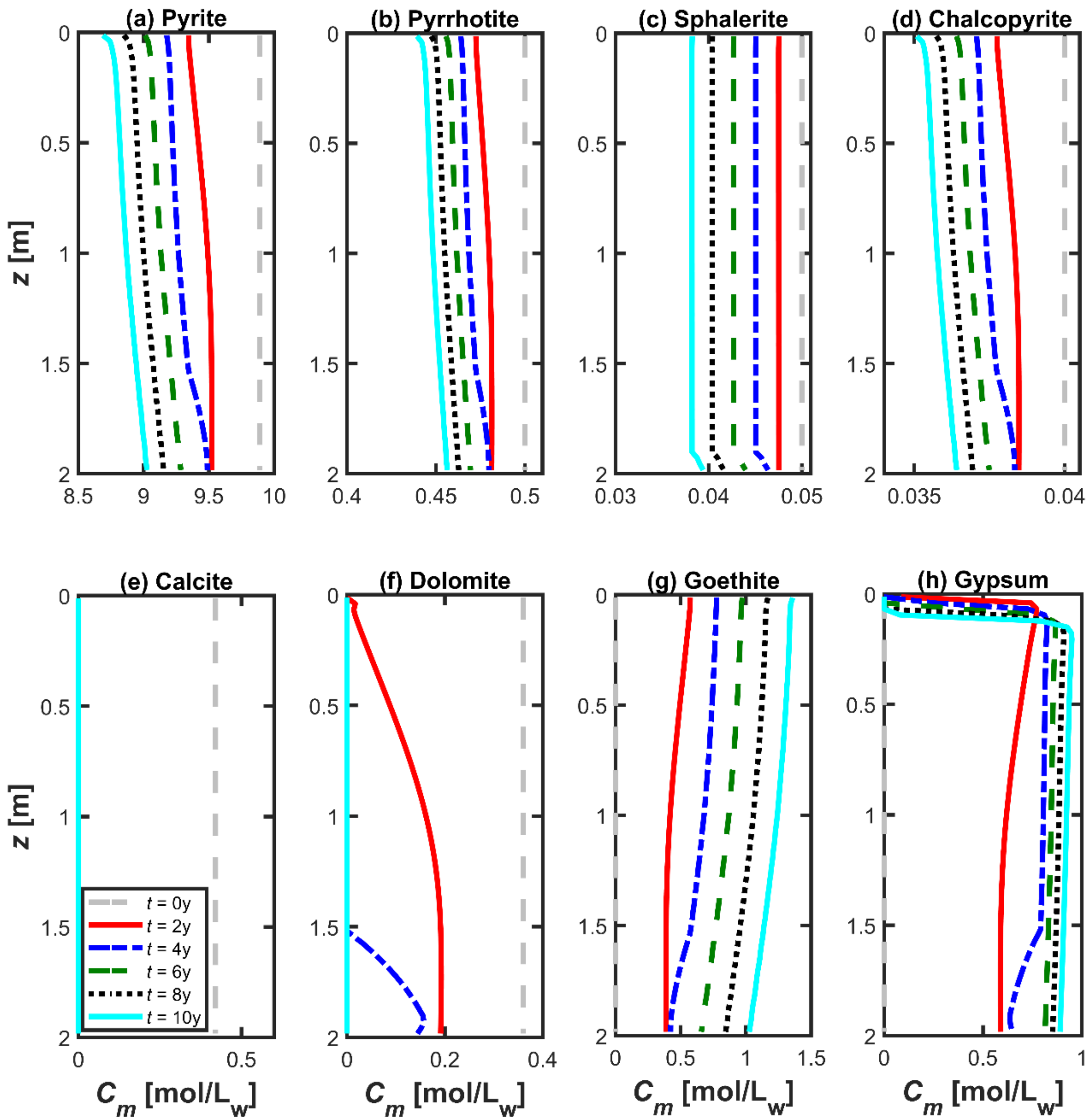
# Example 3: Pyhäsalmi Tailings Facility (cont'd)

**Transport of Gases:**



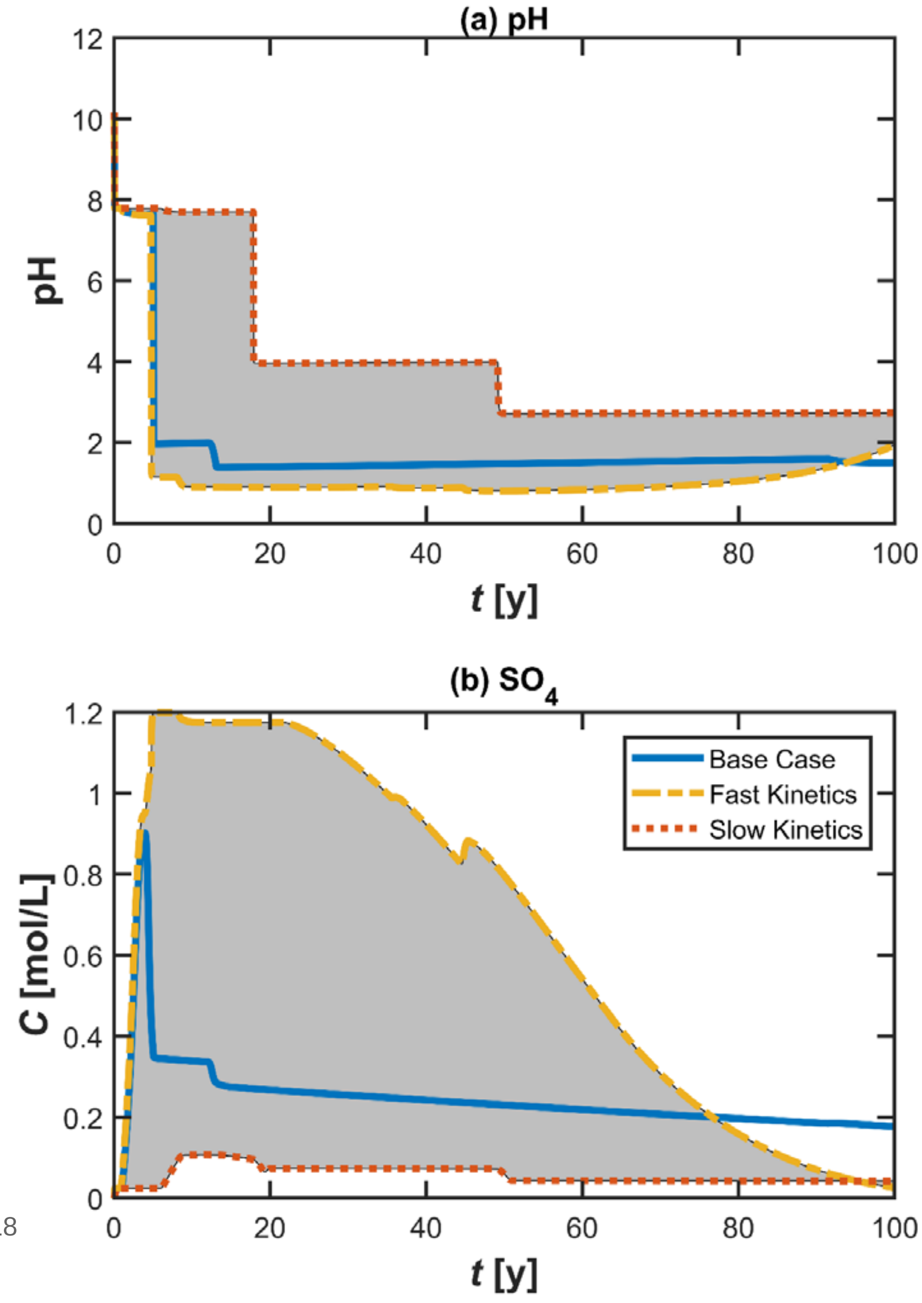
# Example 3: Pyhäsalmi Tailings Facility (cont'd)

Evolution of mineral phases:



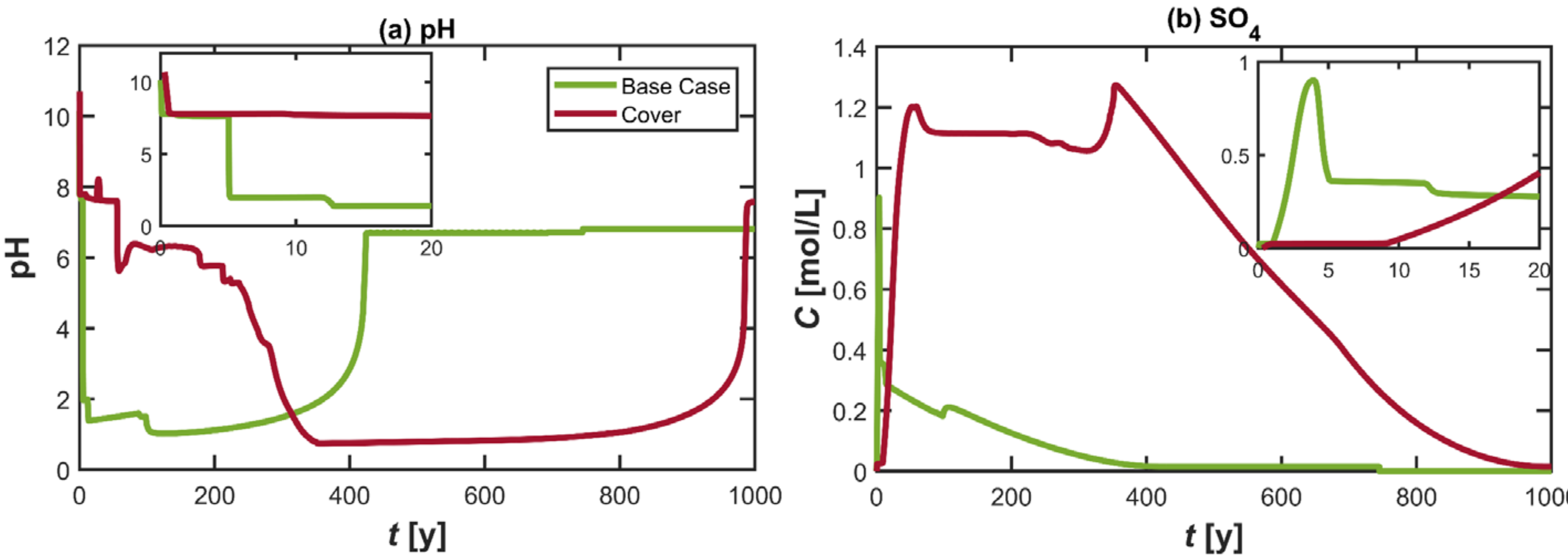
# Example 3: Pyhäsalmi Tailings Facility (cont'd)

Long-term prediction of drainage water quality:



# Example 3: Pyhäsalmi Tailings Facility (cont’d)

Cover scenario:



# Major Sources of Uncertainties

- Heterogeneity: a problem cannot be solved with more computational resources!
  - → Existing analogues can be used
  - → Stochastic concepts can be applied to estimate the likelihood
- Reaction parameters and microbial mechanisms
  - → Mineral reaction parameters should be obtained from the static and kinetic test results
- Seasonal fluctuations
- Water saturation and moisture profiles
- Retardation and sorption like processes
- Dimensionality → 1D, 2D or 3D dominated system!
- Coupling of gas and heat transport



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# Conclusions

- The proposed model seem to be capable of predicting the future key events
  - → Simulation outcomes correspond to the static test results and the measured drainage quality
- Predictive modelling can be performed in an early stage of a mine with limited data
  - → Prediction accuracy is only as good as the conceptual understanding about involved processes
  - → Objective of such modelling would be achieve the right order of magnitude instead of obtaining the exact values
- Effects of uncertainty and the model limitations should be properly acknowledged
  - → especially when such prediction results are used in decision making processes
- Predictive models should be continuously updated with the increasingly collected data during the operational phases

# Thank you for your attention!

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