CHAPTER 13

FARM-BASED TREATMENT OF ACID DRAINAGE WATERS COUPLED WITH INLAND ACID SULFATE SOIL MATERIALS IN WESTERN AUSTRALIA

Brad Degens, 1 Ken McIntosh 1 and Paul Shand 2,3

1Department of Water, WA, P.O. Box K822, Perth WA (Corresponding author)
2Co-operative Research Centre for Landscape Environments and Mineral Exploration, PO Box 1130, Bentley, WA 6102.
3CSIRO Land and Water, PMB 2, Glen Osmond, SA 5064

INTRODUCTION

Shallow saline groundwaters are extensive in the Western Australian (WA) Wheatbelt, particularly in broad valley floors, and the area affected by these is expected to keep increasing for 50 years or more (Hatton et al 2003). This threat has led to increasing use of engineering methods, such as deep (2–3m) open drains and groundwater pumping, to manage rising groundwaters in broad valley floors and protect or recover low-lying land from salinisation (Dogramaci and Degens 2003). More than 5000 km of deep open drains have already been constructed, mostly at farm scales, and there is interest in expanding this to catchment scale drainage networks. This interest has arisen because of the poor success rate of many alternative, mostly vegetation based approaches for managing water-table in broad valley floors. Recent work has identified that many shallow groundwaters in the inland WA Wheatbelt are acidic (pH< 4.5) and may have significant concentrations of trace metals in addition to high concentrations of dissolved salts (Shand & Degens 2008). Deep open drains can intercept these waters and potentially accelerate the transport of acidity and trace metals from catchments.

The ongoing use of deep drains will require safe, practical, and cost-effective options for managing the disposal of such saline, often acidic, waters. Geochemical processes within drains are influenced by the formation of inland acid sulfate soil materials (Fitzpatrick et al 2008) and compound the risks that the drains pose to receiving environments. Treatment of drainage waters may be necessary to halt or control the onset of these inland ASS processes and the impacts of drainage waters on off-site environments.

The acidic waters in WA wheabelt drains are similar to those generated by acid mine drainage and oxidising acid sulfate soils, only more saline (Degens et al 2008). A wide range of technologies has been developed and successfully adapted and applied to treat acidic drainage waters (PIRAMID Consortium 2003; Younger et al 2002; Waite et al 2002). Treatment may be either active or passive. Active treatments use neutralising agents or modified reactive materials in mixing, pumping and settling systems to treat acidity and remove trace metals and are often intended for short-treatment periods or large acidity loads. By contrast, passive treatments involve low maintenance; are frequently gravity–driven (i.e. no pumping), and are intended for long-term operation. Passive treatments can involve the use of neutralising agents such as calcium carbonate or microbial-based neutralisation and metal treatment. The latter approach involves microbial reduction of sulfate to generate alkalinity and promote formation of sulfide minerals that can remove trace metals from waters.

We report on the results of adapting and evaluating selected treatment technologies for acid mine drainage and acid sulfate soils to treat acidic saline waters generated by deep open drains in the WA Wheatbelt. Such treatments would be applicable to the treatment of drainage water from any inland ASS. Field-scale evaluations consisted of lime-based and compost-based (sulphate-reducing) treatment systems
within and at the discharge point of drains. Results of two field trials are presented, with an outline evaluation of a range of other treatment options based on WA-based treatment trials.

Materials and methods
Six acidic water treatment evaluations were established in or at the end of drains at Doodlakine and Beacon, in the eastern WA Wheatbelt. The treatment trials were designed for specific acidity loads and treatment durations. These trials consisted of treatments at source within drains and at the end of drains prior to discharge:

- In-drain lime-sand application: application of lime-sand to form riffle beds within a drain (45 tonnes of lime-sand to treat water for > 2 years)
- Composting drain: creation of an anerobic wetland in ponded sections of a drain (200m section) using wheat straw mixed with sheep manure (5% by volume)
- Lime-sand pond: passive treatment using lime-sand lining a shallow 20m x 25m holding basin for drainage waters (90 tonnes of lime-sand to treat water for >1 year). Water was pumped in and treated in batches of approximately 500kL after which water was pumped out
- Lime-sand tank reactors: pumping of drainage waters through (a) 1.5 tonnes of lime-sand suspended on 4 tables in a 9000L tank or (b) through 400-500kg of lime-sand fluidised in pulsed flow within a 779L column (2.85 m length, 0.6m diameter)
- Hydrated lime dosing: pumping of drainage waters with pH controlled dosing (using a proprietary dosing unit) with 40% Ca(OH)₂ suspension prior to discharge to a creek line
- Anaerobic composting wetland: creation of a 300m² (100m length x 3m width) shallow (0.5m depth) anerobic composting wetland using wheat straw mixed with sheep manure (5% by volume) for treatment of waters at the end of a drain prior to discharge.

The lime-sand used for the trials consisted of 92% CaCO₃ with 99% by weight <0.5 mm sand. A mixture of locally available organic materials (straw and sheep manure) was used in the composting systems based on previous reports (PIRAMID Consortium 2003). Only the results of the lime-sand riffle bed and compost wetland are presented in detail here.

The effectiveness of treatment was evaluated by monitoring the volume and quality of water entering and leaving the treatment systems within the drains (lime-bed, in-drain compost system) and at the ends of drains (lime-sand tank reactor, compost wetland and hydrated lime dosing site). Volumes were continuously monitored using flow meters or water level recorders with V-notch weirs.

Grab samples were taken for water quality and were filtered through 0.45 µm membrane filters in the field then preserved by either addition of ultrapure nitric acid (to a final concentration of 0.1%) or else retained unacidified and stored at 5 degrees C. The concentrations of Cu, Zn, Co, Ni, Cr, Mn, P, V, Fe, Al, Ca, Mg, Ti, Na, K, and S were determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The elements Ag, Ba, Cd, Mo, Pb, Sn, Y, Hf, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, U and Se were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Arsenic was also determined using the hydride generation coupled to ICP. Selected anion analyses (SO₄, NO₃, NH₄, PO₄) were completed using ion chromatography. Titratable acidity and alkalinity was measured by titration to a pH end-point of 8.3 with NaOH and titration to a pH end-point of 4.5 with H₂SO₄, respectively. Titratable acidity for these trials was similar to acidity calculated from major metal ions (mostly because acidity was dominated by soluble aluminium) and was used to calculate net acidity (acidity – alkalinity). Water sampling also included measurements of in-situ pH, EC, temperature and Eh. Only selected results from these analyses are discussed here.

RESULTS AND DISCUSSION

Drainage water quality
The saline drainage waters used for the field evaluations ranged between pH 2.8 (in summer) to pH 4.2 (in winter), containing 20–250 mg Fe/L, 5–150 mg Al/L and 5–10 mg Mn/L contributing to total titratable acidity ranging from 150 to 900 mg CaCO₃/L. Concentrations of total dissolved salts in the waters ranged from 31 000 to 110 000 mg/L and were dominated by Na and Cl. The ranges of trace
element concentrations in the acidic waters were 0–8 µg As/L, 0–4 µg Cd/L, 1–20 µg Cu/L, 30–150 µg Ni/L 12–260 µg Pb/L, 10–340 µg U/L and 5–120 µg Zn/L.

**Treatment evaluations**

The effectiveness of lime-sand in passive treatment situations was limited by high concentrations of dissolved iron in the waters, resulting in rapid coating of the lime-sand with iron oxides (armouring), and decreased neutralisation rates. This is a common problem encountered when neutralising iron–rich acidic waters in passive treatment situations using slow dissolving materials such as CaCO$_3$ (PIRAMID Consortium 2003). Application of lime-sand to an acidic drain as a riffle bed (designed to slow armouring) was effective in increasing water pH from 3.3 to 4.4 and reducing acidity by up to 32% for up to 10 days before significant armouring occurred (Figure 1). Some removal of trace metals such as Pb (from 26–39 µg/L to 16–19 µg/L) was achieved, though there was no significant effect on the concentrations of most. The onset of armouring resulted in neutralisation rates decreasing to a level where less than 20% of the acidity in water flowing through the lime-sand riffles was neutralised (Figure 1). Despite this, consistent neutralisation of approximately 5% of the acidity load was maintained for at least five months after the onset of armouring.

**Figure 1:** pH and total titratable acidity of inflow and outflow waters for a 200m section of drainage channel treated with lime-sand riffles (drainage flows of 130–216 kL/day).

Similar problems with armouring of lime-sand occurred in the 9000L tank reactor within 2 hours when acidic water (pH 3.1) was percolated through lime-sand suspended on 4 tables. These problems did not occur when lime-sand was fluidised in a pulsed flow (on 1 minute cycles) within a column tank reactor. In a single pass through the system, the water pH was increased from 2.9 to more than 5.6 and net acidity was reduced to less than zero (ie outflow waters contained residual alkalinity), despite the waters containing more than 20 mg Fe/L. This effectiveness was sustained for more than 48 hours of treating waters at a rate of 45L per minute (equivalent to 64.8 kL per day). Over several weeks of continuous treatment, acidity treatment fell to a consistent 50-55% of inflow acidity (which ranged from 580 to 620 mg CaCO$_3$/L). Notably, passage of waters through the reactor does not remove any trace metals and these would be expected to be removed from the water by adsorption to alkaline precipitates and sediments in oxidation and settling ponds.

Use of lime-sand as a lining for an evaporation basin was initially effective (for the first two batches) for treating acidic waters, though neutralisation times ranged from 30–50 days. Treatment effectiveness diminished in subsequent batches mainly because of the formation of a clay gel interlayered with a gypsum–rich crust over the lime–sand bed, rather than distinctive armouring by iron oxides. Removal of this crust rejuvenated the effectiveness of this low-cost treatment.
Compost treatment systems harnessing microbial sulfate reduction were effective in neutralising highly acidic waters and removing a wide range of trace metals from these waters for at least six months. Both composting treatment systems achieved high rates of treatment (>95% acidity load), however this was not maintained in the in-drain anaerobic compost treatment system. Inflow pH to the compost wetland decreased from 3.5 to 2.9 over 160 days; although the system consistently maintained an outflow pH of greater than 5.5 (Figure 2). Minimal maintenance was needed over this period, solely consisting of occasionally checking the inflow and clearing amorphous mineral precipitates forming in the outflow pipes. Both the in-drain anaerobic compost treatment and anaerobic compost wetland could remove a wide range of trace elements such as Al, Cu, Cd, Ni, Cu, Zn and Pb to less than 10% of inflow concentrations, though had little effect on Mn, Cr and As. Declining performance in the in-drain compost system was linked with acidity loads being greater than expected which contributed to gradual acidification of the system. Under-performance can be overcome by charging the organic mix with a greater proportion of decomposable organic matter (initially added as sheep manure) to fuel rates of microbial reduction of sulfate at a rate sufficient to cope with the acidity load to the drain section.

**Figure 2:** pH and total titratable acidity of inflow and outflow waters for the compost wetland (treating an average of 3.2 kL/day).

**Treatment comparison**

In a comparative evaluation of the treatment options it was clear that anaerobic compost treatment systems show most promise in achieving low–cost passive treatment of these waters over long time periods (Table 1). In comparison, lime-sand would have limited applications in treating acidic drainage waters containing high iron concentrations without use of fluidised flow systems with regular monitoring and maintenance (Table 1). Reasonable and consistent performance of lime-sand as a neutralising agent appears achievable with a pulsed flow lime-sand reactor offering a low-technology, potentially cheap option (based on the low cost of lime-sand) for waters with high acidity and few trace elements. However, full treatment using a lime-sand reactor would require multiple holding ponds and at least 2 treatment units. In contrast, treatment using the more reactive hydrated lime represents a very attractive option for the short term, though is not ideally suited to long-term treatment (over more than 12 months) due to ongoing pumping costs, reagent supply and reagent storage requirements (Table 1). An important consideration for all neutralising approaches is the need to trap and store iron and aluminium precipitates (which can adsorb and concentrate trace metals) prior to downstream discharge or re-use of waters (e.g. for desalination, saline aquaculture, solar ponds or salt harvesting). Within composting systems, these are mostly retained within the system design (ie not requiring removal).

Land availability may limit where compost wetlands can be used. The 300 m² pilot compost wetland treated acidic waters at a conservative, sustainable average of 1.1 kg CaCO₃ per day, which suggests that up to 1.2 ha of land would be required to treat average baseflow acidity loads from a drain discharging at
1 L/s (assuming a titratable acidity of 500 mg CaCO₃/L). Long-term effectiveness of this treatment depends on attention to design in order to handle expected acidity loads and use of organic materials that will support sustained rates of sulfate reduction. The trials demonstrate that even with a minimal mix of cheap and locally available organic materials (5-6% sheep manure in straw) it is possible to achieve extended treatment of highly acidic waters.

Table 1: Summary of effectiveness (acidity and trace metals) and operational maintenance requirements of a range of passive and active saline acidic drainage treatment options trialled in the WA Wheatbelt.

<table>
<thead>
<tr>
<th>Treatment Option</th>
<th>Effectiveness (acidity)</th>
<th>Effectiveness (trace elements)</th>
<th>Operational maintenance requirements</th>
</tr>
</thead>
</table>
| Passive lime-sand riffles (in-drain) | Very limited with Fe-rich waters (>5 mg/L), greater with Al dominated acidity | Very limited adsorption of metals (poor Fe floc development) | • Retention of Al precipitates within drainage channels and regular cleaning (no Fe floc formation occurred)  
• Annual reapplication of lime to drains  
• Regular, monthly removal of iron crust will be required to achieve >20% acidity treatment efficiency |
| Passive lime-sand lined storage/evaporation basin | Initially high effectiveness (>80% acidity) decreasing with time (beyond 1 month). Limited with Fe rich waters | Effective removal of some elements including Al, Fe, Pb and to a lesser extent U, Ce, La, but not Mn, Ni or Se. | • Annual removal and disposal of Al and Fe precipitates (with trace metals) and fine clays washed into basin may be required  
• Regular reapplications (broadcasting) of lime or removal of iron/gypsum crusts may be required to maintain high acidity treatment effectiveness |
| Active lime-sand tank reactor (vertical flow, fluidised reactor) | Can be >100% during first 48 hours, sustained at 50-60% over longer term. | No removal in reactor. Dependent on elements treated & Fe floc formation (removal by adsorption to Fe precipitates/sediments). | • Retention of Al and Fe precipitates (with trace metals) within settling tanks/ponds  
• Cleaning and disposal of Al and Fe precipitates (also likely to contain trace metals)  
• Ongoing addition of lime-sand and regular, monthly removal of non-reactive/armoured lime-sand  
• Pump maintenance and continuous power supply |
| Active hydrated lime dosing (dosing unit with pumping, dosing and mixing) | Highly effective for a range of acidity loads to target endpoint pH. Aeration can be included to facilitate treatment of Fe-rich waters | Can be highly effective for most elements, except Mn and Ni (in trials). | • Retention of Al and Fe precipitates (with trace metals) within settling tanks/ponds  
• Cleaning and disposal of Al and Fe precipitates (also likely to contain trace metals)  
• Ongoing reloading of hydrated lime slurry (requiring specialist transport and on-site storage)  
• Pump, dosing and mixing unit maintenance  
• Continuous supply of power/fuel for pump |
| Passive anaerobic compost wetland | Can achieve >100% treatment of acidity (pH>6) for more than 6 months when design and organic mix is optimal. | Highly effective for a range of trace elements (e.g. Al, Cu, Cd, Fe, Ni, Pb, U, Zn) but not Mn. | • Periodic additions of new organic matter may be required (every 2–5 years?)  
• Occasional cleaning of outflow pipes and flow checks |
| Passive in-drain anaerobic compost system | Can achieve >100% treatment of acidity (pH>6) for more than 6 months when design and organic mix is optimal. | Highly effective for a range of trace elements (e.g. Al, Cu, Cd, Fe, Ni, Pb, U, Zn) but not Mn. | • Periodic additions of organic matter may be required (possibly every 2–5 years)  
• Sediments will require on-site containment and/or treatment on cleaning of drains (every 5–10 years) |

The uncertainties regarding performance of individual passive treatment options over months to years can potentially be offset using a combination of sequential treatment options distributed throughout a drainage
network (often called a treatment train). This can potentially provide some level of redundancy and capacity to handle changes in acidity loads over future years. Use of multiple options distributed throughout a drainage system also mitigates risks due to under-sizing treatment options. The success of many passive treatment options is dependent on sizing to handle expected acidity loads, which may be difficult to obtain for WA Wheatbelt drains prior to construction.

Management Implications

- Marginal gains in acidity treatment and metal removal can be made with cheap, low-technology passive treatments using a range of locally available materials
- Anaerobic compost-based treatment systems can effectively treat acidic drainage waters removing a wide range of trace elements, but construction will require land area and consistent performance depends on correct sizing and use of suitable mixtures of organic materials during construction
- Passive treatment options are likely to be most applicable in many Wheatbelt drains over the long term since landholders are not likely to have the time to maintain and service active treatment systems. Passive treatment options concentrate effort in the design and construction stages
- It may be possible to integrate passive treatment options of acidic drainage waters within drainage systems to achieve progressive neutralisation of acidity and removal/retention of trace metals at source and during transit down drains. This may also need to be followed by final polishing treatment at the discharge point of drains
- Active treatment can be highly effective in treating acidic drainage waters, but will involve greater on-going maintenance and costs than passive treatment systems.

REFERENCES


