Mine site rehabilitation: Setting realistic goals and adopting sustainable strategies, an international perspective

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Overview

- Setting achievable goals
- Defining a sustainable strategy
- Understanding the conceptual model
- Source control solutions
Goals

• “Impossible trinity” of rehabilitation goals:
  • Revegetate waste surfaces
  • Improve water quality i.e. meet some regulatory target
  • Manage long term stability and safety

• Often practical solutions are not compatible with all goals
  • Reduce infiltration, increase runoff and erosion
  • Reduce infiltration, increase concentration
  • How to define improve water quality, is it just meeting a numerical target value?

Need to avoid “nearly meeting” a number of goals rather than “nailing” the main one.
Economic as well as environmental drivers

- Often sustainable and successful rehabilitation is equated with “making a site green”
- But the social and economic legacy needs to be assessed
  - Consider the communities around legacy mining areas of Wales still mainly economically deprived decades after mining ended
  - At what point are economic and social development of communities considered more important than environmental goals, or visa versa.
  - How much value is being placed on achieving a specific numerical water quality target, is 5ug/l worth £2m and 10ug/l worth £1m? Is this a failure of policy and planning to be in this mind set?
- Pointy end of the “Well being and future generations” act
Ambition and vision

How do we shift ambition and align goals to create opportunity and value for future generations
Sustainable strategy: timeframes

Key factor is timeframe over which to access objectives:

- Unless the source is removed the timeframe to consider is on decades to centuries scale (intergenerational). AMD still occurring from Roman age mines.....

- BUT decisions often made on much shorter term measures, costs to install the system this year, or maintain for 5 years, or meet funding requirements for next financial year etc.

Key question is over what timeframe are your objectives being considered? Need to define timeframe as this input **most important variable in the calculation of NPV.**
## Decision making over the long term

<table>
<thead>
<tr>
<th>Typical management decision criteria</th>
<th>In reality (over the long term)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost to install system A vs system B</td>
<td>Every 25 years or so need to replace system, could the system become redundant as replaced by more efficient or better technology?</td>
</tr>
<tr>
<td>Improve water quality within short timeframe (system needs to work by next year..)</td>
<td>Water is going to be coming out for 100s of years, how much value can be given to the speed of water quality improvement, is 90% improvement over 5 years better than 80% over 2 years?</td>
</tr>
<tr>
<td>Using fixed costs for assumptions</td>
<td>Over 100 years the price of resources changes, what is the cost of sludge disposal in 20 years time? What is the cost of power in 20 years…maybe almost free?</td>
</tr>
<tr>
<td>Performance of technology A vs B today</td>
<td>Scope for improvement may be vastly different, technology A may have only incremental improvement but B may have quantum leap potential or may be <strong>MODULAR</strong>.</td>
</tr>
<tr>
<td>Assess sustainability of option A vs B</td>
<td>What metric do you use over a 100 year period to define sustainability. <strong>Passive systems are not passive over these time periods...</strong></td>
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</table>
In industry mining companies make decisions based on Net Present Value (NPV), need a numerical, risk and cost based criteria to give “certainty” to an uncertain value.

- Key variables are timescale, risk, uncertainty and discount rate.
- NPV assessment involves the assessment of the whole life of project cost and benefit, with results being expressed numerically in terms of probability.
- Adaptive in that inputs used can be updated over time as assumptions change.
- Not done retrospectively to justify a solution, it is a comprehensive assessment that underpins the entire strategy and informs on the choice of solution.

Example is to consider;

“If I make this decision today, how confident am I that I have factored risk, cost, benefit, uncertainty and timescale such that in 20 years time my decision is likely to be considered the most sustainable approach that resulted in the highest value, that could have been envisaged at the time.”
“Solution” to uncertainty: Adaptive management

• This approach is becoming a preferred strategy for dealing with environmental management over extended time periods as part of demonstrating resilience in engineering design.

• Although quantitative modelling can inform predictions, over very long time frames the results are subject to uncertainty as the assumptions for key inputs may only be valid over time periods of 10 years or less.

• Adaptive management seeks to place a high value on the ability to incorporate flexibility into both planning and solutions that are implemented.

• Example: MODULAR design for water treatment, designed to be improved!
Decision making based on robust conceptual model

• Fatal flaw in planning is not understanding the conceptual model
  • Install a “low permeability cover” to reduce infiltration rates to reduce load from waste rock dump. Civil engineering approach to a geoscience problem, but flawed as the conceptual model not well defined.

• Pollution from discharge can be measured: Flow Rate x Acidity and/or metals = Pollution Load.
  • Where source is sulfide oxidation there is a direct correlation between pollution discharge potential and oxygen consumption within the spoil FeS2 + 3.75 O2 + 3.5 H2O = Fe(OH)3 + 2 H2SO4.
  • There is not a direct correlation between load and flow rate unless solubility control limits exist (related to mineral saturation or pH limitation).
Oxygen control vs infiltration control (sulfide source)

**Oxygen control**
- Concentration decreases over time after control introduced.
- Decrease in concentration.

**Infiltration control**
- Control introduced leads to an increase in concentration.
- Increase in concentration.
Oxygen control vs NP control (sulfide source)

**Oxygen control**
- Decrease in load
- Control introduced

**Infiltration control**
- No change in load
- Control introduced

Time

Load

Control introduced
Decrease in load

No change in load
A number of objectives are tied into single solution that has multiple design criteria:

- Permeability of $1 \times 10^{-8}$ m/s: to meet objective of “low” in many existing designs.
- 1m thick: typical thickness adopted based on erosion and NP reduction objectives.
- Surface graded to 5%: based on surface water management objectives.
- Topsoil 30cm thick placed on surface: based on rehabilitation objectives.
In reality likely to “nearly” meet some goals but won’t “nail” any

• 1E-8m/s is still 300mm/year, **not low (a civil engineering term)** and in many cases sufficient to allow transfer of existing loads but as higher concentration seepage.

• Unlikely that 1*10⁻⁸m/s can be achieved at the macro scale using typical construction techniques and materials. Material is also in unsaturated state so a saturated value to define “permeability” is not valid

• Construction to 1m thick over a waste rock surface of low grade means unlikely a perfectly flat profile will be achieved and maintained. Ponding in depressions (now also have positive hydraulic head) reducing surface water drainage efficiency.

• Unless saturation maintained >85% then oxygen control will not be achieved and loads will not reduce over time. Saturation target based on air permeability calculations: not same as ksat.

• Unless solubility limits reached then seepage concentrations will simply increase in smaller volume of water and no effect on loads from with sulfide or non sulfide source.
Alternative: Design split into 3 different specifications to “nail” each specific design criteria

High specification oxygen control barrier within sides of dump (internal) to meet source control criteria

Plateaux is graded and covered based on re-vegetation and surface water management criteria “simple cover”

Slopes are battered and covered based on erosion criteria
Example MEM project: Progressive rehabilitation of largest tailings dam in Indonesia
Design criteria linked to conceptual model

Internal sealing layers are finer textured and maintain saturation to reduce oxygen flux.

Growth medium is 8m thick coarser textured inert waste rock. Objective is to reduce erosion support vegetation.

Vegetation strategy is to establish a fast growing ground cover then populate with larger shrubs over time.
Underground mines/adits

Current civil engineering solutions to AMD from these sites:

• Prevent ARD using pressure bulkheads / hydraulic adit seals and mine flooding.
• Treat the ARD discharged in perpetuity (active or passive).
• Minimise ARD volumes using water management approaches (diversion around workings).

Problems with these solutions:

• Hydraulic seals often difficult to install, and may cause other issues (blowout).
• Treatment in perpetuity is not sustainable. Passive is not passive in the long term.
• Diverting water may not decrease acid/metal loads (simply increase concentration).
Underground mines/adits

Civil perspective: **Reduce flows = reduce problem**

Geoscience perspective:

- For underground mines, backfilled sulfidic waste rock represents the largest source of ARD. Pollution from discharge can be measured: Flow Rate x Acidity + metals = Pollution Load (tonnes/unit time).

- There is a **direct correlation** between pollution discharge and **oxygen consumption** within the voids. FeS2 + 3.75 O2 + 3.5 H2O = Fe(OH)3 + 2 H2SO4.

- There is **not a direct correlation** between load and **flow rate** however unless solubility control limits are breached (related to mineral saturation or pH limitation).
Inert atmosphere technology: MEM working with Earth Systems to implement in UK

• This new technology is based on controlling the gas composition in mine void atmospheres by passively (Stage 1), and if necessary, actively replacing oxygen with an inert gas phase (Stage 2).

• Aim to retard air re-supply to the mine void, but not prevent water discharge. No control is placed on void water levels or discharge rate.

• If the rate of oxygen consumption by sulfidic waste exceeds the rate of oxygen re-supply then oxygen concentrations decrease, resulting in reductions in pollution (acid and metal) generation will occur passively.

• The technology summarised here is currently being implemented at full scale at two decommissioned, polluting mine sites in New South Wales (NSW), supported by the Legacy Mines Program (LMP) of the NSW Department of Planning and Environment.

• Nevada gold mine (Earth Systems, 2017a; Bourgeot et al., 2017) and the Sunny Corner silver-lead-zinc mine (Earth Systems, 2017b; Bourgeot et al., 2017).
Nevada site and monitoring equipment

Figure 3: Oxygen and Carbon Dioxide sensors within the gas sensor assembly.

Figures 4 and 5: Tamper-proof enclosure for gas sensor assembly and related power, data logging and telemetry system.
pH and EC changes after introducing control

Figure 7: pH, EC, and Acidity data from the main adit discharge at the Nevada gold mine.
An 80% reduction in acidity (acid and metals) and a 75% reduction in EC (electrical conductivity) can be achieved over an 18-month period.
Advantages

- Air entry and discharge control works will have a relatively low impact on site heritage values;

- At some sites, Stage 1 works could provide a walk-away solution to chronic AMD, or could lower acidity discharges sufficiently to manage residual loads with passive treatment systems at many sites AND could dramatically increase the design life of passive treatment systems;

- Will be important for stopping AMD at treatment-in-perpetuity sites, where avoiding the costs related to production of sludge are high priorities;

- The cost of a Stage 2 inert gas injection system powered by renewable energy sources (e.g. wind or solar) is expected to dramatically lower the cost of managing AMD from underground mines relative to treatment-in-perpetuity;

- Remote monitoring of sites subjected to Stage 1 or Stage 2 works greatly simplifies the management of chronic pollution issues;
Conclusions: from international project perspective

- Set achievable goals and define the timescale to define success.
- Ensure that design criteria are not lumped together into one solution that may nearly meet some objectives but not achieve the critical one(s).
- Suggest that a “civil engineering approach” is not the optimal one when designing a rehabilitation program rather a geoscience approach.
- Integrated and holistic approach to determining NPV required to demonstrate that decision making is sustainable, resilient, value for money.
- Consider economic and social aspects in perspective when setting vision for rehabilitation
- Source control is likely to rank as highly as an approach when considering holistic approach (timescales, NPV, sustainability and resilience).
- Adaptive management can assist with backend solutions such as treatment. For example small footprint modular treatment systems that can be upgraded, improved, expanded overtime as technology improves likely to prove to be more sustainable options.
Thank you

The Science Behind Success

Mine Environment Management Ltd