A national demonstration site for acid sulfate soil remediation in the Australian tropics – an overview of the East Trinity environmental success story

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Abstract
Cooperation between Queensland Government scientists and CRC CARE scientists from Southern Cross University has led to a successful National Demonstration Site for the Remediation of Acid Sulfate Soils in tropical northern Australia. This 775 ha site became highly degraded and acidified (pH's <3 were common), following the construction of a large dyke through mangroves, installation of one-way floodgates, and an extensive drainage network to remove salt and grow sugar cane. The resulting and ongoing oxidation of acid sulfate soils caused severe soil and water acidification, failure of the agricultural enterprise, acid and metal discharges, and chronic fish kills in the adjacent Trinity Inlet. Conventional remediation by complete mixing of agricultural lime ($CaCO_3$) with the acid sulfate soil was estimated to cost >A$300 million. Instead, a much lower-cost, controlled, lime-assisted tidal exchange technique was trialled and is largely managing and remediating the acid sulfate soils, as well as transforming the once degraded and acidified trial area into a flourishing tidal wetland system. The remaining areas are being similarly treated and detailed measurements are being conducted. The resulting science is increasing the understanding of the complex acid, iron and sulfur chemical hysteresis involved in trying to reverse the site's extreme acidification.

Key Words
Acid sulfate soil, environmental remediation, lime-assisted tidal exchange, wetland.

Site and background

Figure 1. Location of East Trinity site (lighter area across the inlet from Cairns CBD) (Google image)

The East Trinity site is located on >700 ha of low lying coastal plain less than 1 km across the Trinity Inlet from Cairns CBD between the Wet Tropics and Great Barrier Reef World Heritage areas (Figure 1). Rainfall is strongly summer-dominant and East Trinity receives higher annual rainfall than the Cairns mean of 2220 mm due to orographic effects. Up to 4000 mm average annual rainfall drains through the site from the mountains close behind the site. Approximately 90% of the floodplain area is below the +2 m AHD contour (Australian Height Datum or mean sea level). Prior to disturbance, East Trinity was an ecologically diverse area of estuarine floodplain with mangrove communities below the 1 m AHD surface contour, and samphire communities on supratidal flats between 1–2 m AHD (Smith *et al.* 2003). The site experienced a maximum tidal range of up to 3.6 m, with highest tides to 1.9 m AHD.

In the 1970's a large earth sea wall or dyke was constructed across creeks and drainage lines, with one-way floodgates or tidal gates systems installed across the two main creek outfalls—effectively cutting off the tidal influence of Trinity Inlet. More that 27 km of drains were constructed and the land surface was laser levelled in order to reduce water-logging and leach salt out to enable sugar cane production. The lowering of the natural watertable exposed the framboidal pyrite (FeS_2) in the potential acid sulfate soils to air, causing oxidation and the production of sulfuric acid, creating a highly acidified landscape and releasing acid and toxic levels of iron, aluminium and other heavy metals from the soil into the waterways. This resulted in episodic fish kills both within the site and in Trinity Inlet which flows into the Great Barrier Reef Marine Park World Heritage Area. The drainage, removal of tidal influence, resulting in an acidified iron-rich landscape, together with clearing, resulted in loss of on-site mangroves (Figure 2). The alteration of hydrology and the acidification also affected adjacent wetlands outside the dyke, as evidenced by the death of mangroves (see Figure 2). In much of the drained areas, dense communities of *Melaleuca sp*. gradually colonised the highly acidified soils (commonly pH <3). In the first 25 years following disturbance, Hicks *et al.* (1999) estimated that the East Trinity site exported 72 000 tonnes of sulfuric acid (i.e. 1.5×10^9 mol H^+). More recent soil surveys (Smith *et al.* 2003) confirms that much of the potential acidity in the partially oxidised upper metre has been converted to existing acidity (up to 690 mol H^+ $tonne^{-1}$), with substantial amounts of retained acidity due to jarosite and other relatively insoluble, acidic hydroxy-sulfate minerals also present. Below the oxidised layer potential acidity of up to 4100 mol H^+ $tonne^{-1}$ (6.6 % oxidisable sulfur) was recorded.

Acid sulfate soil management approach

Conventional remediation by complete mixing of agricultural lime ($CaCO_3$) with the acid sulfate soil was estimated to cost >A$300 million—far exceeding any potential budget. Therefore the remediation goal for East Trinity was to treat and ultimately prevent the acidic (pH <3) and metallic discharges off-site and to have water of acceptable quality (pH >6) exiting the site on a consistent basis, in all seasonal conditions. Ideally, the selected management system would ultimately not need costly active ongoing treatment. In order to achieve this, a significant decrease in the acid and metal production from acid sulfate soils (ASS) on the site is required, together with prevention of further oxidation of the large store of pyrite still within the soils, particularly below the surface layers.

Lime-assisted tidal exchange was trialled as the principal acid sulfate soil management strategy for the East Trinity site. It involves the progressive and partial re-introduction of tidal waters through adjustable tidal gates, allowing both ingress and exit on each tide, together with the strategic addition of hydrated lime ($Ca(OH)_2$) to buffer incoming tidal water (and outgoing tidal water as necessary) to ensure that off-site acid and metal discharges were minimised and eventually halted. To make sure that treatment was timely and appropriate, and met 'environmental duty of care' an automated water monitoring network (downloading via mobile telephony) was established across the site, with soil and groundwater baselines also sampled at key locations. The lime-assisted tidal exchange was expected to:

neutralise existing acidity in the water column prior to discharge off-site;

neutralise existing acidity in the upper oxidised soil layers;

hydraulically push some of the existing surface soil acidity deeper into the profile where discharge into drains becomes unlikely and reduction reactions can neutralise some acidity;

precipitate iron, aluminium and heavy metals on the site as pH rises, rather than discharge off-site; and

limit further acid production and metal generation from potential ASS layers (still with huge pyrite reserves), through limiting oxygen to those layers by keeping them wet with regular tidal inundation.

Figure 2. Acidified and iron-stained Firewood Creek, 1980's. Note iron staining from actual acid sulfate soils inside the dyke (left) and dead mangroves from acid and hydrological changes outside of the dyke (right).

Overview of results

In the areas which have been receiving regular tidal inundation for some years, substantial increases in soil pH (e.g. pH increases from 3 to 6; Ahern *et al.* 2008) and decreases in titratable acidity provide evidence for the neutralisation and hydraulic suppression of existing soil acidity. Trends in soil field pH and Titratable Actual Acidity (TAA) (Ahern *et al*. 2008) are showing substantial improvements as a result of lime-assisted tidal exchange for the trial Hills Creek catchment at the East Trinity site. Decreases in soil redox potential also show a change from oxidising and acid producing conditions to a more reducing state where pyrite oxidation formation and the production of alkalinity are favoured. The significant improvements in soil and water quality monitoring data is reflected in the environment, with vegetation and a variety of mangrove species (up to 4 m tall) returning to former degraded areas (see Figure 3). Importantly, the pH of water exiting the site has consistently been above pH 6 (Johnston *et al.* 2008, 2009), despite some area of persistent acidic drainage in the upper catchment areas. Levels of dissolved metals measured at discharge points have also dramatically improved under the lime-assisted tidal exchange regime and now meet ANZECC and ARMCANZ (2000) water quality guidelines. Surveys conducted by Queensland DPI Fisheries officers confirm that the previously sterile creeks that were impacted by acid and metals now support healthy populations of fish and crustaceans (Russell 2006).

Conclusion

In the process of remediating the acid sulfate soils, the degraded and acidified soils and contaminated drains and streams in the trial area are being transformed into a flourishing tidal wetland system. While great success is being achieved, this is only a permanent solution to the acid sulfate soil problem if the site is kept regularly wet perpetually (using tidal exchange). Any reversion to former drained conditions without regular tidal inundation would allow oxidation of the reformed sulfides and would reverse the gains, allowing re-creation of an environmental hazard.

Acknowledgements

The authors wish to acknowledge the advice and collaboration of various colleagues from Southern Cross University, CRC CARE, CSIRO, Qld DPI Fisheries, and James Cook University. The major cash funding has come from the Queensland Government, with significant funding from CRC CARE and in-kind support from Southern Cross University.

Figure 3. Lime-assisted tidal exchange has transformed this formerly acidified area (left photo 2003) of the East Trinity site with mangroves up to 4 m high (right photo 2008)

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