Modelling of a Coal Waste Rock Pile Soil Cover and Interpreted Performance

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The Sydney Coalfield
The Sydney Coalfield

- **LEGACY**: waste rock piles (WRPs) – surplus coal and waste rock
The Sydney Coalfield

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- **PROBLEM:** acid mine drainage and metal leaching
The Sydney Coalfield

- **LEGACY**: waste rock piles (WRPs) – surplus coal and waste rock
- **PROBLEM**: acid mine drainage and metal leaching
- **SOLUTION?**: cover system to isolate waste rock from atmosphere

Source: O’Kane and Ayres (2012)
The Sydney Coalfield

Former Lingan Colliery

Background

Lingan WRP

Geochemistry

Flow Model

Conclusions
Lingan Waste Rock Pile
Lingan Waste Rock Pile

Background

Lingan WRP

Geochemistry

Flow Model

Conclusions
Lingan Waste Rock Pile – Description

• 15 m high pile of waste rock
• 380,000 m³ of fill/waste rock
• Surface area = 82,028 m²

Source: Stantec Consultants
Lingan Waste Rock Pile – Description

- 15 m high pile of waste rock
- 380,000 m³ of fill/waste rock
- Surface area = 82,028 m²
- Overlain with 0.5 m of till (moisture store-and-release cover system)
Acid mine water leaves through base of WRP to **groundwater** flowing in N-W direction to ocean.
• Acid mine water leaves through base of WRP to groundwater flowing in N-W direction to ocean
• Acid water through toe of WRP to surface water (Graces Brook) flowing west of WRP to ocean
Lingan Waste Rock Pile – Data Collection

Soil Monitoring Stations

SS-4 SS-1
SS-2
SS-3
Lingan Waste Rock Pile – Data Collection

 Soil Monitoring Stations

Water Content (9 depths)
Lingan Waste Rock Pile – Data Collection

Soil Monitoring Stations

Temperature & Matric Suction (8 depths)
Lingan Waste Rock Pile – Data Collection

Soil Monitoring Stations

Background  Lingan WRP  Geochemistry  Flow Model  Conclusions

Pore-Gas
(3 depths)
Lingan Waste Rock Pile – Data Collection

CMT Wells

Source: Solinst Canada Ltd
Lingan Waste Rock Pile – Data Collection

CMT Wells

Temperature (6 depths)

Source: Solinst Canada Ltd
Lingan Waste Rock Pile – Data Collection

**CMT Wells**

- Differential Pressure (2 depths)
- Pore-Gas (4 depths)

Source: Solinst Canada Ltd
Lingan Waste Rock Pile – Data Collection

CMT Wells

Source: Solinst Canada Ltd
Lingan Waste Rock Pile – Remote Control

- Site has capability for complete data monitoring via remote control.
Lingan Waste Rock Pile – Remote Control

- Weather Station acts as master
Lingan Waste Rock Pile – Remote Control

- Weather Station acts as master
Lingan Waste Rock Pile – Remote Control

- Weather Station acts as master

20 W Solar Panel

12V Battery
Lingan Waste Rock Pile – Remote Control

- Weather Station acts as master

- 20 W Solar Panel
- Datalogger
- 12V Battery

Images: Remote control equipment setup with solar panel, battery, and Datalogger.
Lingan Waste Rock Pile – Remote Control

- Weather Station acts as master

![Remote Control Setup]

- 20 W Solar Panel
- Datalogger
- Cell Phone Modem
- 12V Battery

Background
Lingan WRP
Geochemistry
Flow Model
Conclusions
Lingan Waste Rock Pile – Remote Control

- Weather Station acts as master
Lingan Waste Rock Pile – Remote Control

- Soil Stations act as slaves
Lingan Waste Rock Pile – Remote Control

- Soil Stations act as slaves
Lingan Waste Rock Pile – Remote Control

- Soil Stations act as slaves
Objective

- Develop a geochemical conceptual model and flow model of the Lingan WRP to understand and predict the loading and impacts to the environment
Geochemical Conceptual Model

- Waste Rock Pile

Surface Area = 82,028 m²
Volume = 380,000 m³
Geochemical Conceptual Model

- Basic moisture store-and-release cover system

![Diagram of 0.5 m thick imported till](image-url)
Geochemical Conceptual Model

- Environmental receptors: groundwater
Geochemical Conceptual Model

- Environmental receptors: groundwater and surface water
Geochemical Conceptual Model

- Atmospheric Ingress: Water and Oxygen
Geochemical Conceptual Model

- Acidity and contaminants of concern (COCs)

- Water
- Oxygen
- Stored Acidity
- Potential Acidity
- Metals
- Surface Water
- Groundwater
Geochemical Conceptual Model

• Loading to the environment/receptors

- Water
- Oxygen
- Stored Acidity
- Potential Acidity
- Metals
- Surface Water
- Groundwater
- Basal Seepage

Background | Lingan WRP | Geochemistry | Flow Model | Conclusions
Geochemical Conceptual Model

- Loading to the environment/receptors

Water

Oxygen

Stored Acidity

Potential Acidity

Metals

Surface Water

Groundwater

Toe Seepage

Basal Seepage
Geochemical Conceptual Model

- Atmospheric Ingress: Water and Oxygen

```
Surface Water
```

```
Groundwater
```

```
Water
```
```
Oxygen
```
Atmospheric Ingress: Water

- Water balance to estimate net percolation

Atmosphere

Cover

Waste Rock

Net Percolation To Waste Rock

Reproduced from Meiers et al. (2012)
Atmospheric Ingress: Water

- Water balance to estimate net percolation

Reproduced from Meiers et al. (2012)
Atmospheric Ingress: Water

- Water balance to estimate net percolation

Net Percolation into Waste Rock:
\[ NP = \text{PPT} - R + \text{AET} + \Delta S + \text{LP} \]

Reproduced from Meiers et al. (2012)
Atmospheric Ingress: Water

- Water balance to estimate net percolation

Net Percolation into Waste Rock:

\[ NP = PPT - R + AET + \Delta S + LP \]

354 mm/yr (0.92 L/sec)

Reproduced from Meiers et al. (2012)
Atmospheric Ingress: Oxygen

- Diffusion
Atmospheric Ingress: Oxygen

- Diffusion

Diffusion: 655,164 mol/yr

Atmosphere

Cover

Waste Rock

Oxygen Flux

High O2

Depleted O2
Atmospheric Ingress: Oxygen

- Advection

Atmosphere

Oxygen

Diffusion: 655,164 mol/yr
Advection: 0 mol/yr

Cover

Waste Rock

Oxygen Flux
Atmospheric Ingress: Oxygen

- Dissolved

**Atmosphere**

Oxygen

- Diffusion: 655,164 mol/yr
- Advection: 0 mol/yr
- Dissolved: 21,834 mol/yr

**Cover**

**Waste Rock**

Infiltrating Water

Oxygen Flux
Atmospheric Ingress: Oxygen

- **Total**

  - **Atmosphere**
    - Oxygen
      - Diffusion: 655,164 mol/yr
      - Advection: 0 mol/yr
      - Dissolved: 21,834 mol/yr
      - Total: 676,998 mol/yr

  - **Cover**
  - **Waste Rock**

  **Oxygen Flux**
Geochemical Conceptual Model

- Atmospheric Ingress: Water and Oxygen

- Water: 0.92 L/sec
- Oxygen: 676,998 mol/yr
Geochemical Conceptual Model

- Acidity and Contaminants of Concern (COCs)

- Water: 0.92 L/sec
- Oxygen: 676,998 mol/yr
- Stored Acidity
- Potential Acidity
- Metals

Surface Water

Groundwater

Background  Lingan WRP  Geochemistry  Flow Model  Conclusions
Acidity and Contaminants

- Acid Base Accounting (ABA) testing
- Determines ‘acid-neutral’ and ‘acid-generation’ potential
Acidity and Contaminants

- Acid Base Accounting (ABA) testing
- Determines ‘acid-neutral’ and ‘acid-generation’ potential
- 11.50 kg CaCO3 / tonne of sulfide-sulfur

7,432 tonnes of potential acidity
Acidity and Contaminants

- Acid Base Accounting (ABA) testing
- Determines ‘acid-neutral’ and ‘acid-generation’ potential
- 10.71 kg CaCO3 / tonne of sulfate-sulfur

6,922 tonnes of stored acidity
Geochemical Conceptual Model

• Acidity and Contaminants of Concern (COCs)

- Water: 0.92 L/sec
- Oxygen: 676,998 mol/yr
- Stored Acidity: 6,922 tonnes
- Potential Acidity: 7,432 tonnes
Geochemical Conceptual Model

- **Loading to the Receiving Environment**

  **Water**
  - 0.92 L/sec

  **Oxygen**
  - 676,998 mol/yr

  **Stored Acidity**
  - 6,922 tonnes

  **Potential Acidity**
  - 7,432 tonnes

- **Surface Water**
  - **Toe Seepage**
  - **Basal Seepage**

- **Geochemistry**
Loading to the Environment – Surface Water

Net Percolation
354 mm/yr

0.92 L/s

Toe Seepage

Basal Seepage

Background Lingan WRP Geochemistry Flow Model Conclusions
Loading to the Environment – Surface Water

Toe Seepage Loading:

\[ C_{TOE} \times Q_{TOE} \]
Loading to the Environment – Surface Water

Toe Seepage Loading:

\[ C_{TOE} \times Q_{TOE} \]

100.2 mg/L \times 0.17 L/s = \textbf{0.54 tonne/yr}
Loading to the Environment – Surface Water

Toe Seepage Loading:
\[ C_{TOE} \times Q_{TOE} \]

100.2 mg/L \times 0.17 L/s = 0.54 tonne/yr

Graces Brook Loading:
\[ C_{DOWN} \times Q_{DOWN} - C_{UP} \times Q_{UP} \]
Loading to the Environment – Surface Water

Toe Seepage Loading:

\[ C_{TOE} \times Q_{TOE} \]

100.2 mg/L \times 0.17 L/s = 0.54 tonne/yr

Graces Brook Loading:

\[ C_{DOWN} \times Q_{DOWN} - C_{UP} \times Q_{UP} \]

3.60 t/yr - 2.33 t/yr = 1.27 tonne/yr
Loading to the Environment – Ground Water

- Basal Seepage = Net Percolation – Toe Seepage
Loading to the Environment – Ground Water

- Basal Seepage = Net Percolation – Toe Seepage
  
  \[ \text{Net Percolation} = 354 \text{ mm/yr} \]

  \[ \text{Toe Seepage} = 0.92 \text{ L/s} \]

\[ \text{Basal Seepage} = \text{Net Percolation} - \text{Toe Seepage} = 0.92 \text{ L/s} \]
Baseline Seepage = Net Percolation – Toe Seepage

= 0.92 L/s – 0.17 L/s
Loading to the Environment – Ground Water

- Basal Seepage = Net Percolation – Toe Seepage
  
  = 0.92 L/s – 0.17 L/s

Basal Seepage: 0.75 L/s
Basal Seepage Loading:

\[ C_{BASAL} \times Q_{BASAL} \]
Basal Seepage Loading:

\[ C_{BASAL} \times Q_{BASAL} \]

98.24 mg/L x 0.75 L/s = 2.33 tonne/yr
Basal Seepage Loading:
\[ C_{BASAL} \times Q_{BASAL} \]

\[ 98.24 \text{ mg/L} \times 0.75 \text{ L/s} = 2.33 \text{ tonne/yr} \]
Loading to the Environment – Ground Water

**Basal Seepage Loading:**

\[ C_{BASAL} \times Q_{BASAL} \]

98.24 mg/L \( \times \) 0.75 L/s = **2.33 tonne/yr**

**Downgradient Loading:**

\[ C_{DOWN} \times Q_{DOWN} \]

255.2 mg/L \( \times \) 0.14 L/s = **1.7 tonne/yr**
Geochemical Conceptual Model

- Depletion of waste rock acidity

Water: 0.92 L/sec
Oxygen: 676,998 mol/yr

Stored Acidity: 6,922 tonnes
Potential Acidity: 7,432 tonnes

Basal Seepage: 2.32 t/yr
Toe Seepage: 0.54 t/yr

Surface Water

Background | Lingan WRP | Geochemistry | Flow Model | Conclusions
Model conceptualisation

- Vertical variably saturated 2D aquifer – FEFLOW 6.0
- Triangular prisms
- 17,085 elements and 8,868 nodes

<table>
<thead>
<tr>
<th>Layer</th>
<th>Material</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>Till growth medium</td>
<td>0.5m</td>
</tr>
<tr>
<td>Layer 2</td>
<td>Waste rock</td>
<td>0.5m</td>
</tr>
<tr>
<td>Layer 3</td>
<td>Waste rock</td>
<td>0.3m</td>
</tr>
<tr>
<td>Layer 4</td>
<td>Waste rock</td>
<td>0.5m</td>
</tr>
<tr>
<td>Layer 5</td>
<td>Waste rock</td>
<td>12m</td>
</tr>
<tr>
<td>Layer 6</td>
<td>Till</td>
<td>0.5 to 5m</td>
</tr>
<tr>
<td>Layer 7</td>
<td>Bedrock</td>
<td>Upto 0 masl</td>
</tr>
</tbody>
</table>
Boundary Conditions

River head boundary

Seepage face

Recharge Boundary
**Input parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
<th>Layer 4</th>
<th>Layer 5</th>
<th>Layer 6</th>
<th>Layer 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity (max)</td>
<td>cm/s</td>
<td>1.51E-03</td>
<td>5.00E-04</td>
<td>2.50E-04</td>
<td>1.15E-04</td>
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<tr>
<td>Porosity</td>
<td></td>
<td>0.28</td>
<td>0.27</td>
<td>0.29</td>
<td>0.29</td>
<td>0.3</td>
<td>0.25</td>
<td>0.11</td>
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<tr>
<td>Van Genuchten (Empirical model type)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ss Maximum Saturation</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sr Residual Saturation</td>
<td></td>
<td>0.025</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>α (Fitting coefficient)</td>
<td>l/m</td>
<td>0.12</td>
<td>0.12</td>
<td>0.25</td>
<td>0.08</td>
<td>0.08</td>
<td>0.0016</td>
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</tr>
<tr>
<td>n (Fitting parameter)</td>
<td></td>
<td>2.6</td>
<td>2.6</td>
<td>2.68</td>
<td>1.4</td>
<td>1.4</td>
<td>1.37</td>
<td>1.964</td>
</tr>
</tbody>
</table>

- Used homogenous values for each layer all parameters
- Porosity and K values for cover and waste rock material (OKC - 2011)
- K values for Till and Bedrock (Senes – 2009)
- Net percolation used OKC water balance

![Graph showing precipitation and model recharge](image)
- June 2012
- 4 CMT Wells
- Average water level – 2008 MWs
Model Calibration

- June’ 2012 to Dec’ 2014
- Moisture Content
  - SS2 and SS4
  - At depth 0.5m and 1.8m
  - Adjusting Van Genuchten fitting parameter
- Porosity
- Hydraulic head
  - CMT 2 and CMT 4
  - Hydraulic conductivity
Model Calibration

- Moisture Content

**SS2_Soildata (0.5m)**

- Field MC
- Model MC

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**Background**

**Lingan WRP**

**Geochemistry**

**Flow Model**

**Conclusions**
Model Calibration

- Moisture Content

SS2_Soildata (0.5m)

SS2_Soildata (1.8m)
Model Calibration

- Groundwater level

CMT - 2

Field Hydraulic head
Model Hydraulic head

Hydraulic head (m

Field Hydraulic head
Model Hydraulic head

Time (M)

Jun-12 Nov-12 Apr-13 Sep-13 Feb-14 Jul-14 Dec-14
Model Calibration

- Groundwater level
- Model - Final Calibration Results
  \((R^2 = 0.65)\)
Pressure head distribution in the WRP

Pressure head – Dec 2014

Pressure head – June 2012

Background  Lingan WRP  Geochemistry  Flow Model  Conclusions
Acidity Transport

- Acidity 98.24 mg/l
- WR/Till interface below CMT-4
Conclusions

- Conceptual and numerical models are valuable tools for investigating the environmental impacts of WRPs
- Moderate oxidation rate of potential acidity (~205 years) but slow release of stored acidity from WRP (~5000 years)
- Development of variably saturated flow model to simulate and predict the migration of acidity from the Lingan WRP
- Detailed geochemical reaction modelling coupled with variably saturated flow model is being developed
Thank you!!!

Questions?