Author(s): **Dave Trumm, CRL Energy Ltd**

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Title: **Methodology to Determine Management Strategies – Objective-3 Milestone-1 CRLX0401 (AMD Treatment Component)**

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Methodology to Determine Management Strategies (Objective 3)

1.0 Introduction

The overall goal of Objective 3 is to provide options to reduce impacts to acceptable levels. Impacts are defined as acid mine drainage (AMD) and neutral mine drainage (NMD) with high arsenic levels. Although, water quality targets are typically set by resource consent for a discharge point from a mine site it is up to mine operators to decide *how* to meet these targets. Objective 3 provides:

- Options for mine operators to meet targets
- Method to select options
- Confidence to stakeholders that mine operators have ability to meet targets

The questions that Objective 3 addresses are:

- What prevention / remediation options are available to meet water quality targets?
- For each option:
  - What is the potential effectiveness?
  - What is the risk of failure?
  - What are the limitations?
  - What is the relative cost?
- What parameters need to be measured to select options?
  - Why are these important?
  - How much data on each parameter is necessary?
- How are prevention / remediation options selected using critical parameters?
- How are the prevention / remediation options implemented?

Management strategies can be divided into two categories: Upstream Control and Downstream Control. Upstream Control involves preventing and/or minimising mine drainage through overburden management strategies. Downstream Control involves treatment of mine drainage using water treatment systems. Selection of appropriate Downstream Control strategies is presented in the following sections.

2.0 Method to Select Appropriate AMD Treatment

Step 1. Data collection:

- Determine AMD water chemistry by sampling monthly for approximately one year
  - Field Measurements: pH, conductivity, temperature, dissolved oxygen, Fe^{2+} concentration
  - Laboratory Analyses: Fe, Al, Mn, Ni, As (dissolved and total concentrations), sulphate, hot acidity, titrations prepared in the field and laboratory analysed for metals (dissolved and total) - see Appendix A for Titration Methodology
- Determine range of flow rates and response of flow to precipitation events, either by spot sampling or preferably via data logger. Also determine effect of flow variation on water chemistry by sampling during these events.

- Document surface topography and available land area for treatment systems

Step 2. Determine treatment goals (water quality endpoints) and requirements for remediation options. This includes using the titration results from step 1 to establish the appropriate treatment level (including amount of neutralizing material required):

- Use the laboratory results for metals to calculate acidity
- Tabulate all results and graph titration results.
- Use the results of Objective 2 to determine the degree of impact anticipated from this site. Report this to the group of parties that are to decide the level of acceptable impact (typically this will include the responsible party, the regional authority, and non-governmental organisations).
- Use the acceptable level of impact to determine the level to which metals and pH should be reduced
- Select the appropriate treatment level (NaOH equivalent from titration results) to lower concentration of metals and pH to acceptable levels

Step 3. Use treatment goals to determine mass of contaminants to be removed from AMD (assume contaminants to be removed as hydroxides, 5% solids by weight). This data is necessary to design appropriately-sized settling ponds.

- Kg/day $CaCO_3$ consumed
- Kg/day $Fe(OH)_3$ removed
- Kg/day $Al(OH)_3$ removed
- Kg/day MnO_2 removed
- Other metals/metaloids

Step 4: Select potential remediation options using collected data and flow chart. See Appendix B for an explanation of the two basic treatment strategies, Appendix C for flow chart, and Appendix D for a description of the most common treatment methods, including an evaluation of effectiveness, limitations, and indicative costs.

Step 5. Undertake pilot trials to determine most cost-effective remediation options

- Design system using programs such as AMD Treat
- Divert only the amount of AMD that can be treated with systems

Step 6. Collect data on a regular basis (weekly, fortnightly, or monthly)

- Collect samples from inlet to systems and outlets (stagger samples according to residence times of systems)
- Field: pH, conductivity, temperature, dissolved oxygen, Fe^{2+} concentration, flow rate
- Laboratory: Fe, Al, Mn, Ni, As, Ca (dissolved and total), sulphate, hot acidity to background pH, hot acidity to pH 8.3, alkalinity
- AMD treated in these field trials can be used in ecotoxicology experiments to determine if remediation is sufficient for recovery of the ecosystem.

Step 7. Analyse Data

- Caculate residence times in systems
- Calculate removal rates of contaminants
- Calculate treatment efficiencies

- Determine effectiveness in reducing mortality rates of macroinvertebrate community

Step 8. Based on the results of the field trials, select system(s) based on effectiveness, implementability, and cost (see Appendix D)

- Effectiveness: a qualitative assessment of how effective each alternative is expected to be in meeting the treatment goals. This includes an assessment of the expected successful duration of each remedial activity.
- Implementability: a qualitative assessment of the practicability of implementing each alternative based on the complexity of the required technologies, site-specific constraints (such as space availability, terrain, etc.), and the amount of experience the construction community, in general, has with using these technologies.
- Cost: an order-of-magnitude cost estimate to allow comparison of the alternatives from a cost standpoint. These estimates are developed using quotations by vendors and estimating values.

Appendix A

AMD Titration Methodology

AMD Titration Methodology

Equipment:

20% NaOH
Digital (or otherwise) titrator
pH, conductivity meter
Portable Merck Photometer SQ 300 to measure Ferrous iron
0.45 micron syringe filters (10)
About 10 bottles for lab analysis for metals (100ml, nitric preserved)
Flasks for titrations (250ml)

Methodology:

<u>RAW AMD</u>

1. Fill small vial for measuring Fe^{2+} concentration
2. Measure and record Fe^{2+} concentration
3. Fill flask with AMD (250ml)
4. Filter 100 ml through 0.45 micron filter into 100ml bottle for lab analysis for dissolved metals (Fe, Al, Mn, Zn, Ni)
5. Record pH, conductivity of remaining AMD in flask

<u>First Titration</u>

6. Empty flask, rinse in AMD, refill with untreated AMD
7. Titrate with 0.05ml 20% NaOH
8. Stir sample
9. Filter 100 ml through 0.45 micron filter into 100ml bottle for lab analysis for dissolved metals (Fe, Al, Mn, Zn, Ni)
10. Record pH, conductivity of remaining AMD in flask

<u>Second Titration</u>

11. Repeat Steps 6-12 using 0.10ml NaOH

<u>Third Titration</u>

12. Repeat Steps 6-12 using 0.15ml NaOH

13. Continue titrations each time adding 0.05ml more NaOH than last titration until pH reaches 7

Appendix B

Potential Remedial Strategies for AMD

Potential Remedial Strategies for AMD

Remediation of AMD using passive remediation technologies can be placed into two broad categories: oxidising and reducing strategies. AMD is generated through an oxidation process, which results in the dominant contaminant, iron, being present in two states, ferrous (Fe^{2+}) and ferric (Fe^{3+}). Remediation systems employing the oxidising strategy remove iron from the AMD by continuing the oxidation process such that all ferrous iron is oxidised to ferric iron, and once the pH has been raised sufficiently, precipitated out of the AMD as ferric hydroxide ($Fe(OH)_3$). In remediation systems using the reducing strategy, iron cations and sulphate are reduced and compounds such as FeS_2, FeS, and H_2S are formed, thereby removing iron and sulphate from the AMD.

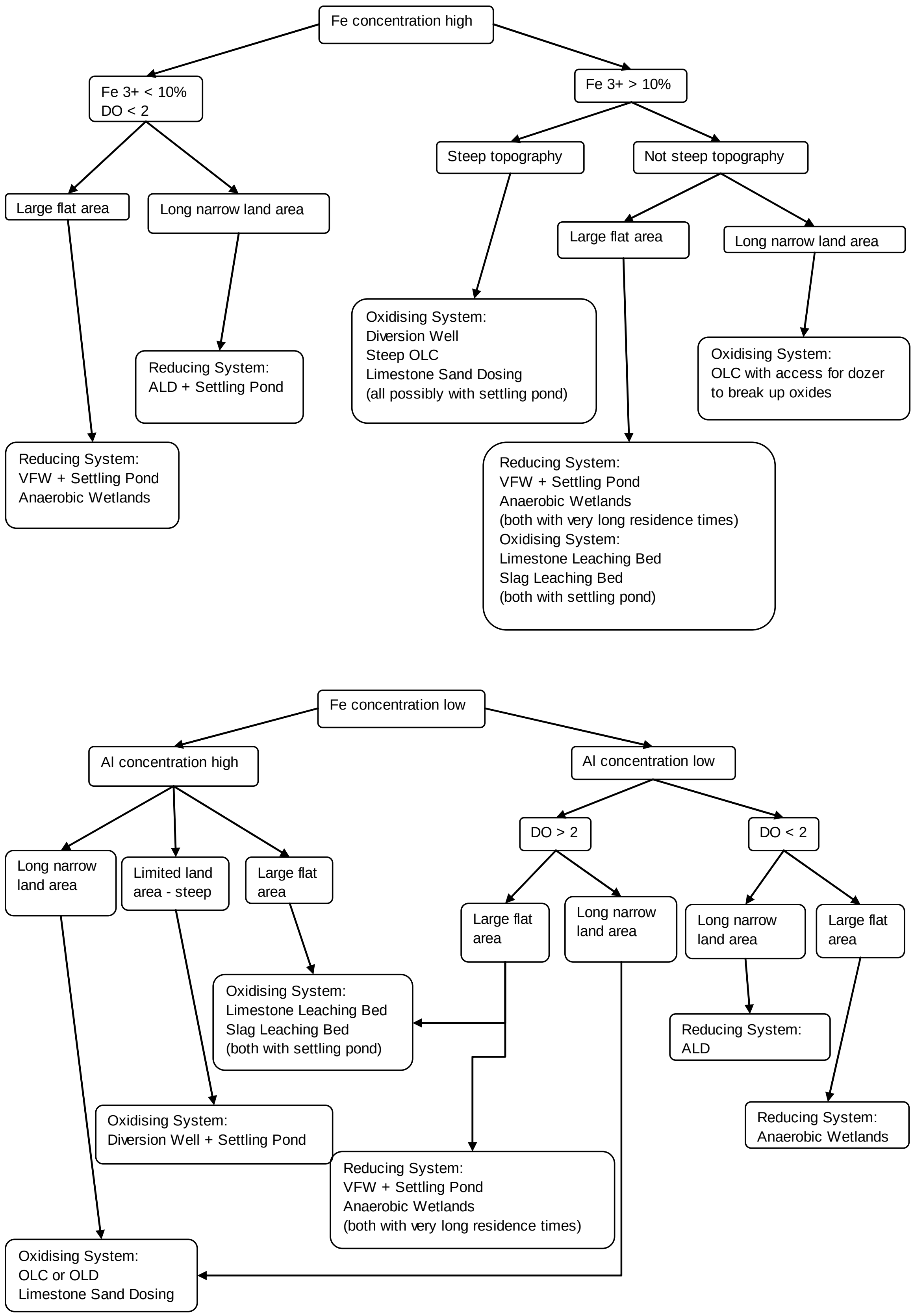
In the oxidising strategy, alkalinity is added to the AMD water by the dissolution of limestone or other alkaline materials, and DO is added by aerating the AMD water. Typical remedial systems that employ the oxidising strategy are open limestone channels and diversion wells. In the open limestone channel, limestone is placed along the sides and bottom of culverts, ditches, or stream channels. The limestone diversion well is an active treatment method in which limestone gravel is added to the well periodically. These systems typically require a steep topography in order to generate the necessary aeration and to prevent armouring of limestone by metal hydroxides, which can inhibit the dissolution of limestone. Settling ponds usually complete the system to capture and store metal hydroxide precipitates.

For the reducing strategy, DO is stripped from the AMD water using a system that creates an anaerobic environment, and alkalinity is then added by the dissolution of limestone. After the pH is raised, metals not already removed as sulphides precipitate as metal hydroxides. Typical remedial systems that employ this strategy are anaerobic wetlands, anoxic limestone drains, and successive alkalinity producing systems (SAPS), also known as vertical flow wetlands (VFWs). In anaerobic wetlands, water is passed through organic rich substrates and dissolved metals are reduced. Some wetlands may have a layer of limestone at the base to increase pH. Anoxic limestone drains are buried trenches filled with limestone gravel. Under anoxic (low DO) conditions, the limestone does not coat or armour with iron hydroxides. VFWs are a combination of an anoxic limestone drain and an organic substrate. Sulphate reduction and iron sulphide precipitation can occur in the compost material whilst the underlying limestone adds alkalinity to the AMD. These systems typically require that the AMD remain in the system long enough for reduction reactions to occur.

The choice between appropriate strategies is based on the water chemistry (largely DO content and ferrous/ferric (Fe^{2+}/Fe^{3+}) iron ratio), flow rates, surface topography, and available land area.

Appendix C

Flow Chart to Choose Among Passive Treatment Systems



Flow chart to use to select among AMD passive treatment systems (produced by Dave Trumm).

Key to use to Choose Among the Passive Systems (for low pH AMD). By Dave Trumm (CRL Energy)

1. Fe concentration high--2
   Fe concentration low---6
2. Fe^{3+}% low to high (10-100%) (see note 1 below)--3
   Fe^{3+}% low (<10%), DO <2 (see note 2 below)--5
3. Steep topography--Oxidising
   - Diversion Wells (possibly with settling pond)
   - Steep OLC (possibly with settling pond)
   - Dosing AMD with limestone sand (possibly with settling pond)

   Not Steep topography--4
4. Long narrow land available--Oxidising
   - Gentle OLC with access for doser to breakup rocks periodically (possibly with settling pond)

   Large flat area available---Oxidising or Reducing
   - Oxidising
     - Limestone leach bed with very coarse rocks and good flushing system+settling pond
     - Slag leach bed with very coarse slag and good flushing system+settling pond
   - Reducing
     - VFW with very long residence time in organic layer+settling pond
     - Anaerobic Wetlands with very long residence time (must design for accumulation of sludge)
     - Organic Bioreactor?
5. Long narrow land area available---Reducing
   - ALD+settling pond

   Large flat area available---Reducing
   - VFW+settling pond
   - Anerobic wetlands
6. Al concentration high (see note 3 below)---7
   Al concentration low (see note 4 below)--8
7. Limited land area available, steep topography--Oxidising
   - Diversion wells+settling pond

   Long narrow land area available, steep or not steep topography-----------------------Oxidising
   - Open limestone channels
   - Dosing AMD with limestone sand

   Large flat area available--Oxidising
   - Limestone leach beds+settling pond
   - Slag leach beds+settling pond
8. DO <2---9
   DO >2--10
9. Long narrow land area available---Reducing
   - ALD

   Large flat area available---Reducing
   - Anerobic wetlands
10. Long narrow land area available--Oxidising
    - Open limestone channels / Open limestone drains
    - Dosing AMD with limestone sand

    Large flat area available--Oxidising or Reducing
    - Oxidising Strategy
      - Limestone leach beds
    - Reducing Strategy
      - VFW (but need long residence time at high DO)
      - Anerobic wetlands (but need long residence time at high DO)

Note 1:

- Treatment considerations:
- AMD highly oxidised
- $Fe(OH)_3$ readily precipiates if pH raised
- Oxidising strategy appropriate but must prevent armouring of limestone and must capture hydroxide precipitates. Primary concern is to remove Fe. If Fe remains prevalent throughout the remainder of the passive treatment system, performance will deline over time from armouring in conjunction with general hydraulic conductivity reductions from iron sludge deposition.
- If use reducing treatment strategy need to strip DO, reduce Fe^{3+} to Fe^{2+} prior to contact with limestone
- Add flume/holding pond prior to system

Note 2:

- Treatment considerations:
- AMD not highly oxidised
- Fe^{2+} will readily oxidise to Fe^{3+} upon addition of DO

Note 3:

- Treatment considerations:
- Acidity in AMD mostly from pH and Al concentration
- $Al(OH)_3$ readily forms at a pH of about 6, however aluminium hydroxides geneally do not armour limestone to the same extent as iron hydroxides
- Oxidising strategy appropriate but must incorporate settling pond for storage of hydroxides

Note 4:

- Treatment considerations:
- Acidity in AMD mostly from pH
- Precipitation from metal hydroxides a minor concern

ALD = Anoxic Limestone Drain, OLC = Open Limestone Channel, OLD = Open Limestone Drain, VFW = Vertical Flow Wetland

Appendix D

Descriptions of AMD Passive Treatment Systems

AMD Passive Treatment Systems

This section underway. For each system will provide the following:

- Description of system
- Effectiveness of treatment
- Limitations
- Indicative cost

Systems to be included:

- Oxidising strategies:
  - open limestone channels
  - diversion wells
  - Limestone leach beds
  - Slag leach beds
  - Aerobic wetland (with/without limestone) (high ph)
  - Dosing AMD with limestone sand
  - Foundation drains
- Reducing strategies:
  - anaerobic wetlands
  - anoxic limestone drains
  - vertical flow wetlands (SAPS)