REMEDIATING THE SEVERE ACID SULFATE SOIL PROBLEM AT EAST TRINITY, CAIRNS, AUSTRALIA

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Abstract
Lime-assisted tidal exchange forms the cornerstone of the innovative acid sulfate soil remediation program being undertaken by the Queensland State Government at the severely degraded East Trinity site in tropical north Queensland, Australia. This strategy has been chosen to address the acid sulfate soil problem, given the overriding site characteristics identified in the extensive site characterisation phase of the remediation strategy and severe access constraints.

Remediation will involve progressively and cautiously replace the existing acidified freshwater environment with a managed tidal wetland system—ironically, by modifying and managing the infrastructure that triggered the problem some 30 years ago. This is expected to:

- Hydraulically suppress acid export from the soil and buffer existing water acidity;
- Prevent the generation of further acid;
- Enable treatment of acid water if necessary; and
- Minimise risk and maximise the effectiveness of the remediation program.

Preliminary soil and water quality data from a short period of lime-assisted tidal exchange show some promising results. Longer-term data is required to verify the effectiveness of the strategy at the East Trinity site.

Additional Keywords: lime-assisted tidal exchange, management

Introduction
In May 2000, the Queensland Government purchased the 940 ha East Trinity property with the aim of maintaining the green tropical backdrop to Cairns, and to address the extreme acid sulfate soils problem. The property is situated approximately 1 km from the Cairns central business district on the eastern side of Trinity Inlet. The Wet Tropics World Heritage Area adjoins the property to the east, and a bundwall forms the western boundary, separating the site from the mangrove fringe of Trinity Inlet.

Prior to the establishment of a sugarcane farm in the 1970's, much of the East Trinity site was a tidally affected zone dominated by mangrove and saltmarsh communities. A bundwall was constructed with floodgates placed on the creek outlets, and a large pump was sited at the floodgates on Hills Creek with the intention of eliminating tidal water and lowering the natural water table to facilitate cane production. More than 30 years later, after much clearing and substantial recontouring, considerable drying of marine muds has resulted in the oxidation of extensive areas of formerly benign acid sulfate soils. This has caused the release of sulfuric acid and associated toxic metals from the soil, as well as the shrinking of some of the land surface to 1–2 metres below the previous land level.

Based on available data, the cost of total rehabilitation by conventional lime treatment of the acid sulfate soils was estimated to be $62 million (plus earthworks). Logistically and environmentally this approach was considered impractical with the need to incorporate neutralisation products to a depth of 1–2 m in areas that support dense vegetation. Another approach of simply treating the acidified waters over the next 25 years was estimated to cost $55–70 million. Instead, a lime-assisted tidal exchange process was chosen to address the problem given the severe access constraints and other overriding site characteristics, as well as substantially reduced cost compared to conventional approaches.

East Trinity site
A substantial bund separates the estuarine area from land that was originally drained for sugarcane at East Trinity. Outside the bundwall, the subtidal mudflats are abutted by an intertidal mangrove forest and more limited areas of supratidal salt flats. Within the bunded area, the terrain has little undulation with approximately 90% of the area lying between 0 and 2 m Australian Height Datum (AHD). An extensive network of drains was constructed to collect surface water and channel it into Hills and Firewood Creeks, thereby lowering the natural water table across the site. Where these creeks exit the site at the bundwall, flapgates ensure that drainage water exits on outgoing

tides, while preventing the entry of saline water on an incoming tide. The total length of drains on the site is about 27 km, giving an average drainage density of 33 m/ha.

Much of the East Trinity site consists of drained estuarine deposits that are heavily infested with weeds and remnants of failed sugarcane crops. In the south-western part of the site, former intertidal mangrove soils that have subsided following drainage now support Melaleuca woodlands.

Recent studies on the groundwater dynamics of the site have shown that the surface Holocene sediments have effectively sealed the deep groundwater aquifers below. The shallow upper groundwater layers are vertically confined to oxidised soil layers, or surficial chenier ridge sands that form isolated occurrences across the site. These surface layers are laterally linked to the drainage network, providing a conduit for both acid and soluble neutralising agents.

Hills Creek is the major stream traversing the site. On-site there is 400 ha of catchment area, though the creek originates in a 3000 mm annual rainfall catchment of the Murray Prior Range. Hills Creek has an extremely low pH (<4) during periods of low flow in the late dry season (Hicks *et al*. 1999). More recent data from drains within the Hills Creek floodplain support this assertion, with drain water pHs as low as 1.98 recorded in April 2002 by field officers. Three sets of tidal gate structures enable Hills Creek to discharge through the bundwall with flapgates allowing freshwater from storm runoff to exit from the site, while preventing the entry of incoming tidal water. Additional location and geomorphological details are provided in Graham *et al*. (2004), these proceedings.

Acid sulfate soils at the East Trinity site

It is considered that virtually all of the site below 1.5 m AHD contains at least some actual acid sulfate soils (ie. about 65% of the floodplain area). However the actual acid sulfate soils are generally confined to the areas below the 1 m AHD surface contour, particularly below the 0.5 m AHD surface contour. Most of the existing acidity resides in the upper soil profile, particularly in the upper 0.5 m of the soil profile. Existing acidity levels range from 18 to 686 mol H^+/tonne (0.03 to 1.1 equivalent %S) with an average of 197 mol H^+/tonne (0.37 equivalent %S). These areas were predominantly mangrove communities prior to drainage of the site.

To put the problem into perspective, it has been estimated (Hicks *et al*. 1999) that since disturbance the East Trinity property has produced 72 000 t of sulfuric acid (1.5 x 10^9 moles H^+) at an annual rate of 34 t $ha^{-1}y^{-1}$ (7.0 x 10^5 moles H^+ $ha^{-1}y^{-1}$). It is well established (Cook *et al*. 2000) that bodies of ASS can produce significant quantities of acid and associated soluble metals even 30 years after being activated. In these circumstances, it is likely that the ASS at East Trinity will continue to adversely affect the environment for many years to come—unless remedial actions are implemented. A more detailed discussion of the acid sulfate soils at the East Trinity site is given in McElnea *et al*. (2004), in these proceedings.

Off-site impacts from the East Trinity site

The first recorded fish kill attributed to discharges from the East Trinity site occurred in 1972. The deaths were correlated with heavy seasonal rains flushing low pH water from the newly bunded East Trinity site (Olsen 1983). Since then, Department of Primary Industry fisheries officers have investigated fish kills associated with poor water quality discharges from the site (Garrett 1978 and Russell 1980). Russell and McDougall (2003) report periodic fish kills in the creeks draining the East Trinity property.

Hicks *et al.* (1999) report an average discharge pH of 3.4 for waters exiting the East Trinity site, with concentrations of iron and zinc regularly exceeding the ANZECC Guidelines, and aluminium concentrations recorded at up to 6000 times the guideline level. Similarly, Cavicchiolo (2001) reported acidic discharges (pH 3.5–4.0) and iron-rich floc. This is supported by Hall (2002) who reported high suspended loads of iron floc in discharge waters and the formation of encrustations along creek banks.

Remediation strategy: Lime-assisted tidal exchange

Remediation will involve progressively and cautiously replacing the existing acidified freshwater environment with a managed tidal wetland system—ironically, by modifying and managing the infrastructure that triggered the problem some 30 years ago. This is expected to:

- Hydraulically suppress acid export from the soil and buffer existing water acidity;
- Prevent the generation of further acid;

- Enable treatment of acid water if necessary; and
- Minimise risk and maximise the effectiveness of the remediation program.

In developing the strategy, full advantage was taken of the low-lying terrain and existing infrastructure: the bund that separates the Hills Creek catchment from the sea has floodgate structures to allow water egress to the Inlet, and the extensive drainage network. While floodgates needed to be replaced and modified, the tidal exchange strategy involved opening one or more of these gates to allow daily tidal inundation over the areas where significant soil acidification has occurred, ie. where actual acid sulfate soils (AASS) exists.

A comprehensive site characterisation exercise commenced in 2001. Information gathered from this exercise forms the basis for strategic implementation of lime-assisted tidal exchange—trialled firstly in Hills Creek before transferring the technology to Firewood Creek—and for the monitoring and management of the remediation process.

Acidified areas unable to be inundated will be considered in the light of the laboratory analysis and a management strategy, almost certainly involving soil liming, will be put in place.

Implementation of the remediation strategy

Two new floodgates with Automatic Tide Regulator (ATR) devices were fitted to the Hills Creek barrage in May–June 2002. These devices allow automated operation of regular and frequent water exchange, however the extent of the inundation achieved with this ATR configuration alone was insufficient to achieve inundation to 0.5m AHD, that is, inundation of the most acidified areas. In February 2003 the inundation level was increased through manually lifting and locking one of the remaining large flapgates.

The tidal exchange process has been augmented by the application of hydrated lime to water bodies. The controlled application of hydrated lime has proven to be effective in treating both incoming water to bolster its neutralising capacity, as well as treat retreating water that has become too acidic for release to Trinity Inlet.

Monitoring

A network of stations was set up across the site to assess and monitor the following: soil solution and soil redox potential; surface and groundwater quality; suspended solids and colloids; and stream biota. Detailed site descriptions, methodologies and installation details are given in Smith *et al.* (2003).

Results and discussion

Existing acidity

The introduction of lime-assisted tidal exchange to acidified areas of the site has had a positive effect on reducing the acidity of the soil solution in these areas. Despite the relatively short (ecologically speaking) monitoring period, increases in the order of 1 pH unit have been observed in the soil solution to a depth of 1.2 m below ground level (bgl) after 12 months of continuous lime-assisted tidal exchange as shown in Figure 1.

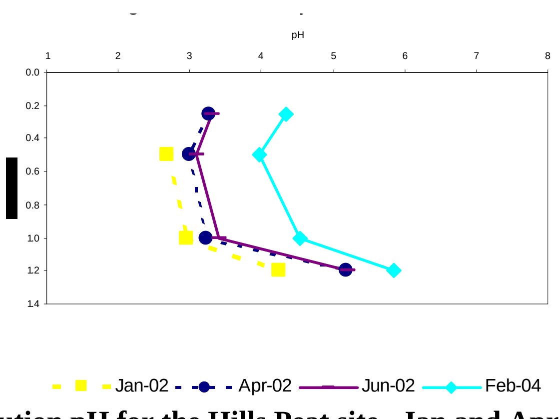

Figure 1. Changes in soil solution pH for the Hills Peat site. Jan and Apr 02 are pre-tidal exchange data. Jun 02 sampled during Hills Creek floodgate replacement. Feb 04 data were recorded after 12 months of lime-assisted tidal exchange.

However, the soil solution is still quite acidic, and drainage water from these areas is still very acidic with pH values of 3 and 4 commonly recorded. This is attributed to the continued acid contribution of acidified areas above the level of consistent inundation. Despite this, exit waters from Hills Creek have largely been maintained above pH 6 (Figure 2) with the addition of hydrated lime to drains and streams in the upper reaches of the site.

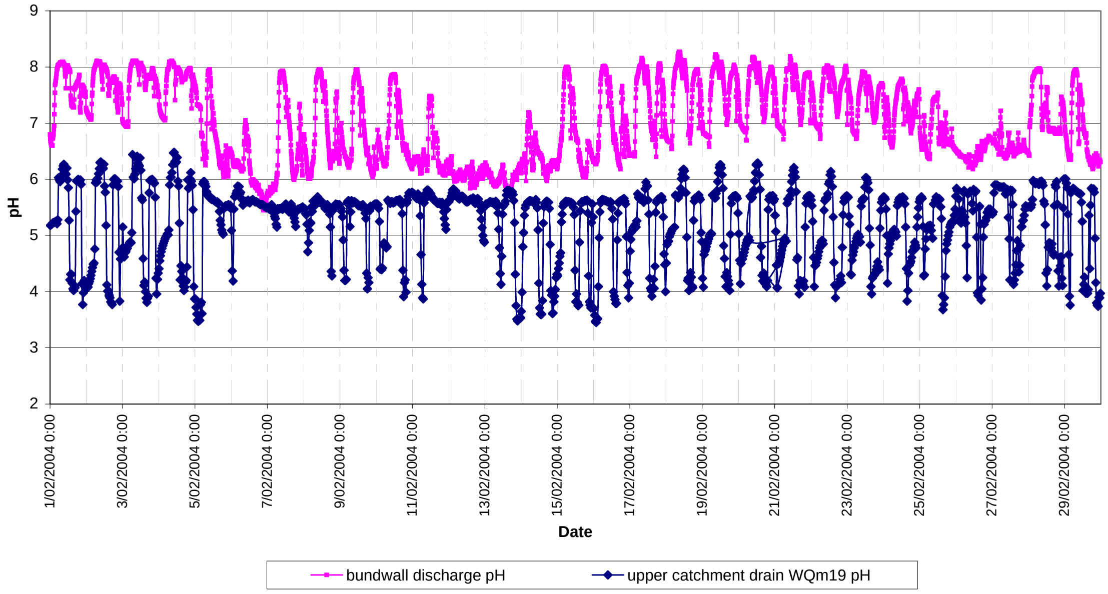

Figure 2. February 2004 pH data for 2 sites on Hills Creek: at the bundwall discharge point and in an upstream drain (WQm19).

Firewood Creek had been subjected to several months of ‘opportunistic’ tidal exchange when floodgates were vandalised and an entire flap removed. During this period, the pH of the water in the creek improved from 3.5 (recorded by Cavicchiolo (2001)) to more neutral values (Figure 3), with the tidal signature quite obvious. When the flap was replaced on 17 August 2001, a dramatic drop in pH, EC and dissolved oxygen was recorded at the monitoring station located near the Firewood Creek floodgates, indicating that improvements in water quality due to tidal exchange are reversible.

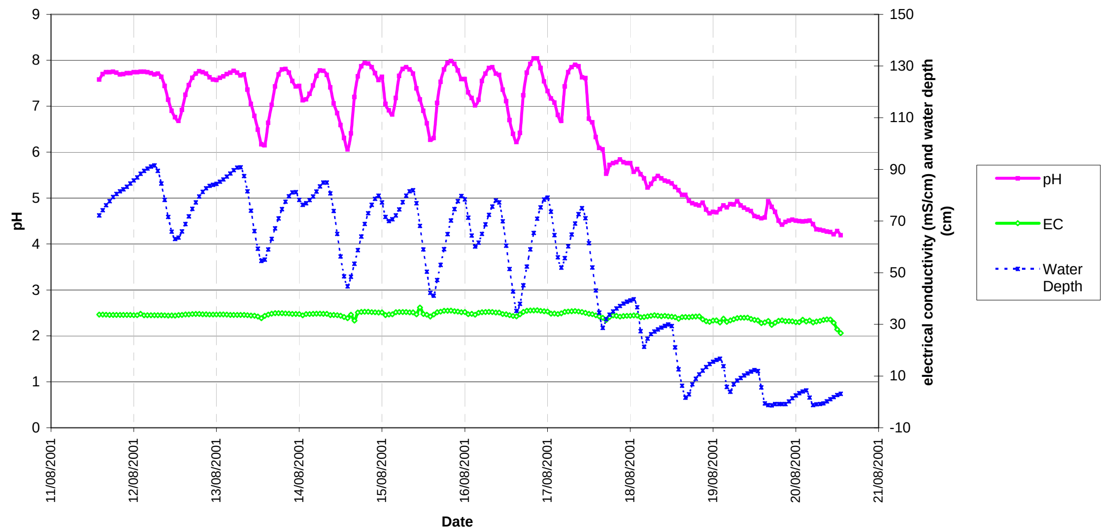

Figure 3. pH, electrical conductivity and water depth data for Firewood Creek discharge 11–26 August 2001.

Potential acid generation

Prior to the commencement of lime-assisted tidal exchange the soil redox status was highly oxidising throughout the profile to a depth of 1 m in many areas. This favours the oxidation of pyrite and the production of acid. This is evident in Figure 4 where the redox data for a peaty area near Hills Creek show pe values >10 (Eh 0.6 V vs SHE).

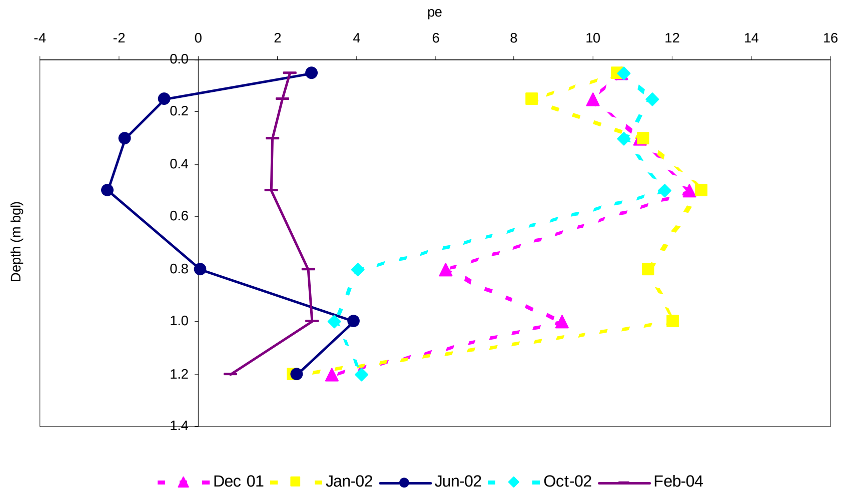

Figure 4. Changes in the soil redox profile at Hills Peat site (where pe=Eh (V)/0.059). Dec 01 and Jan 02 data are pre-tidal exchange data. Jun 02 sampled during Hills Creek floodgate replacement. Oct 02 data recorded at low level of inundation. Feb 04 is 12 months after lime-assisted tidal exchange commenced.

The June 2002 data (from the period of floodgate replacement) show a distinct decrease in redox due to the increased level of inundation associated with having 2 full floodgates removed for a 3-week period (Figure 4). Once the gates were replaced and the site was no longer inundated, oxidising conditions returned in the upper 0.8 m of the profile, as evidenced by the October 2002 data. Following a full year of lime assisted tidal exchange, the February 2004 data show a return to more reducing conditions throughout the soil profile. The reversibility of the process has implications for future management of the site with the requirement to keep inundated areas wet infinitum, to prevent the site from reverting to acid producing conditions.

Hydraulic suppression of acid export

Evidence in support of the hydraulic suppression of acid export is provided in Hicks and Fitzpatrick (2003), albeit on a limited dataset. Their work showed that the soil solute concentration of aluminium, iron and acidic cations decreased in the surface 0.25 m and increased between 2 and 30 times at 0.5 m depth after the 3-week period of inundation in May–June 2002. The increase was apparent whether average or maximum pre-exchange concentrations were used, and the result was attributed to displacement of soil solution as tidal water entered the profile through piston flow. Thus the case for hydraulic suppression is supported by the displacement of acidic cations down the soil profile.

Conclusions and recommendations

Data from both Hills and Firewood Creeks show that even after a limited time period, lime-assisted tidal exchange appears to have beneficial effects on the acid sulfate soils and discharge waters at East Trinity. Improvements in soil solution pH of up to 1 unit have been observed to a depth of 1.2 m bgl, and the pH of discharge water was improved to more neutral values. Redox data show a change from oxidising, acid producing to more reducing conditions throughout the soil profile with the introduction of lime-assisted tidal exchange, and even after a 3-week period hydraulic suppression of acidity was observed in the upper 0.5 m of the soil profile.

However, these beneficial effects are not permanent. Cessation of tidal exchange or even decreasing the level of inundation has been shown to cause a reversal, causing the site to revert to its previous acid generating, degraded state. Additionally, areas that are above the level of consistent inundation will require neutralisation to prevent their continued acid contribution to drains and waterways.

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