MINE POLLUTION ATLAS OF SOUTH AFRICA: TOWARDS HOLISTIC MANAGEMENT OF MINE IMPACTS

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Impacts of AMD

• Acidification
  – Disturbs ecosystems
  – Mobilises other components of ores, wastes and country rock, including heavy metals
  – Renders water unfit for use

• Precipitation of yellow boy
  – Kills aquatic plants, fish and microorganisms
  – Armours reactive surfaces which could neutralise AMD
1. Pyrite oxidises to form an acidic solution of iron II and sulphate

$$4\text{FeS}_2(s) + 14\text{O}_2(g) + 4\text{H}_2\text{O} \rightarrow 4\text{Fe}^{2+}(aq) + 8\text{SO}_4^{2-}(aq) + 8\text{H}^+(aq)$$

2. Iron II oxidises to iron III

$$4\text{Fe}^{2+}(aq) + \text{O}_2(g) + 4\text{H}^+(aq) \rightarrow 4\text{Fe}^{3+}(aq) + 2\text{H}_2\text{O} \,(l)$$

3. Iron III precipitates as ferric hydroxide, producing further acid

$$4\text{Fe}^{3+}(aq) + 12\text{H}_2\text{O}(l) \rightarrow 4\text{Fe(OH)}_3(s) + 12\text{H}^+(aq)$$

Net effect

$$4\text{FeS}_2(s) + 15\text{O}_2(g) + 14\text{H}_2\text{O}(l) \rightarrow 4\text{Fe(OH)}_3(s) + 8\text{SO}_4^{2-}(aq) + 16\text{H}^+(aq)$$
AMD simplified
pH and Acidity

- pH is a measure of the free hydrogen ion concentration in a solution.
- pH and acidity are not the same thing.
- Acidity is related to the dissolved metal concentrations i.e. the ability of a solution to decrease its pH.

<table>
<thead>
<tr>
<th>pH</th>
<th>Substance</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Bleach</td>
</tr>
<tr>
<td>13</td>
<td>Ammonia</td>
</tr>
<tr>
<td>12</td>
<td>Baking Soda</td>
</tr>
<tr>
<td>11</td>
<td>Pure distilled water</td>
</tr>
<tr>
<td>10</td>
<td>Orange juice</td>
</tr>
<tr>
<td>9</td>
<td>Vinegar</td>
</tr>
<tr>
<td>8</td>
<td>Lemon juice</td>
</tr>
<tr>
<td>7</td>
<td>Battery acid</td>
</tr>
<tr>
<td>6</td>
<td>Drinking water</td>
</tr>
<tr>
<td>5</td>
<td>Irrigation</td>
</tr>
<tr>
<td>4</td>
<td>Aquatic ecosystems</td>
</tr>
<tr>
<td>3</td>
<td>DWAF Guidelines</td>
</tr>
<tr>
<td>2</td>
<td>AMD</td>
</tr>
</tbody>
</table>

Basic to Acidic.
The AMD problem

- Acid Mine Drainage (AMD) is one of the most serious and potentially enduring environmental problems for the mining industry.

- Left unchecked, it can result in such long-term water quality impacts that it could well be the mining industry’s most harmful legacy.
Time perspectives

- AMD can be a long-term problem
- Large mines and interconnected networks of mines can continue to produce acid drainage for periods of tens to hundreds and even thousands of years
- The time horizons are longer than lives of most mines, presenting serious closure and post-closure challenges
Yellow boy – Iron hydroxide precipitates In the Rio Tinto – Spain (impacted by 5,000 years of mining)
AMD Management

Mine features as potential AMD sources

- Opencast pit (open/backfilled pit; unflooded; partially flooded; flooded; operational; defunct)
- Underground mine (unflooded, partially flooded, flooded; operational, defunct)
- Mine residue deposits (Coarse / spoils heap; fine)
- Foot prints

Main Receiving environment

Surface water
- Ground water

The problem

Prevention

AMD

Remediation Mitigation Treatment

Solutions / Management plans (includes financial liabilities)

- Establish management and control over the AMD problems.
- Prevent problems before they occur
- Prevent problems from becoming worse than the status-quo during mining
- Allow for improvement in the future
**UG/open pit /MRDs (Tailings/waste rock dumps)**

**UNDERGROUND SCENARIO**

**LEGEND**
- Hydraulic Connection
- Connate Water
- Meteoroic Water
- High geochem. Reactivity stopes
- Med. geochem. Reactivity stopes
- Low geochem. Reactivity stopes

**Preferential flow paths**
- Large particle
- Small particle

**Water moves along preferential flow paths, thereby contacting some particles and not others.**

**Sulphide minerals and neutralising minerals occur in different size fractions.**

**Water table**

**Possible coal dust/residue**

**Openpit**

**Rainfall onto top & sides**

**Runoff from top & sides**

**Water table**

**Large particle**

**Small particle**

**Water moves along preferential flow paths, thereby contacting some particles and not others.**

**Sulphide minerals and neutralising minerals occur in different size fractions.**

**Rainfall onto top & sides**

**Runoff from top & sides**

**Evaporation & evapotranspiration**

**Infiltration along preferential flow paths**

**Oxygen diffusion**

**Oxygen connection**

**Plant generation and transport**

**Stagnation**

**Preferential flow paths**

**No 1 SHAFT**

**No 2 SHAFT**

**Zone 1**

**Zone 2**

**Zone 3**

**No Rainfall**

**Evaporation**

**Rainfall**

**Runoff**

**Evaporation**

**Mining area for pre-depositional modeling**

**Coal seams**

**Water table**

**Possible coal dust/residue**

**Openpit**
The solution

• prediction
• Prevention & control
• Cure/Treatment
  – Remediation/mitigation
  – Rehabilitation
• Monitoring
• Financial liabilities
• Technology transfer
Identify and develop first conceptual model (Underground mine, mine residue deposits, footprints)

- Design sampling program
  - Analyze and data review
  - Revise and finalize conceptual model
  - Identify various management options & agree with mine & authorities
  - Characterize options in terms of O₂, water balance

- Implement sampling program
  - Develop monitoring and validation programs
  - Develop mathematical model inputs
    - Water balance
    - Geochemistry
  - Finalize modeling approaches
  - Produce pollution profiles & risk in terms of flow & quality for the facilities as are

- Model management options
  - Compare and recommend options

- Undertake screening level risk assessment

FINAL REPORT

Figure 1: A flow chart for pollution assessment, prediction, remediation and mitigation for AMD
The Solution: research - AMD assessment and prediction tools

PREDICTION OF POLLUTION FROM MINING SITES

Understand the mining scenario to be assessed, the mechanisms and factors that need to be considered and define the questions that need to be answered

DEVELOP CONCEPTUAL MODEL

Understand the capabilities and limitations of the tools

POLLUTION PREDICTION ASSESSMENT TECHNIQUES TOOLBOX

<table>
<thead>
<tr>
<th>ANALYTICAL TOOLS</th>
<th>MATHEMATICAL TOOLS</th>
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<tbody>
<tr>
<td>STATIC</td>
<td>KINETIC</td>
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<tr>
<td>Acid/Base Accounting</td>
<td>Humidity Cells</td>
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<td>Mineralogy</td>
<td>Leach Columns</td>
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<tr>
<td>Particle Size Analysis</td>
<td>Special simulations</td>
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<td>Field measurements</td>
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<td>Borehole analysis</td>
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<td>GEOCHEMICAL</td>
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<td>Empirical models</td>
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<td>PHYSICAL</td>
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<td></td>
<td>Hydrological models</td>
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<tr>
<td></td>
<td>Oxygen flux models</td>
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<td>Temperature models</td>
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<tr>
<td></td>
<td>Geohydrological models</td>
</tr>
</tbody>
</table>

INCREASED COST & CONFIDENCE
### Key factors controlling AMD formations

**Primary factors**
- Sulphide mineral
- Oxygen
- Water
- Ferric iron
- Catalysing bacteria

**Secondary factors**
- Buffer minerals
- Weathering of oxidation products by further reactions

**Tertiary factors**
- Properties of the tailings material (PSD, weathering tendency, hydraulic characteristics)
- Geohydrological conditions within the deposits
- Pore water flow due to fluctuating phreatic surface due to external water source (e.g., climate)

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**Mineralogy/geochemistry**

**Hydrogeology**

**Biology**
AMD challenges in South Africa: from gold, coal and base metal mines
Environmental impacts from the mining industry is a national problem.

Affected/impacted resources – e.g., water
Holistic Approach towards solutions

“addressing nationwide environmental impacts from past and current mining activities with emphasis on AMD (water resources)”

- Natural resources e.g., water resources (AMD)
- Land use & degradation
- Air pollution
- Etc.;

Environmental impacts from the mining industry is a national problem – not only a WITS problem!

Geo-environmental provinces:
- Witwatersrand Goldfields
- Barberton Greenstone Belt
- Giyani Greenstone Belt
- Murchison Greenstone Belt
- Sabie-Pilgrims Rest Goldfield
- Alluvial diamond mining areas
- Palaborwa area
- Coalfields
- Bushveld Complex
- Namaqualand copper district
- Karoo uranium mining areas
- Asbestos mining areas
Solution – National & Holistic approach

HOLISTIC APPROACH TOWARDS BEST MANAGEMENT

INTEGRATED & HOLISTIC IMPACT ASSESSMENT

INTEGRATED & HOLISTIC MANAGEMENT
Scientifically Holistic

- Geochemistry & AMD
- Water quality (surface & GW)
- Hydrogeology
- Hydrology
- GIS & Remote sensing
- Ecotoxicology
- Physical hazard
- Geophysics
- Air Quality
- SD & Legislation
CATCHMENT BASED APPROACH

- Assessment of impacts (qualitative & quantitative)
- Best management practices on Impact prevention, control, reclamation rehabilitation & remediation
  - Prevention
  - Reclamation and rehabilitation
  - Remediation
- Methodology - Catchment based approach
CATCHMENT BASED APPROACH: Progress
Integrated & holistic impact assessment: Progress

• Screening level assessment for The Olifants
• Screening level assessment for The Komati-Crocodile
MRDs & AMD hot spots

An old mine dump at Agnes Gold Mine leaching out acid water
MRDs & AMD hot spots

Acid mine drainage leaching from the Nestor dam, flowing towards Sable river

Acid leachate in the paddocks of the Nestor dam

Eroded sediments from the Nestor dump leaching out acid water
AMD hot spots

### Water Sampling Points

#### Sub-Gold Mines
- 01/03/2012: Nestor Gold Mine (gold dump) (QN/001) -25.983101
- 01/03/2012: Paardekraal water (QN/002) -25.983101
- 01/03/2012: Klein Sabra Bridge (QN/003) -26.6782302
- 01/03/2012: Reitshoek Mine (Adit) (QN/004) -25.10028002
- 01/03/2012: Consort Gold Mine (QN/005) -25.5651649
- 20/02/2012: Segal tailings disposal facility (QN/006) -25.54537201
- 20/02/2012: Fairview Gold Mine (Return Water Dam) (QN/007) -25.73985302
- 29/02/2012: Sheba Gold Mine (QN/008) -25.71413593
- 29/02/2012: Sheba Gold Mine (QN/009) -25.6840198
- 02/03/2012: Aquila Gold Mine TDF leachate (QN/010) -26.81988201

#### Ermelo Coalfield
- 06/03/2012: Mimosa Colliery (QN/011) -26.16766989
- 06/03/2012: Mimosa Colliery (QN/012) -26.16584604
- 06/03/2012: Mimosa Colliery (QN/013) -26.17309939
- 06/03/2012: Abandoned u/g mine no 4 (QN/014) -26.17362995
- 20/03/09: Abandoned mine no 3 (QN/015) -26.16255004
- 13/03/12: UMtsho Colliery (QN/016) -26.82888057
- 14/03/12: Sopheta Colliery (QN/017) -26.922956
- 14/03/12: Imbani Colliery (return water dam) (QN/018) -26.85729041
- 14/03/12: Abandoned Mine no 1 (QN/019) -26.11501651

#### Kangwane/Komatiland Coalfield
- 20/03/15: Matatendi Colliery (QN/020) -25.83507556
- 20/03/15: Emangeni Colliery (QN/021) -25.783461

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Council for Geoscience
Towards national mine pollution atlas
Towards national mine pollution atlas
Towards national mine pollution atlas
Towards national mine pollution atlas
Solution – National & Holistic approach

HOLISTIC APPROACH TOWARDS BEST MANAGEMENT

INTEGRATED & HOLISTIC IMPACT ASSESSMENT

INTEGRATED & HOLISTIC MANAGEMENT
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- Foot prints

The problem
- Prevention
- Remediation
- Mitigation
- Treatment

Solutions / Management plans (includes financial liabilities)

Main Receiving environment
- Surface water
- Ground water

• Establish management and control over the AMD problems.
• Prevent problems before they occur
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• Allow for improvement in the future
INTEGRATED & HOLISTIC MANAGEMENT
AMD Treatments Technology in SA

• Prevention and treatment
• In situ MRD management
  – Synthesis of Fe nanoparticles from PGE mine tailings & their application to the treatment of AMD
  – Stabilization of Au Tailings via geo-polymerisation
• AMD Treatments Technology in SA
  – Various active treatment plants
    • HDS treatment plants mainly geared towards lowering the sulfates to acceptable effluent
    • HDS $\rightarrow$ RO combined - e.g., eMalahleni Water reclamation treatment plant
Implementable solutions – Carolina as a show case
Hot spot - Carolina

EM Geophysical map to delineate shallow AMD plume in Carolina

Acid leachate in the paddocks of the Nestor dam

Fanienel AMD decant point & a pond created to attempt treatment

Eroded sediments from the Nestor dump
## Summary of the water chemistry in comparison with the DWA Guideline

<table>
<thead>
<tr>
<th>Description</th>
<th>pH</th>
<th>EC mS/m</th>
<th>Al (mg/l)</th>
<th>Fe (mg/l)</th>
<th>Mn (mg/l)</th>
<th>SO$_4^{2-}$ (mg/l)</th>
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<tr>
<td><strong>Guideline for Human Consumption, DWAF 1996</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>6--9</td>
<td>0 - 0.15</td>
<td>0-0.1</td>
<td>0-0.05</td>
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<td><strong>Sample number</strong></td>
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<td></td>
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<tr>
<td><strong>Description</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>S1a</td>
<td>3.1</td>
<td>235</td>
<td>37.24</td>
<td>308</td>
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<td>S1b</td>
<td>3.2</td>
<td>280</td>
<td>26.00</td>
<td>128</td>
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<tr>
<td>S2</td>
<td>7.4</td>
<td>9.02</td>
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<td>&lt; 0.1</td>
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<td>S3</td>
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<td>929</td>
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<td>0.05</td>
<td>4</td>
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<td>32</td>
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<td>&lt; 0.1</td>
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<td>S23</td>
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<td>0.49</td>
<td>2</td>
<td>0.95</td>
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</table>
## Implementable solutions – Carolina as a show case

<table>
<thead>
<tr>
<th>No</th>
<th>Problem Area</th>
<th>Management Options</th>
<th>Relative cost</th>
</tr>
</thead>
</table>
| 1  | Boesmanspruit dam. Abstraction point for the municipality water supply. The water quality in the dam is very poor. | **Short-term measures**: Municipality reported DWA provided mobile filtration plants (heavy metals)  
Boesmanspruit dam -still acidic → immediate actions. CGS proposes in-situ treatment (alkaline dosing increase pH and PPtn of the heavy metals. +, By-pass treatment plant (e.g., Reverse Osmosis) is also proposed. | Cost of in-situ treatment of the dam = R 500 000.00 |
| 2  | Fani nel decant = AMD decant point into the Boesmanspruit. Sephete Colliery attempting to manage previously underground mined out area. | **Short-term measures**: Integrated active-passive treatment (Alkaline (lime) dosing system → Settling pond & Passive Treatment System (Successive alkalinity producing system) for polishing purposes.  
Long-term management → Passive Treatment. | Capital cost = R 630 096.00,  
Operational cost/annum = R 316 456.00 (cost estimated based on AMD treat 3.1 software) |
| 3  | Old mine opening. This is adjacent to the Fani nel decant (filled with AMD). | In situ treatment (fly ash) and ingress point sealing | In-situ treatment cost = R 150 000.00 |
| 3  | AMD seepage pond. = old back filled open cast. Adjacent Mimosa coal washing plant. | In situ treatment (fly ash) | In-situ treatment cost = R 100 000.00 |
| 5  | AMD underground decant 1. The flow rate is very low (10m³/day) | Integrated passive Treatment (Settling ponds + Anoxic Limestone Drains (ALDs). | Construction cost f(20 years life) = R 350 000.00 |
| 6  | AMD underground decant 2. Water quality is not bad (~ neutral pH and low EC). But Fe, Al and Mn > required water quality limits. | Limestone drains (Place crushed limestone along flow path to induce precipitation of heavy metals). | Construction cost for the life of 20 years = R 150 000.00 |
| 7  | Other pollution points are directly related to the existing mining activities, such as Tselentis discharge points and MRDs. | Liaise with the response parties (mining houses) regarding and ensuring compliance. | |
• prediction
• Prevention & control
• Cure/Treatment
  – Remediation/mitigation
  – Rehabilitation
• Monitoring
• Financial liabilities
• Technology transfer
AMD assessment and prediction tools: a need to standardize – continentally?

- MEND - Canada
- ACMER - Australia
- ADTI of the USA
- PADRE – Europe (PARTnERSHIP FORACIDDDRAInAGE REMEDIATION in Europe)
- JOGMEC, Japan
- others?
African AMD challenges?

Is there a need for standardization of techniques for Methods of assessment, prediction and management of AMD from the mining industries of Africa?
Thank you!

“No problem can be solved from the same consciousness that created it”

“The eternal mystery of the world is its comprehensibility”

Albert Einstein