THE UNIVERSITY OF NEW SOUTH WALES

Dr M.D. Melville
Visiting Associate Professor
School of Biological, Earth, and Environmental Sciences
Faculty of Science

May 15, 2015

The General Manager,
Tweed Shire Council

Dear Sir,

re: **Proposed Management Plan for Bruce Chick Park**

It has been my privilege since 1989 to complete research on best management of acid sulfate soils (ASS), in collaboration with TS Council and Officers, and local landowners from the McLeods Ck area.

This area particularly, and TSC area generally, is probably the World's most important location for research upon this global environmental issue. There have been more than 30 PhD, MSc and BSc Honours research studies, wholly or in part, completed on ASS in this location. Arisng from some of this research, I append here three publications that describe the issue of ASS management and how this has been addressed (Smith *et al.*, 2003, Kinsela and Melville, 2004, White *et al.*, 2007) .

I am aware that local landowners are concerned that due cognizance may not have been given in the proposed plan of management of the Bruce Chick Park, for the continued and adequate egress through the Park of floodplain drainage waters from Stotts Ck, McLeods Ck, Robert Quirk's egress drain, and Leddays Ck.

This need also includes the existing approval (as I understand it) to clear obstructing vegetation and complete limited dredging in the Stotts Channel. Such operations in Stotts Channel would also better enable isolation of the critically important Stotts Island Nature Reserve from invasion by feral organisms.

It may have been considered and I missed it in my reading of the draft, but I wonder whether due recognition has been made about future climate change and sea-level rise because I know that local landowners on the adjacent floodplain are becoming increasingly concerned about the issue.

It is disappointing for me to learn that this important resource has fallen into disrepair because I have visited the site and its arboretum with Bruce Chick when he explained to me the nature and intents of his efforts and I explained our research efforts on ASS. I have used the site for many teaching experiences with conference field visits, and my university and local high school student groups.

However, I am particularly pleased that TSC is continuing its environmental stewardship in the Proposed Plan of Management.

Yours sincerely,

M. D. Melville

Michael D Melville

UNSW SYDNEY 2052
AUSTRALIA
Email: m.melville@unsw.edu.au
Telephone: +1 (970) 631 8395

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Spatial distribution and management of total actual acidity in an acid sulfate soil environment, McLeods Creek, northeastern NSW, Australia

J. Smith*, P. van Oploo, H. Marston, M.D. Melville, B.C.T. Macdonald

School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia

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Abstract

The spatial distribution of total actual acidity (TAA), defined as the total amount of acidity which exists in a soil at the time of sampling, was examined across an acid sulfate soil floodplain in northeastern New South Wales (NSW), Australia. Despite generally uniform soil conditions, there is considerable variation in the amount of acidity, and the amounts of soluble and exchangeable ionic species in the soil profile are positively correlated with this acidity. The surface hydrology of the site has been extensively modified for sugarcane production. It is hypothesised from air photo interpretation and the spatial soil data that variation in TAA is a result of the natural geomorphic environment, and that the current distribution pattern is a remnant of past natural land formation and hydrological processes controlling pyrite oxidation and acidity export. The degree to which land drainage caused the acidity is unclear, but the drainage systems provide the conduit for its increased transfer to estuaries. By investigating the distribution of acidity in the landscape, 'hotspots' can be identified and land managers can target these areas. Currently, the acidity is managed by a containment program in which it is kept within the soil profile and discharge into the estuary is minimised. Work is under way to apply emerging technology from the mining industry so that any acidity that enters drains is neutralised prior to discharge from the site.

Keywords: Acid sulfate soils; Total actual acidity; Geomorphology; Management

* Corresponding author. Tel.: +61-2-9385-4394.
E-mail address: jodie.smith@student.unsw.edu.au (J. Smith).

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1. Introduction

The term acid sulfate soils (ASS), in its broadest sense, has been applied to soils in which sulfuric acid will be produced, or has been produced in sufficient quantities to have a lasting effect on the main soil characteristics (Pons, 1973). Sedimentary materials that contain iron sulfides (usually pyrite, FeS_2) in a reduced condition, in which no oxidation has taken place, have been termed potential acid sulfate soils (PASS). Acidification can occur if the soil is exposed to an oxidising condition. Actual acid sulfate soils (AASS) once contained pyrite, and may still contain some, but have been oxidised or are being oxidised by drainage or exposure to form sulfuric acid, thereby decreasing the pH to less than 3.5 (Fitzpatrick et al., 1998). Since both oxidising and reducing conditions may occur in the same profile, the term ASS refers to both AASS and PASS, encompassing all the factors, processes and characteristics of these soils that are likely to be encountered in the landscape.

Pyrite is generally stable under anoxic conditions below the watertable. It is only when it is exposed to oxygen, such as in periods of prolonged drought, or after draining, dredging or excavation, that problems occur (White et al., 1997). Sulfides in the sediment oxidise to form sulfuric acid. This acid reacts with the host clay minerals to release silica and metal ions, principally aluminium, iron, potassium, sodium and magnesium (Sammut et al., 1996). Other ions, such as manganese and trace heavy metals, can also be released (van Breemen, 1973). Detrimental impacts of sulfide oxidation include decreased plant growth, corrosion of engineering infrastructures, massive fish kills and fish diseases, and dramatic changes to stream ecology (White et al., 1997).

In Australia, ASS occur in the coastal plains where favourable topographic, hydrological, social and economic conditions encourage land reclamation, for either agriculture or urban construction (Lin, 1995). The National Working Party on Acid Sulfate Soils (1999) estimated that sulfidic sediments occupy 4×10^6 ha in coastal Australia. ASS had previously been reported by Walker (1972), but his warnings of the hazards from mismanagement of these materials were largely unheeded. However, recently, it has been recognised that detrimental environmental consequences can arise from disturbing them (White et al., 1997; Cook et al., 2000). Drainage and flood mitigation works that have altered the natural hydrological regime of the floodplain have probably increased acidity by oxidising the sulfides, and large areas ($>0.5\times10^6$ ha) of sulfidic floodplains and wetlands have been drained for agriculture and urban development in eastern Australia (Sammut et al., 1996). It is unclear how much of the existing sulfide oxidation and its concomitant acidity is actually caused by drainage because oxidation of sulfides can also occur naturally under drought conditions (Lin et al., 1995a).

Although the processes and controls of pyrite oxidation are known, the spatial distribution of acidity in the landscape is not understood. Dent (1986) pointed out that ASS are not uniformly and equally debilitating, but only a few studies have investigated spatial variations in these soil properties and their causes. If management techniques are to be effective, it is important to understand the nature of the soils as well as the quantity and location of acidity in the landscape. As stated by Dent (1986), points of severe acidity often form intricate patterns. Amelioration techniques are expensive so it is more practical to target the acid 'hotspots'.

This paper describes the spatial distribution of total actual acidity (TAA) in a representative estuarine floodplain in eastern Australia, and outlines the underlying physical reasons for the observed distribution pattern. TAA is defined by Konsten et al. (1988) as the total amount of acidity which exists in a soil at present. Lin et al. (2000) describe how TAA is comprised of soluble acidity, exchangeable acidity, acidity from protonated variably charged particles and acidity carried by basic sulfate minerals. The severity of the acid hazard has been quantified to highlight the acid 'hotspots', which can then be targeted in soil management plans. The current management strategy for TAA at our study site, involving containment of acidity within the soil profiles, is also described.

2. Study site

The study site is at McLeods Creek, a right bank tributary of the Tweed River, on the far north coast of New South Wales (28°18′ S, 153°30′ E) (Fig. 1). The site is in the backswamp area of the Tweed River estuarine embayment and the floodplain at the site

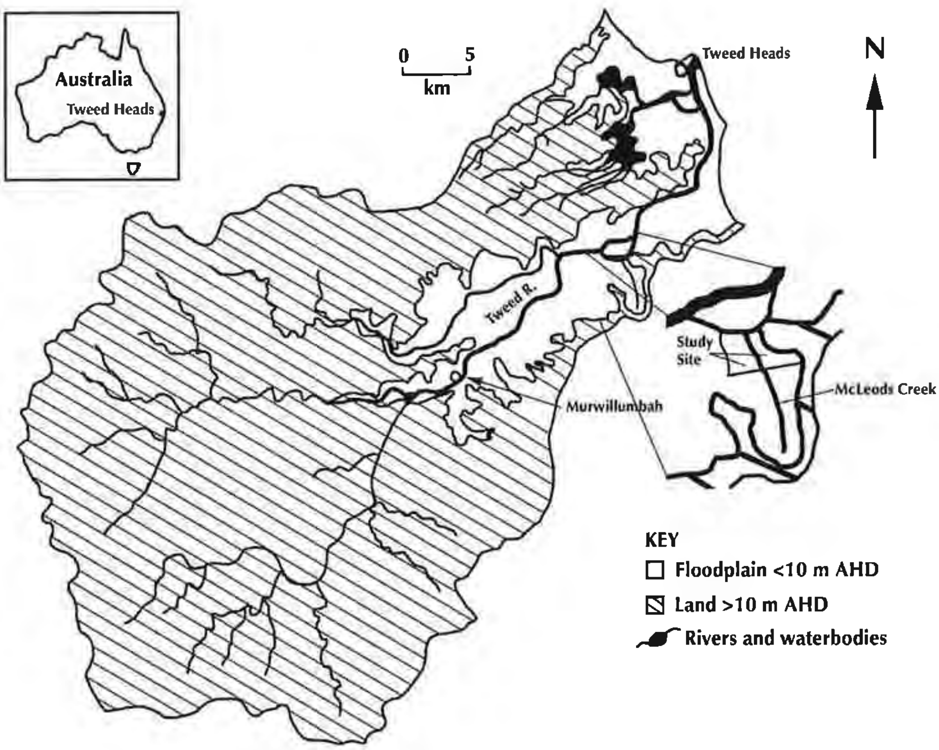

Fig. 1. The Tweed River catchment and McLeods Creek study site. Adapted from Lin et al. (1998a). AHD Australian Height Datum (approximates mean sea level).

covers an area of 4.5 km^2 (Yang, 1997). The soil was investigated in a 180-ha area at the northern end of the backswamp, in two sub-catchments on either side of McLeods Creek (Fig. 1).

The Tweed River catchment has a humid subtropical climate with a marked wet season from December to March. The regional average annual rainfall is approximately 1700 mm (van Oploo, 2000) and storms as intense as 45 mm h^{-1} for short periods have been recorded (Wilson, 1995). Average annual evaporation for the region is 1600 mm (van Oploo, 2000). At the study site, evaporation generally exceeds rainfall from July to November and rainfall exceeds evaporation from December to May (Wilson, 1995; van Oploo, 2000). Alternating high and low rainfall periods each lasting several decades have been recognised in eastern Australia (Cornish, 1977). Annual rainfall increased markedly after 1948, following a low rainfall, drought-dominated period from 1895 to 1948. During such prolonged drought episodes, dry season watertables would have been much lower than at present, although even now, shorter-term but significant droughts occur during El Niño Southern Oscillation (ENSO) events.

The floodplain vegetation at the time of European settlement comprised rainforest species on the levee of the Tweed River grading through Casuarina forests to Melaleuca/fern swamps in the backswamps. Mangroves were identified only as riparian margins throughout the tidal sections of the Tweed River (Wilson, 1995). Significant areas of freshwater peatland existed at that time. Very little of the natural vegetation remains in the backswamp areas of the Tweed River because of land clearance for agriculture with some drainage and burning of the peat areas. The site is now under the management of sugarcane farmers.

A natural drainage network existed prior to the development, straightening and widening of the existing drainage channels. It consisted of wide, shallow depressions in the low-lying areas of the backswamp. Natural levees formed along the main stream and its tidal tributaries entering these depressions. This is typical of most eastern Australian coastal floodplains, which have pronounced levees and low-lying backswamps (Walker, 1972).

McLeods Creek was modified to form the trunk drainage canal in the 1930s to remove water from wetland areas for cattle pasture and later for sugarcane production, and has been widened and straightened since then (van Oploo, 2000). Field drains were constructed for sugarcane production approximately 30 years ago (Wilson, 1995). They surround each sugarcane block and were intended to drain the soil under the crop and to remove surface water from fields as quickly as possible (Wilson et al., 1999). However, White et al. (1993) and Wilson et al. (1999) showed that the elevation of the shallow watertables under the crop is controlled by evapotranspiration. Lateral drains collect water from several field drains and then discharge into McLeods Creek (Wilson et al., 1999). The trunk drain and several of the lateral drains have one-way flap gates to prevent tidal inflows (Lin, 1995; Wilson et al., 1999).

The eastern sub-catchment does not receive upland surface runoff because a hillslope interception drain was constructed in 1970. Water level in the eastern sub-catchment drain outlet is maintained at a constant −0.6 m Australian Height Datum (AHD, approximates to mean sea level) by an automatically controlled electric pump. The western sub-catchment is hydrologically isolated from the surrounds (except in floods) by bunds and natural levees, and drain water level is kept at a constant −0.5 m AHD by automatic pump.

3. Methods

3.1. Sediment sampling

Eighteen sediment profiles from the eastern sub-catchment and 27 from the western sub-catchment were sampled to examine the spatial distribution of TAA. Their surface elevation was measured relative to AHD. Sampling locations were along Transects 1 (Fig. 2, A to B), 2 (Fig. 2, C to D) and 3 (Fig. 2, E to G), which were selected to show sediment variation across the two catchments and from the northern levee to the backswamp.

The sediment was extracted at 0.1 m intervals to a depth of about 2.5 m using a bucket auger and soil gouge. Soil pH and reaction of pyrite to 30% hydrogen peroxide (H_2O_2)

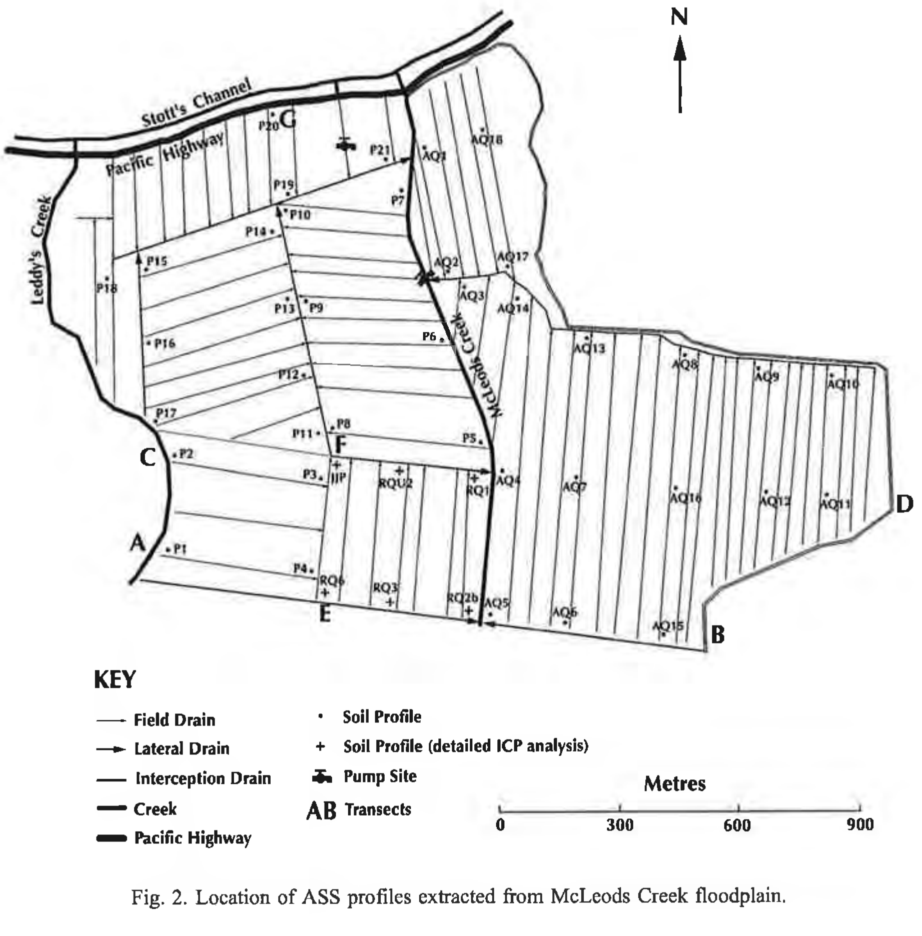

Fig. 2. Location of ASS profiles extracted from McLeods Creek floodplain.

were measured in the field as pH alone does not suffice to identify PASS. The peroxide test devised by van Beers (1962) involved noting the degree of effervescence after addition of 1 ml of 30% H_2O_2 to the soil. Other profile characteristics were also recorded, including the location of any jarosite, mottling, roots, shells and other organic matter. Five samples were selected from each profile to represent each horizon based on the field profile descriptions. The samples were sealed in plastic bags and frozen for transportation to the laboratory to minimise further oxidation of any pyrite in the samples. van Oploo (2000) found that the concentrations of S, Cl, Na, K, Ca and Mg in porewater from in situ dialysis membrane samplers ("peepers") were in good agreement with those determined by centrifuging soil samples after freezing and thawing.

3.2. Sample preparation and analysis

The samples were rapidly oven-dried overnight at 85 °C, and then ground to pass through a 2-mm sieve. Oven drying was intended to destroy sulfide-oxidising bacteria and minimise the oxidation of pyrite. For each sample, 1:5 sediment/water and 1:5 sediment/1 M KCl extracts were prepared using 5 g of oven-dried soil and 25 ml of either deionised water or 1 M KCl. Aliquots of these extracts were used to measure pH, electrical conductivity (EC) and TAA.

The method for determining TAA was adapted from Konsten et al. (1988). In ASS research, a pH value of 5.5 is often chosen to delineate between AASS and PASS (Konsten et al., 1988). For the samples with pH<5.5, a 5-ml aliquot was titrated using 0.01 M NaOH to an endpoint of pH 5.5, and the amount of TAA present was calculated in mol H^+ kg^{-1} for each horizon depth increment.

An overall TAA value for each profile was calculated by summing the depth-weighted horizon values and converting the total to equivalent tonnes of H_2SO_4 per hectare, assuming a bulk density of 1 t m^{-3}. Previous studies at the site have shown this to be a reasonable bulk density estimate for the oxidised upper parts of ASS profiles (van Oploo, 1994). The profile TAA values are approximate rather than absolute indications of the amount of acid within each profile, but the differences between profiles are probably quite accurate.

Air photo interpretation, field observations and personal communication (R. Quirk) were used to identify an area that contained elevated land surfaces and adjacent lower backswamp areas. Six profiles, which were previously sampled from this area in the western sub-catchment (indicated by crosses in Fig. 2), were further analysed for ionic species. Chloride and sulfate were measured in water extracts. Chloride was determined with an Activon Chloride Combination Electrode, coupled with a Unicam 9455 pH/ISE meter, and sulfate was determined by the turbidimetric method (Rhoades, 1982). Al, Ca, Fe, Mg, Mn and Na in the water- and KCl-extracts and K in water extracts were measured using an inductively coupled plasma-optical emission spectrometer (ICP-OES). These are the major elements in the soil porewaters and variation in their concentrations can be used to indicate pyrite oxidation and pedogenic processes.

Total potential acidity (TPA) of the unoxidised sediment was determined on three profiles (RQ1, JJP and P10—see Fig. 2). van Oploo (2000) also determined TPA on five profiles along levee to backswamp transects within the study site and these results were incorporated into the current study. The method used, adapted from Konsten et al. (1988), involved rapid oxidation of sulfides with 30% H_2O_2 and determination of the acidity generated by titration. Sediment/KCl mixtures (1:5) were prepared by adding 25 ml of 1 M KCl to 5 g of oven-dried soil. Twenty milliliters of 30% H_2O_2 was then added and the sample heated to accelerate the reaction. The mixture was left to stand overnight and additional aliquots of 30% H_2O_2 were added until oxidation had ceased. The samples were then heated to decompose excess 30% H_2O_2. After cooling to room temperature, deionised water was added to return the sample to the original 1:5 composition, and the mixture was filtered. An aliquot was titrated using 0.01 M NaOH to an endpoint of pH 5.5, and the amount of total potential acidity present was calculated in mol H^+ kg^{-1}.

4. Results

4.1. Soil profile characteristics

The profile descriptions indicate a fairly consistent stratigraphy (Table 1), although the boundaries between units vary in depth. Most profiles show fairly similar sequences with minor variations on the levees and in the middle of the backswamp. The profiles contain three distinct horizons: the A horizon including organic topsoil, which is thickest on the levees adjacent to Stott's Channel and Leddy's Creek (Fig. 2); the sulfuric B horizon, known as the AASS layer, characterised by jarosite and iron hydroxide mottles; and the unconsolidated, sulfidic, blue-grey clayey C horizon, also known as the PASS layer. A transition zone of variable thickness (usually 0.2–0.3 m) lies between the B and C horizons. It lies at or just below the minimal height of the watertable and contains the oxidation front.

The three transects are shown in Fig. 3a–c. The water level heights for the two sub-catchments are above the sulfidic C horizon in all profiles except P4 (Transect 1), AQ6 (Transect 1) and P20 (Transect 3). There are large variations in depth to the transition zone and its thickness both within and between sub-catchments.

Table 1
Typical ASS profile at McLeods Creek

Horizon	Depth (m)	Field pH	Reaction to H_2O_2	Description	Munsell colour
A	0–0.25	>4	None	Dark, organic topsoil	10YR2/1; 10YR4/3
B	0.25–0.9	2.68–4.4	None or slight	Brown, jarosite, iron hydroxide mottles, oxidised roots, shear-planes	10YR4/3; 10YR4/6; 10YR5/6; 10YR7/8
Transition zone	0.9–1.1	4.0–5.8	Moderate	Colour change from brown to grey, oxidation restricted to root channels	10YR5/3; 10YR5/2
C	>1.1	>5.7	Strong	Unconsolidated blue-grey gel, no oxidation products	5B5/1; N/5

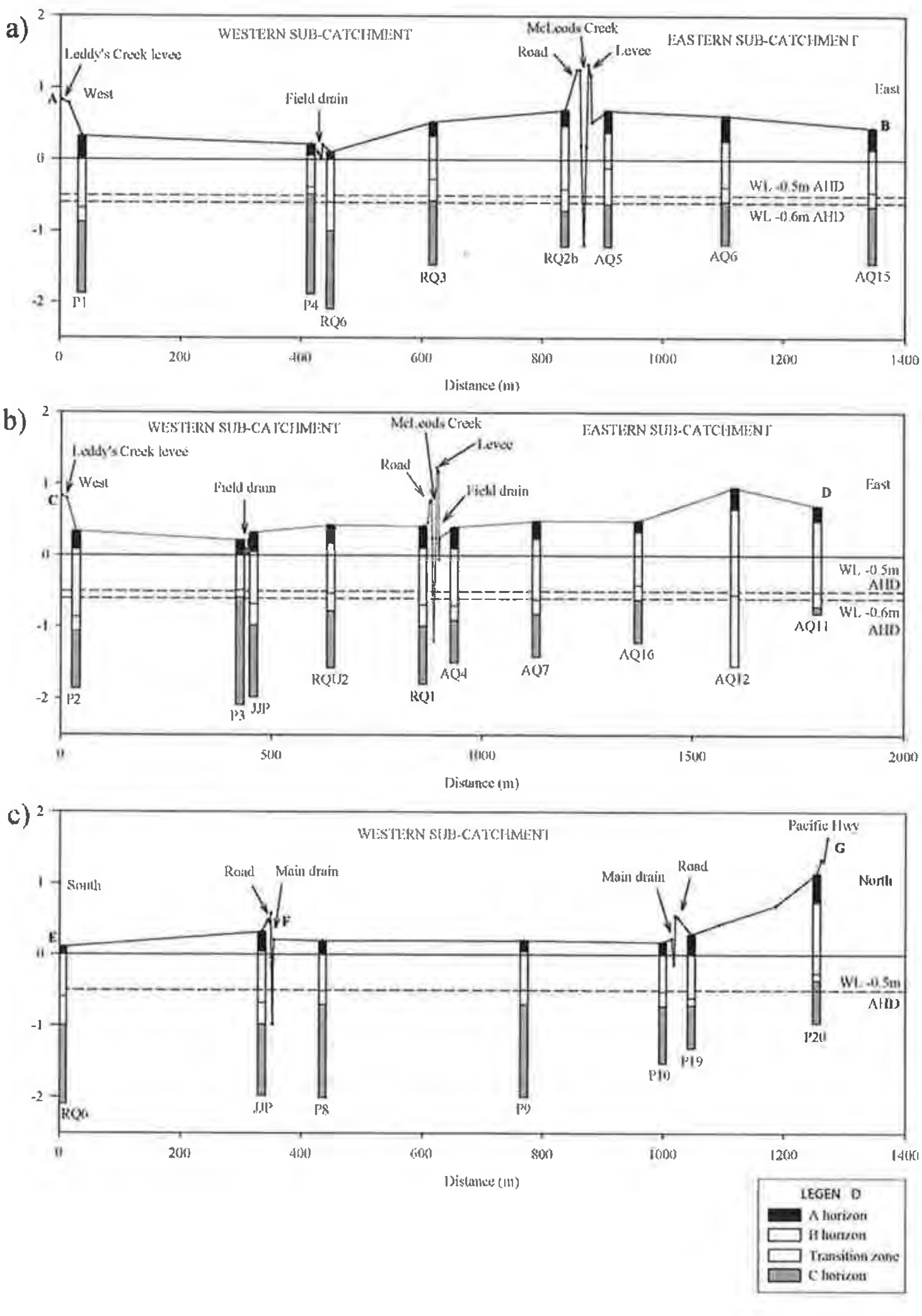

Fig. 3. ASS profile transects across McLeods Creek floodplain. (a) Transect 1 (A to B). (b) Transect 2 (C to D). (c) Transect 3 (E to G). WL: The height at which the water level (WL) in drains is maintained in both catchments is shown. AHD: Australian Height Datum (approximates to mean sea level).

4.2. Total actual acidity

Mean TAA values for all 45 profiles were calculated in 0.2-m increments. They generally decrease with depth (Fig. 4), but the greatest concentration (0.057 mol H^+ kg^{-1}) is between 0.2 and 0.4 m. This represents the top of the capillary fringe above the most common watertable elevation where evaporation leads to concentration of acidity in its various forms.

Below the transition zone, at a depth of 1.1 m, the amount of TAA decreases rapidly and is minimal in the sulfidic C horizon. The pH of the water and KCl extracts of some samples in the C horizon were acidic (pH<4). Also, some samples in the C horizon contained slightly greater TAA values than expected from field pH. This was because of chemical oxidation of reduced metal ions, especially Fe^{2+}, after sample collection, so the values were excluded in calculating the mean TAA values.

TAA values ranged from 0 to 73 t (H_2SO_4) ha^{-1} across the floodplain (Fig. 5). Means for the eastern sub-catchment, western sub-catchment and entire site were 37, 31 and 33 t (H_2SO_4) ha^{-1}, respectively.

Lin et al. (2000) reported that the method used here accounts for only 70% of the TAA in ASS because it includes only soluble acidity and most (but not all) of the exchangeable acidity. This correction has now been accepted by the ASS Management Advisory Committee (ASSMAC) and will be included in their revised ASS manual (Melville, personal communication). Consequently, the measured profile TAA values were adjusted to estimate 100% of the TAA. The revised values indicated that TAA in the ASS landscapes of McLeods Creek is about 50 t (H_2SO_4) ha^{-1}. Johnston (1999) determined similar adjusted profile TAA values for the adjacent Cudgen Lake catchment where pasturelands are predominant.

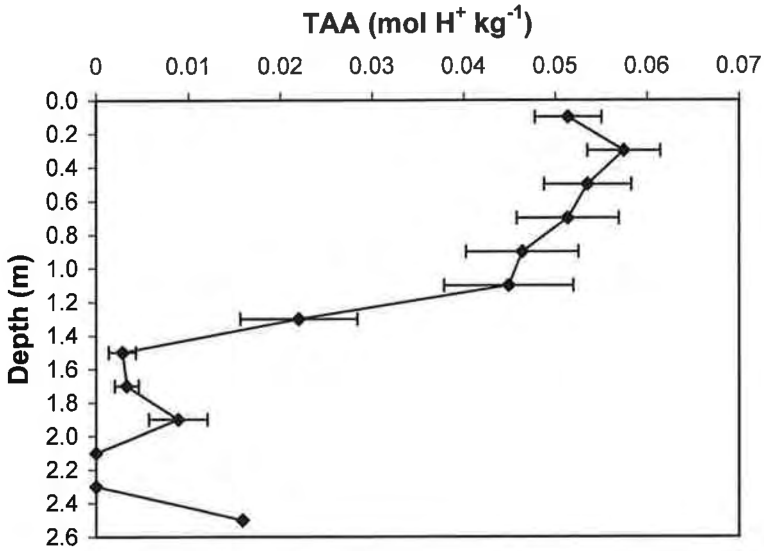

Fig. 4. Mean TAA values versus depth for all ASS profiles.

Fig. 5. The 1962 air photo of McLeods Creek floodplain showing values in total actual acidity (t H_2SO_4 ha^{-1}).

Most profiles in the eastern sub-catchment had greater depths of the oxidation front and TAA values than those in the western sub-catchment. With only a few exceptions, profiles with the deepest oxidation fronts (below 1.2 m in the eastern sub-catchment and below 1.0 m in the western sub-catchment) also contained above-average TAA values. A strong positive relationship between oxidation front depth and TAA showed that 70% of sites with a greater than average oxidation front depth (>1 m) also had a greater than average unadjusted TAA value (i.e. >33 t (H_2SO_4) ha^{-1}).

Superimposition of the TAA values onto an air photo of the site (Fig. 5) taken in 1962, before the intensive sugarcane drainage system was installed, shows that the largest TAA values correspond to natural drainage lines. For example, point X, which consists of low-lying swampland with several small drainage lines flowing into the depression, contained up to 62 t ha^{-1} TAA. At the northern end of McLeods Creek, large TAA values correspond to a large cluster of trees (point Y). We suggest that the high TAA here results from lowering of the watertable by evapotranspiration, thus enhancing pyrite oxidation. In general, the profiles with the greatest TAA occur where drainage lines flowed into low-lying depressions. Smaller values occurred along the natural levees, particularly along Stott's Channel and Leddy's Creek (e.g. point Z, Fig. 2) where the levees are most pronounced. Van Oploo (2000) reported similar results along two levee to backswamp transects within the study site. For both those transects, profile acidity was greater in the backswamp than on the levee, reflecting greater oxidation in the lowland area.

4.3. Soil chemical properties

There were no distinct profile trends for soluble and exchangeable cations in the samples from the six profiles selected for ICP analysis (Fig. 2). However, positive relationships between both soluble (R^2=0.74) and exchangeable (R^2=0.79) cation concentrations and TAA were evident in the six profiles.

Difficulties are often encountered when identifying the sources of single ions in soil porewater; for example, sulfate from pyrite oxidation cannot be distinguished from that derived from seawater. It is better to compare ratios of ions in the porewater with the same ratios in likely source waters. The ratios of soluble ion concentrations in shallow, estuarine floodplain groundwater should be similar to those of seawater only if there has been no significant fluviatile sedimentation, no inflows of freshwater and no significant mineralogical changes in the soil profile, such as the acidification and subsequent clay dissolution that occur in ASS (Dent, 1986; Sammut et al., 1996). Table 2 shows the ratios of soluble ions calculated from mean ionic concentrations in the soil porewater from the six selected profiles and the same ratios in seawater (Hem, 1985) and Tweed River water. The values for the Tweed River into which McLeods Creek discharges are similar to those of seawater and represent a brackish, tidal system.

The Cl/SO_4 ratio of the soil extracts is smaller than that of either the marine or the Tweed river waters, indicating major addition of sulfate. We conclude that this is derived from the oxidation of the sulfidic minerals in the floodplain sediment. The minimum Cl/

Table 2
Mean ratios of soluble ions[a] at various depths in six selected ASS profiles

Depth (m)	Cl/SO_4	Cl/Na	Na/K	Na/Mg	Na/Ca	Ca/K
0–0.1	0.61	16.8	3.3	1.8	1.1	3.7
0.4–0.5	0.28	6.2	2.3	2.3	3.1	0.9
0.7–0.8	0.4	4.9	1.1	3.3	6.8	0.2
1.0–1.1	0.21	3.8	2.2	2.7	6.8	0.4
1.2–1.3	0.18	3.0	4.2	1.9	4.1	0.9
1.6–1.7	0.38	3.7	4.2	3.7	7.9	0.5
Seawater[b]	7.0	1.8	26.9	7.8	25.6	1.05
Tweed River water[c]	15.4	2.1	26.7	9.4	26.7	1.3

[a] As measured in 1:5 soil/water extracts.
[b] From Hem (1985).
[c] Tweed Shire Council Water Quality Data (External Studies—EPA 94 Water Quality Data).

SO_4 value of 0.18 occurs in the transition zone (approximately 1−1.25 m depth), where oxidation of pyrite is producing sulfuric acid.

The Cl/Na ratio is greater in all the soil extracts than in seawater and river water, especially above the transition zone. The depletion of Na relative to chloride is probably because Na^+ from seawater is sorbed on clays, especially those weathered in the acidified soils (Sammut et al., 1996). This depletion of Na is also evident in a smaller Na/Mg ratio compared with seawater.

With the exception of Ca/K in the topsoil (0−0.1 m depth), which has been limed, the Na/K and Ca/K ratios in and above the transition zone are smaller than in both seawater and river water. This is probably because K^+ is released by the acid breakdown of mica-like clay minerals in the floodplain soils (Sammut et al., 1996). Jarosite may act as a temporary K^+ store but as it hydrolyses the K^+ is released to the soluble and exchangeable phases of the porewater.

The Na/Ca ratios at all depths are much less than that for seawater. This is because of sorption of Na^+ and acid-induced dissolution of shell fragments may be an additional source of Ca^{2+} (Sammut et al., 1996). The Na/Ca ratio is least in the topsoil because of the addition of agricultural lime to the soil surface.

With the exception of Cl/Na, the soil extract ionic ratios at 1.65 m (unoxidised pyritic material) are all smaller than seawater, though the porewater at this level should be similar to seawater, given the depositional environment. However, from dialysis membrane sampling of ASS porewater profiles, van Oploo (2000) found that downward diffusion of soluble oxidation products (including SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+} from pyrite oxidation and clay dissolution) occurred to more than a meter below the oxidation front.

TPA values in the unoxidised sediment of eight profiles were fairly uniform, with a mean value of 0.451 ± 0.013 mol H^+ kg^{-1} (n=35). This is equivalent to 0.72% reduced sulfur or 1.44% pyrite. Lin et al. (1995b) reported a mean pyrite content of 1.6% for upper PASS sediments on the Tweed River floodplain.

5. Discussion

5.1. Profile development

Deep drilling and ^{14}C dating of sediments at McLeods Creek and other sites on the Tweed River floodplain (Roman, 1999) showed that the bedrock embayment was infilled to an average of more than 10 m by predominantly marine/estuarine sediment during the last post-glacial marine transgression resulting from a rapid sea level rise (about 9 m/1000 years). As the ratio of estuarine floodplain area/total catchment area of the Tweed River is quite large (1:10) and catchment denudation rates would be small in such a well-vegetated upland humid environment, the river cannot have provided all the sediment. Nevertheless, the sediment infilling from all sources was about 6−7 m/1000 years, less than the rate of sea level rise. Roman (1999) showed that when present sea level was reached about 6500 BP, the sediment surface in the embayment was about 3−4 m below sea level, and proposed that an estuarine mud basin (Lake Tweed) was impounded by a beach sand barrier system, as commonly occurred elsewhere along the NSW coast (Roy, 1984). Lake

Tweed was probably then infilled by tidal flood delta inputs from sediment stores on the continental shelf through the breach in the beach barrier. An increasing degree of fluvial deposition over the sulfidic estuarine deposits is discernible in the natural levee deposits associated with the contemporary and paleo-channels of the Tweed River, and in the upper parts of profiles on the floodplain backswamps.

Several studies, including Lin et al. (1998a), Wilson (1995) and van Oploo (2000), have shown a relatively uniform sulfide concentration throughout the unoxidised estuarine profile (about 3.5% pyrite to >9 m depth). Lin et al. (1998a) showed that the pyrite concentration of estuarine sediments at McLeods Creek does not greatly decrease upwards (except for the topsoil), indicating that water salinity did not limit the accumulation of pyrite. Constant concentrations of iron sulfides throughout the Holocene sediments support the theory of the infilling of the Tweed mud basin under a saline brackish lake, with a similar environment throughout the history of deposition (van Oploo, 2000).

Lin (1995) suggested that spatial patterns of ASS often reflect the historical evolution of mangrove tidal environments and coastal sedimentary processes. However, van Oploo's (2000) analyses of pollen, molluscs and foraminifera in a deep core from McLeods Creek support the brackish estuarine mud basin sediment characteristics; mangrove pollen, along with sugarcane pollen, occurs only in the uppermost sediments (0–0.3 m). The deposition of sulfidic materials in McLeods Creek backswamp resulted in fairly homogeneous lake-bed sediments, so depositional processes cannot be used to explain the spatial variations found in the ASS at McLeods Creek. It is difficult to determine the boundary between the underlying estuarine sediments and overlying fluviatile materials because pyrite oxidation has occurred since the formation of the floodplain (Lin et al., 1998b). We also do not know the original concentration of oxidisable sulfides in the surface sediment that is now AASS. The TPA concentration (0.451 mol kg^{-1}) from the upper PASS would give nearly 10 times more acidity than exists in the AASS (mean 0.057 mol kg^{-1}). A value so large as in the PASS could have originally existed, but it is far more likely that the increasingly fluviatile sediments contained much smaller amounts of oxidisable sulfides.

Pedogenesis in the coastal floodplains of eastern NSW has been dominated by oxidation of the pyritic estuarine substratum, by seasonal watertable movements, and the properties and thickness of alluvium (Willett and Walker, 1982). The non-pyritic topsoils which overlie the pyritic estuarine sediments vary in thickness because of the landscape variables that control terrestrial discharge to the estuary (Lin et al., 1995b). Willett and Walker (1982) showed that differing degrees of development of ASS of a floodplain in southeastern NSW are related to drainage as influenced by topography.

On the Webbs Creek floodplain, to the south of the Tweed River, Lin et al. (1995a) showed that pyrite-induced acidification has occurred in the non-artificially drained ASS. This was interpreted as resulting mainly from lowering of the watertable during prolonged droughts before European settlement. A similar natural control on pyrite oxidation could occur in any area of ASS which has experienced a period of low rainfall (Lin et al., 1995a). At McLeods Creek, the alternating high- and low-rainfall regimes over several decades could have controlled oxidation–reduction processes in the ASS (Lin, 1995). Pyrite oxidation was perhaps initiated naturally by watertable lowering resulting from evapo-transpiration during prolonged drought episodes before the present higher rainfall regime started about 1949 (Lin, 1995). Therefore, significant amounts of acidity would have been produced prior to the artificial drainage of the land.

The low pH and small Cl/SO_4 values suggest that the acid sulfate materials have not been re-pyritised to a significant extent in the reducing conditions during subsequent periods of high rainfall. The acidified sulfuric layer acts as a sink for pyrite oxidation products, which can be moved upwards by capillary action and acidify the non-pyritic topsoils (Lin et al., 1995a).

The strong positive correlations between TAA and cation concentrations probably result from the reaction between acidified porewater and soil constituents, mainly clay minerals, which liberates ions, principally aluminium, iron, potassium, sodium, calcium, magnesium and heavy metals into the soil porewater (Fitzpatrick et al., 1998). In dry periods, sulfuric acid and other ions such as iron, aluminium and potassium move vertically upwards by capillary action and are deposited in the surface layers as secondary minerals (jarosite, iron and aluminium hydroxides, aluminium sulfates) (Slavich and Chin, 2000). During run-off events, these iron and aluminium products may then be hydrolysed and transported to lower parts of the landscape.

5.2. Causes of variation in TAA

There are two reasons for the greater amounts of TAA in the low-lying areas of the McLeods Creek backswamp. First, the low points are zones of accumulation. There has been movement of acidity from the higher areas to the low-lying areas by surface flow or natural and artificial drains. Essentially, the low points in the backswamp represent large acid sinks within the landscape. Second, the fluvial deposits over these low-lying areas are thinner than on the levees and so the PASS was closer to the surface and, therefore, more prone to oxidation, especially in drought periods. Also, tidal inflow of saline water through the levee into these low-points was limited, and so there was little natural neutralisation of the acidity.

Hamming and van den Eelaart (1993) suggested that geomorphology controls variations in TAA in low-lying backswamps. In undrained locations, exchange of water between soils and estuaries may be limited because of low hydraulic gradients and limited egress of drainage water. In such sites, even though pyrite may be oxidised in dry periods, the acidity remains in the soils because of limited outflow of soil water. The discharge of acidity to estuaries from ASS floodplains such as McLeods Creek on the Tweed River is less that 0.5 t ha^{-1} $year^{-1}$ (Wilson et al., 1999). White et al. (1997) noted that products of oxidation could remain within the landscape for 100–1000 years before being either neutralised or leached from the system. Therefore, it is not unreasonable to link present-day acidity levels with geomorphological features of the past.

Dent (1986), Willett et al. (1993) and others have suggested that landscape drainage for agricultural land uses, such as with sugarcane production, is the direct cause of pyrite oxidation in ASS landscapes. However, our results and other studies at McLeods Creek (e.g. White et al., 1996; Wilson et al., 1999) suggest that this is an incomplete picture because the draw-down of the watertable results mainly from evapotranspiration. Oxidation of sulfidic sediments occurred long before engineered drainage (White et al., 1997). Nevertheless, it is clear that artificial drainage for flood mitigation or water table control in

ASS landscapes has increased the rate of transmission and provides the conduit by which acidity is transported from the backswamp stores to the estuaries.

5.3. Water management strategies for minimising sulfide oxidation and export of acidity

Two issues must be addressed for management of ASS landscapes: (a) how to eliminate further sulfide oxidation, and (b) how to minimise the export of acidity from existing stores in the landscape (Slavich and Chin, 2000). Atkinson and Tulau (2000) proposed four ways of decreasing export of acidity: containment, neutralisation, dilution and transformation. They suggest that containment is often the only viable option available. It involves isolating the acid from the environment, particularly from the receiving waters (Atkinson and Tulau, 2000).

ASS management at McLeods Creek has concentrated on containing acidity within the soil profile and minimising subsoil discharge from the acidified zone into nearby drains (Tulau, 1999). Drainage of water from the soil into the surrounding drains occurs only when the watertable is above the elevation of the nearest drain base (Wilson et al., 1999). There is no lateral flow of water below the drain base and evapotranspiration is the only cause of watertable lowering below the drain base (Wilson et al., 1999). Except in extended drought periods, watertable levels in the fields are maintained above the PASS, thereby minimising further generation of acid by pyrite oxidation and reducing acid release (Dent, 1986; Atkinson and Tulau, 2000). The lower watertable under the sugarcane crop also provides a large soil moisture storage capacity to reduce runoff during periods of rain.

This acid containment program has been operational in the eastern sub-catchment for the past 16 years where water level in the outlet drain has been kept to a constant −0.6 m AHD with an electric pump. For at least 4 years, a pump has maintained water levels in the lateral drains of the western sub-catchment at a constant −0.5 m AHD. Prior to this, a tractor-mounted pump was used to remove excess surface water rapidly after flood events. Pumping maintains drain water levels above the sulfidic C horizon (see Fig. 3) and provides storage capacity for rainwater. In the western sub-catchment, approximately 25 mm of rainfall can be stored in the drains with this management regime. During dry periods, when the drains are below the automatic pump water level, up to 50 mm of rainfall can be stored.

The sugarcane fields have been levelled by a laser-controlled scraper bucket to produce a uniform slope of very low gradient. The scraper bucket collects soil from elevated areas and deposits it in depressions. This work began in the 1990s and has helped reduce infiltration during rain because it increases surface run-off and prevents localised water-logging (White et al., 1997; Wilson, 1995). The total length of field drains has been halved by drain infilling and this is expected to substantially decrease the acid export from oxidising drain banks. Therefore, evapotranspiration control of watertable fluctuation, minimising surface water infiltration by laser levelling, and drain water pumping, together lessen watertable rise and acid discharge from ASS.

At McLeods Creek, where total annual rainfall usually exceeds evaporation, it is not possible to design completely closed containment systems. However, it is possible to design systems in such a way that discharges occur only at times of high flow when the opportunity for dilution of the acid is maximised (Atkinson and Tulau, 2000). The success of this strategy is enhanced by the installation of a hillside interception drain, which allows the acid store to be isolated from upland flow so that run-on to the floodplain is eliminated. This allows upper catchment water to be transported through the floodplain without raising water levels or transporting additional acid (Atkinson and Tulau, 2000).

Although this method reduces acid discharges, it does not neutralise acidity or result in long-term improvements in porewater quality (Blunden et al., 2000). The 'stored' acidity will ensure that the porewater pH is maintained at approximately 3.5–4, and that the concentration of dissolved aluminium will remain in equilibrium with aluminium sulfate minerals that form under acidic conditions (Blunden et al., 2000). Clearly, the sustainable use of the ASS landscapes depends upon having perennial crops such as sugarcane that provide an adequate evapotranspiration pump, and can survive these chemically hostile environments.

A number of new acidity management initiatives are being developed and trialled at McLeods Creek by our research team in collaboration with the cane farmers. These include minimal tillage and cane trash retention combined with agricultural lime application to minimise discharges from ASS profiles. The additional organic matter in the soil surface reacts with metallic ions, such as Al^{3+}, Fe^{2+}, Fe^{3+} and Mn^{2+}, leading to the formation of insoluble metal-organic compounds (Jenkinson, 1988). Evangelou (1995) recommended the addition of limestone and organic matter to pyritic soils because of the increase in potential of such materials to absorb heavy metals, including Fe^{2+}, Fe^{3+} and Mn^{2+}. This is analogous to the Reducing and Alkalinity Producing Systems (RAPS) approach that is proving effective with Acid Mine Drainage (AMD) management (Jarvis and Younger, 2000). Other techniques adopted from the mining industry, including active and passive acidity barriers and neutralisation systems, are also being installed in the outlet drains from cane land areas, so that acidity in the drain water is neutralised prior to discharge to the estuary. The objective here is the retention of the estuary water's alkalinity for use by other components lower in the estuary ecosystem.

6. Conclusions

The McLeods Creek site contains levels of acidity and associated oxidation products that, upon direct release into the river system, can cause devastating impacts such as those witnessed in the Tweed River in 1987 (Easton, 1989). Such a release of acidity into the waterways would cause major environmental and economic costs to the industries that rely on the Tweed River as a resource.

Significant variations in TAA occur across the backswamp, showing that the main acid load is coming from particular low-lying areas of severely affected ASS. We propose that pyrite oxidation mainly occurred during prolonged drought episodes prior to the construction of the existing drainage systems, and that the spatial variation in TAA is a reflection of the geomorphology and drainage patterns of that period, with low-lying areas containing greater TAA.

Successful management of ASS must take into account the specific nature of the site so that areas with greater TAA can be targeted. The current acid containment program aims to minimise the export of acidity from the site, and techniques such as lime and organic matter application, which target the areas where acidity has already been concentrated would be the most effective.

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Mechanisms of acid sulfate soil oxidation and leaching under sugarcane cropping

A. S. Kinsela[A,B] *and M. D. Melville*[A]

[A]School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia.

[B]Corresponding author; email: a.kinsela@student.unsw.edu.au

Abstract. Analysis of acid sulfate soils (ASS) under sugarcane cropping at a site on the Tweed River, north-eastern New South Wales, showed that the majority of the acidity and higher valence ions generated through pyrite oxidation was retained within an individual caneblock. It appears that the oxidation products generated >1 m away from the field drain edge primarily remain where they were formed, and are not exported to the adjacent field drain. Capillary rise and diffusion control the transfer of oxidation products within this area. Leaching and mass movement dominate the transport of ionic species in the topsoil and close to the field drain edge (~1 m). Soluble ion movement within the unsaturated zone also appears to be influenced by nutrient uptake of the growing sugarcane, adsorption and exchange reactions, and convective/dispersive forces.

The almost ubiquitous degree and depth of oxidation of ASS profiles along most of the coast, even where no artificial drainage has occurred, leads us to propose natural hydrological and pedogenic processes as the cause. While artificial drainage systems may not have caused the acidity that is stored in backswamps, they do provide the conduit for acidity export. Therefore, management regimes should focus on maximising the retention of acidity in the backswamp and treating that which is exported. Whilst a reduction in the drain frequency appears a logical solution to a reduction in the acidity export from the site, consideration must be given to the benefits field drainage provides before any subsequent changes can be made. An integrated approach of drain minimisation, laser levelling, and active watertable control would appear to be the most appropriate policy in containing the acidity within the soil profile. This approach, combined with the strategic application of lime, offers a means for minimising acid export from the sampled site.

Additional keywords: acidity, diffusion.

Introduction

The acid sulfate soils (ASS) on the New South Wales north coast, Australia, are located in what were originally tidally influenced floodplain areas, adjacent to ecologically sensitive land and aquatic ecosystems. The large tidal range, small catchment size, and low outflows characteristic of eastern Australian embayments have resulted in the extensive deposition of typically fine-grained Holocene sulfidic sediments (White *et al.* 1997). Indeed, concentrations of pyrite have been previously measured at >3% over most of the ASS profile within the McLeod's Creek catchment (van Oploo 2000), a tributary of the Tweed River. The oxidation of these sediments and the export of the oxidation products (particularly acidity and dissolved metals) has resulted in significant environmental impacts, including massive fish kills and outbreaks of epizootic ulcerative syndrome, within the study area (Easton 1989), as well as in other eastern Australian estuaries (Callinan *et al.* 1993; Sammut *et al.* 1993, Sammut *et al.* 1995, 1996; Willett *et al.* 1993).

Most of the Tweed River floodplain is used for broad-acre sugarcane production with well-established drainage systems. It is commonly believed that drainage systems with 1-way flap gates have caused the observed oxidation of pyritic sediments and the associated discharge of acidity by the lowering of the watertable relative to the sulfidic sediments (Walker 1972). However, Lin *et al.* (1995) demonstrated that oxidation of ASS landscapes occurred even without drainage.

Smith *et al.* (2003) showed that the concentration of existing acidity stored in ASS profiles is in the order of 50 t H_2SO_4 equivalent/ha, but only about 100–200 kg H_2SO_4/ha is exported from the Tweed floodplain each year (Wilson *et al.* 1999). Greatest concentrations of existing acidity occur along original natural drainage lines (Smith *et al.* 2003). Understanding the sources and mechanisms of transfer of this acidity is extremely important to the health of downstream aquatic ecosystems. Any insight regarding the transfer of the chemical constituents within the ASS profiles under sugarcane also allows for the development of

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appropriate management strategies. The extent of drainage-induced oxidation and its effects on the transfer of oxidation products will therefore be extremely site-specific, depending on the geomorphology of the area, the antecedent hydrology and drainage system in place, and the localised watertable fluctuations.

Therefore, the specific aim of this paper is to examine the concentrations of soluble ions at a representative location on the Tweed River, and by inferring the transport processes occurring, suggest possible management/amelioration strategies that may minimise the transfer of such oxidation products from the system. It should be noted that this is a preliminary study, and further measurements need to be made to confirm the trends outlined, as well as to identify whether the results are comparable to other areas along the Australian coastline. The issue of anthropogenic *v.* natural causes of ASS oxidation and acidity production will also be addressed.

Materials and methods

Soil sampling

The soil sampling was undertaken during February 2000 on the backswamp floodplain of McLeod's Creek (28°18′S, 153°31′E), a tributary of the Tweed River, north-eastern NSW (Fig. 1). The climate of the Tweed River is humid and subtropical, with an average annual rainfall of >1400 mm, and a pronounced wet season extending from December to March (Wilson *et al.* 1999). McLeod's Creek was first modified in the 1930s to remove water from wetland areas for cattle pasture and later for sugarcane production (van Oploo 2000). It has subsequently been widened and straightened, and with the construction of field drains approximately 30 years ago, there is currently >100 km of drains with McLeod's Creek being the largest (Wilson *et al.* 1999).

Sixteen soil profiles were extracted from a single canefield in 2 parallel transects crossing over a typical field drain. The profiles were taken at intervals of 0, 0.5, 1, and 5 m perpendicular to, and on each side of, the drain. One side of the drain was fallow, the other under cane. Of the soil profiles extracted and described in the field, 6 were chemically analysed in the laboratory, with the remainder used for watertable measurements. The configuration of the analysed profiles is shown in Fig. 2. From the field description, which included pH, reaction to peroxide, and physical attributes, layers within the profiles were identified and representative samples were selected for laboratory analysis. These included material from the topsoil, the jarosite layer, above and below the oxidation front, and from the deep, unoxidised blue-grey gel. The selected samples were sealed in airtight plastic bags and frozen for transportation back to the laboratory. At each profile, a 0.1-m-diameter PVC pipe was inserted into the space where the soil had been removed, enabling the subsequent measurement of watertable elevations at regular intervals. The ground surface was accurately surveyed, relative to Australian Height Datum (AHD).

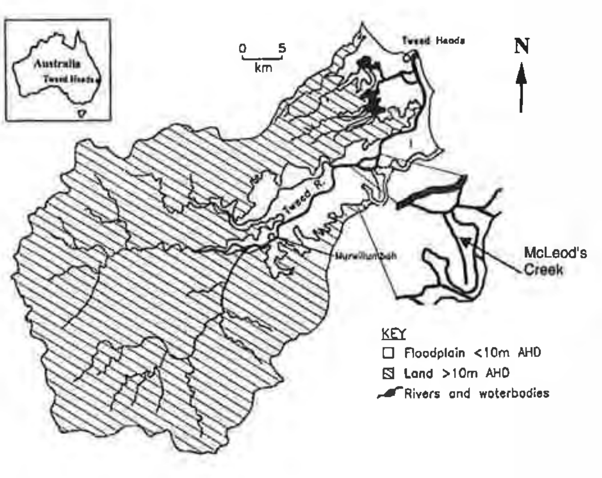

Fig. 1. Location of McLeod's Creek within the Tweed River catchment (modified from Lin *et al.* 1998).

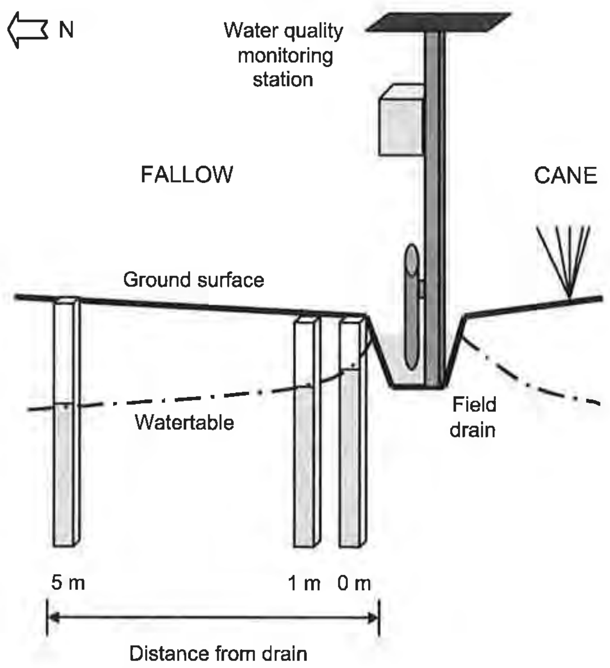

Fig. 2. Configuration of the soil profiles chemically analysed. Two parallel transects, perpendicular to the northern/fallow side of a typical field drain.

Chemical analyses

Standard laboratory methods were used to measure the concentrations of soluble ions and acidity in ASS profiles at 0.1-m depth increments in the 6 profiles. The extracted samples were rapidly dried in an oven at 85°C for 24 h and allowed to cool. Laboratory analysis included 1 : 5 soil : deionised water extracts measuring a range of soluble cations and anions by ICP-OES (aluminium, Al; calcium, Ca; iron, Fe; potassium, K; magnesium, Mg; manganese, Mn; sodium, Na; sulfur/sulfate, SO_4; silicon, Si; strontium, Sr). Further soil : deionised water extracts were used to measure electrical conductivity, chloride ion (Cl) concentration (using an Activon chloride combination ion electrode), and acidity by titration to pH 5.5 with sodium hydroxide. Total actual acidity (TAA) was measured by titration with sodium hydroxide to pH 5.5 on 1 : 5 soil : 1 M KCl extracts. Total potential acidity (TPA) was also conducted on 1 : 5 soil : 1 M KCl extracts treated with hydrogen peroxide. Both TAA and TPA measurements were performed in accordance with the analytical methods set out in the Acid Sulfate Soils Management Advisory Committee (ASSMAC) Guidelines (Stone *et al.* 1998).

Results

Field description

The field descriptions show an organic surface layer characterised by a brown to dark brown colour, and richness in organic matter. It extends to a depth of around 0.0 m to –0.2 m AHD, and its pH is generally >4.0. The oxidised sulfuric layer is characterised by a distinct colour change to lighter brown, along with mottling of yellow jarosite, and red/brown iron oxides/hydroxides, possibly goethite. The B layer extends to a maximum depth of –0.5 m AHD, and its pH ranges from 2.7 to 4.0. The transition zone exhibits qualities of the actual ASS above it, and the potential ASS below it. There is a gradual change in texture from a brittle or crumbly consistency to a labile or plastic texture towards the bottom of the transition zone. The pH also traversed from acidic at the top (~3.5) to near neutral at the bottom (~6.0). Planes of iron oxidation and jarosite still occur in this layer, along with fine roots. The sulfidic or potential ASS layer consists entirely of unconsolidated blue-grey gel, extending beyond the depth of sampling (–1.15 m AHD). The pH slowly increases down the profile from near-neutral to neutral (~6.9). Intermittent depths contain fine roots and shell fragments. No jarosite or iron oxidation products occur at these depths.

Chemical analysis

A fundamental requirement for the use of any water quality or soil extract dataset is that the total charge of anions should equal the charge of cations. Here, the charge-sum of water soluble anions (y) approximately equals the sum of water-soluble cations (x) ($R^2 = 0.99, y = 1.06x - 8.52, n = 33$). In addition, there is a clear linear relationship between electrical conductivity (y) and the sum of water soluble cations (x) ($R^2 = 0.97, y = 0.02x - 0.02, n = 33$). The latter 2 variables are measured independently of one another. The high correlation coefficients for these 2 relationships therefore allow confidence in making subsequent interpretations of the presented data.

All soluble species were shown to have smaller concentrations in the topsoil and sulfuric layer than the underlying sulfidic sediments. Several distinct trends in the soluble ion chemistry were observed along the transect, when moving away from the field drain edge towards the centre of the sampled canefield (Fig. 3). Most noticeable was the decrease in Cl and Na, simultaneously coupled with the increase in SO_4, Ca, and Mg when moving from the drain edge (0 m) to within the canefield (5 m).

The acidic cations (Al, Fe, and Mn), which are shown in Fig. 4, have elevated concentrations in the 5-m profiles compared to the 0-m profiles. Within both the 5- and 1-m profiles, the concentration of each ion reaches a maximum at the top of the transition zone. This fact is masked within the 0-m profile with the reduced values of all ions.

The depth-weighted average, calculated for a single transect, showed the TAA was >2.5 times greater within the canefield (5 m) than at either 1 or 0 m from the field drain edge. Values ranged from 46.14 t H_2SO_4/ha at the 5-m profile to 19.97 and 18.92 t H_2SO_4/ha, at the 1- and 0-m profiles, respectively. As these calculations were performed on only a single transect, further repetition of the analysis is needed to confirm this trend. However, the values are commensurate with the 45 profile measurements made by Smith *et al.* (2003) for profiles within cane blocks at the study site.

Comparison of the TAA and TPA results (Fig. 5) shows the extensive store of potential acidity throughout the solum, with a large increase below the oxidation front, where the

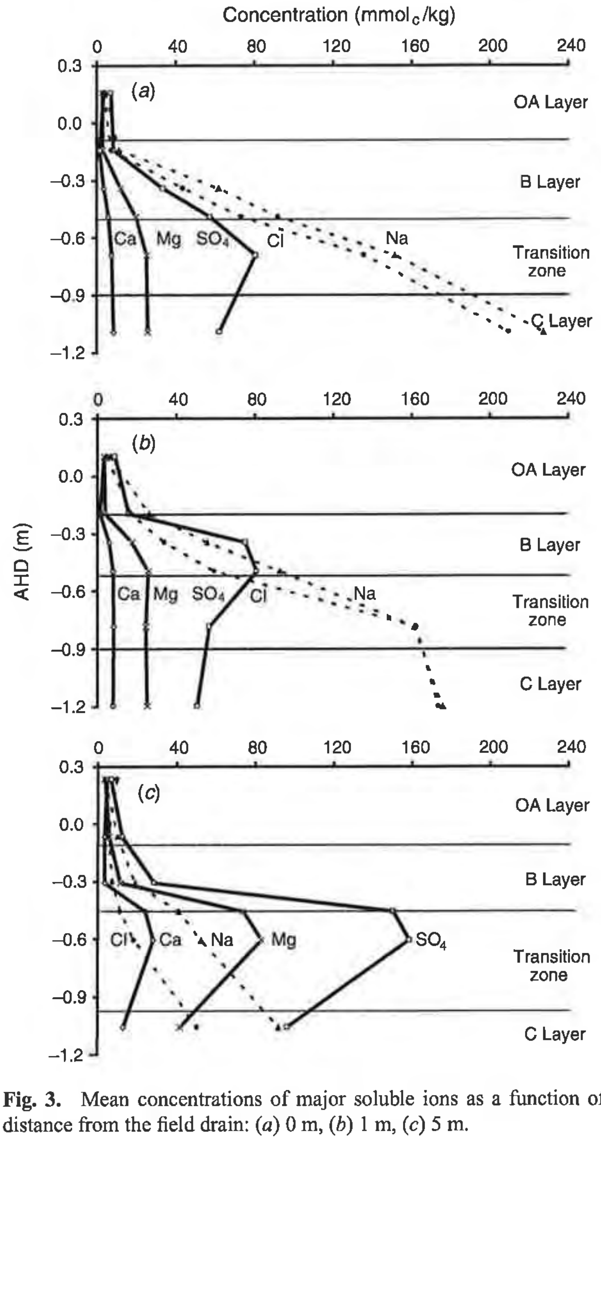

Fig. 3. Mean concentrations of major soluble ions as a function of distance from the field drain: (*a*) 0 m, (*b*) 1 m, (*c*) 5 m.

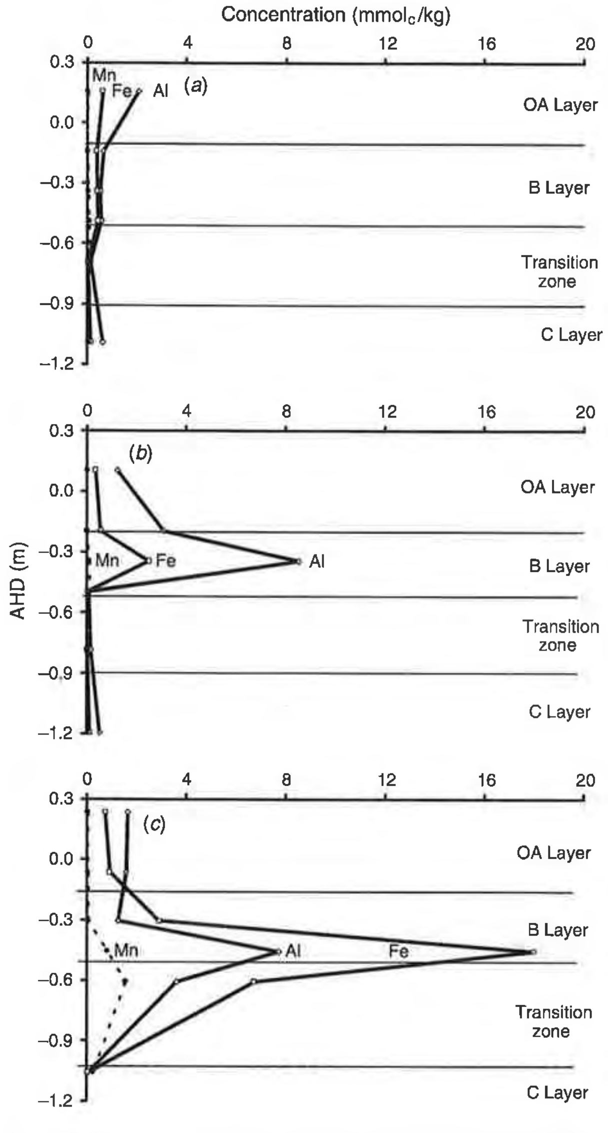

Fig. 4. Mean concentrations of soluble acidic ions as a function of distance from the field drain: (*a*) 0 m, (*b*) 1 m, (*c*) 5 m.

pyrite remains unoxidised. The elevated levels of potential acidity in the sulfidic layer (~450 mol H^+/t) compared with the TAA at the same depth (<20 mol H^+/t) represents the actual ASS overlying the potential ASS, typical of any ASS environment. The elevated levels of TPA compared with TAA in the sampled topsoil can only be explained by the limitations of the TPA methodology, particularly the interference of minor amounts of sulfate minerals and organic matter (Clark *et al.* 1996; Lin *et al.* 1996; Sullivan *et al.* 1999). More importantly though, the TPA results in Fig. 5 highlight the relatively uniform concentration of potential acidity along the transects. Therefore, the data collected are consistent with the theory that most acidity from protons and hydrolysable ions released into the adjacent drain water is coming from only within 1 m of the field drain edge.

When the field descriptions of the soil profiles were compared with watertable measurements taken from the extracted profiles, it was apparent that at the time of sampling the watertable existed primarily within the sulfuric layer, as shown in Fig. 6. The observable increase in elevation of all layers at 0.5 m from the field drain is due to the compaction of the ground by tractors and other heavy machinery on the adjacent cane-growing surfaces, a point reinforced by the vertical exaggeration of the figure. It should be noted that Fig. 6 represents the watertable during the February soil sampling period, which is during the middle of the wet season for the area. Rainfall measurements preceding and during the time of sampling were less than the average annual measurements previously recorded. Similar measurements taken during April and July of that year showed the same outcome, that the watertable existed above the oxidation front.

Discussion

The results of the field descriptions and detailed laboratory analysis suggest that under the current drainage regime, most of the acidity and other soluble ions generated from pyrite oxidation and being exported into the drain is doing so <5 m from the field drain edge. Leaching and mass movement associated with watertable fluctuations and local rainfall are primarily responsible for the removal of ionic species at the field drain edge, and within the upper layers of the soil profile. Solute movement within the unsaturated zone will also be influenced by the nutrient uptake of growing sugarcane and by adsorption and exchange within the soil's exchange complex, as well as by convective and dispersive forces that will be especially active close to the field drain edge where concentration gradients are at their maximum. These points are illustrated by the progressive decrease in acidity, sulfate, and higher valence metal ions away from the centre of the canefield, dispersed from the point of generation. The converse can be seen with the Na and Cl profiles, which show a progressive decrease into the canefield, away from their actual source, the brackish drain water.

These effects decrease slightly within the lower layers, due in part to the rapid decrease in hydraulic conductivity measured at depth (White *et al.* 1993), and also due to locations further into the canefield. The low pH and large concentrations of sulfate in the upper horizons indicate that capillary action and diffusion play a vital role in the transfer of oxidation products within the sampled canefield (i.e. > 1 m away from the field drain edge). It is likely that these mechanisms transfer most of the oxidation products upwards along moisture potential gradients during low watertable regimes under such artificial drainage conditions. This interpretation is consistent with that identified by Lin *et al.* (2001), also at McLeod's Creek. Downward leaching of dissolved ions during rain-fed infiltration is probably negated

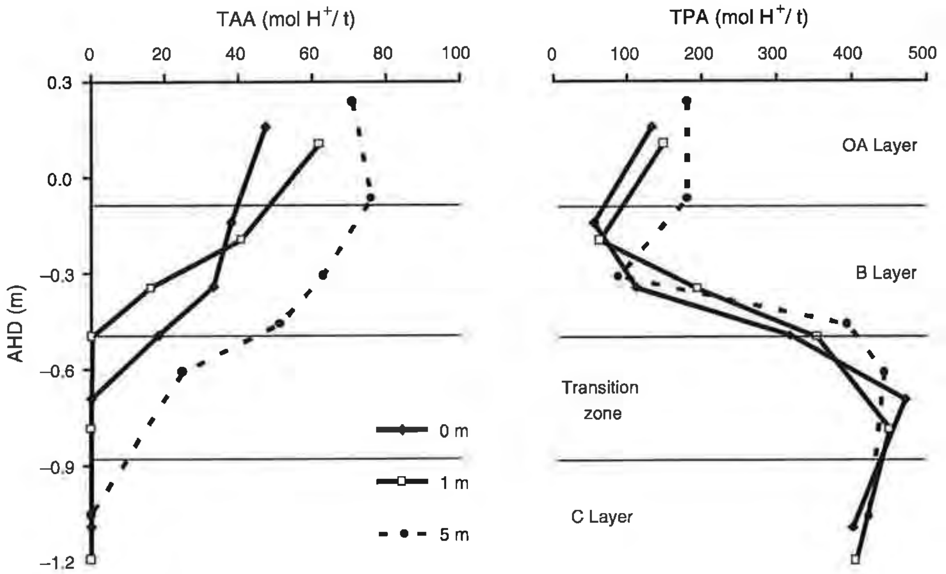

Fig. 5. Total actual acidity (TAA) and total potential acidity (TPA) as a function of distance from the field drain.

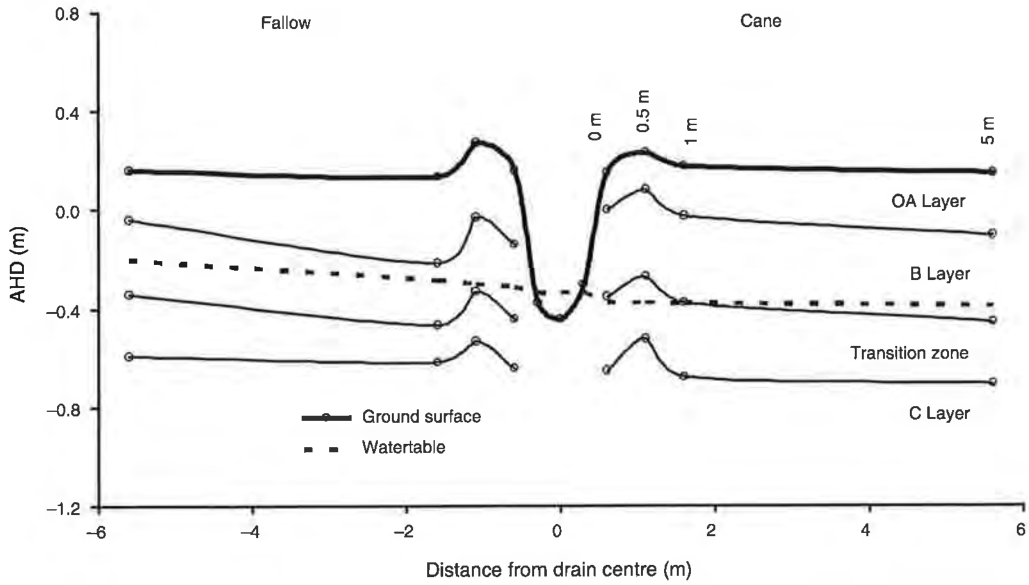

Fig. 6. Watertable and horizon layer heights (AHD) as a function of distance either side of a typical field drain.

by the upward movement of the watertable in response to the infiltration. The overall affect of rainfall infiltration, upward watertable and capillary concentration of salts, is for a net leaching regime of upward-and-out to surface drainage (Fig. 7).

Natural v. anthropogenic oxidation of ASS landscapes

The Australian ASS literature appears to generally propose that European drainage of backswamp ASS landscapes has been the predominant cause of the observed oxidation and acidification problems. We have been a party to this view (e.g. see Callinan *et al.* 1993; White *et al.* 1993; Willett *et al.* 1993), perhaps greatly influenced by the earlier literature based on drainage-induced acidification in Dutch polders that were previously shallow coastal seas (e.g. Pons 1973). This is also unambiguously the case in Australia where bund walls and flap-gates were constructed in permanently tidal-saturated landscapes, such as in the

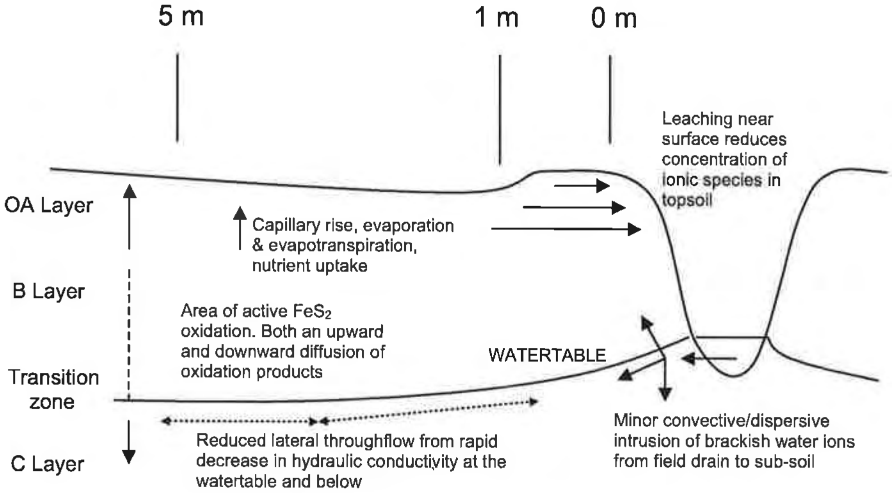

Fig. 7. Dominant processes controlling the movement of soluble ion species in the sampled transects.

mangrove swamps on the southern shore of Trutes Bay (a left-bank tidal embayment of the lower Tweed River), or on the right-bank shore of East Trinity Inlet, Queensland (see Cook *et al.* 2000). However, in estuarine floodplain backswamps, the belief of a European drainage-caused landscape oxidation appears to be founded on the general observation that when artificial drainage systems were first installed, increased acidic discharge and their environmental impacts occurred. However, such observed acidic discharge would also occur if the drainage system only provided the new conduit for enhanced acidity export from an already naturally oxidised landscape. We now propose the importance of this latter, natural pedogenesis, acidity cause, based on many field observations (e.g. Lin *et al.* 1995; Donner and Melville 2002; Smith *et al.* 2003), and this has been accepted by the NSW Healthy Rivers Commission (HRC 2003, pp. 47–48). Unfortunately, it is now difficult to test natural pedogenesis satisfactorily because most of these floodplain backswamps on east coast Australia have already had some degree of drainage, and no sufficiently detailed pre-drainage analysis of ASS and the landscape hydrology has been undertaken.

It is logical that such drainage systems markedly reduced the duration of backswamp inundation (White *et al.* 1993), but it has not been established that the changed degree and duration of backswamp inundation altered watertable elevations and ASS profile saturation sufficiently to cause the observed, almost ubiquitous, >1 m depth of ASS profile oxidation. The lowering of the watertable should be seen as preferential oxidation down drained, generally vertical macropores. To some degree this does occur; however, most commonly at McLeod's Creek and at other sites where such drainage systems exist, a uniformly horizontal oxidation front occurs within the saturated sediment and below any observable watertable elevation (Wilson *et al.* 1999; van Oploo 2000). This oxidation depth of generally >1 m exists in the fine-grained sulfuric/sulfidic sediment with a very small pore size that gives an effective capillary fringe and saturated sediment near to the ASS mineral profile's surface. To drain the pores in this sediment would require a watertable elevation much lower (>>1 m) than any observed in the past 15 years of study at McLeod's Creek. This period recently coincided with the most severe and prolonged drought recorded in European settlement of the Tweed area. Such an apparently uniform and deep oxidation front is also observed where no artificial drainage has occurred (see Lin *et al.* 1995). The existence of this oxidation front below the watertable appears most likely due to downward diffusion of some oxidants through the saturated soil. This is currently under research at McLeod's Creek so that a clearer picture of ASS landscape pedogenesis may be obtained.

Some authors (Blunden and Indraratna 2000; Johnston *et al.* 2002) have presented results where at least some of their study site materials are sandier and/or apparently have a greater degree of lateral hydraulic conductivity than that described for McLeod's Creek. Nevertheless, these represent exceptions to the nature of the materials deposited in the geomorphic mud basins that generally formed behind east coast sand barriers.

Coastal geomorphology, sea level, and climate changes during the Holocene

The geomorphological variations in sediment characteristics and stratigraphy are not well recognised in ASS research, so that the oxidised sediment at the top of the ASS profile is presumed to have been the same as that below the oxidation front, particularly with respect to the original sulfide mineral content. This is unlikely to be the case because, whereas the deeper estuarine sediment was deposited in brackish tidal water conditions (rich in dissolved sulfate), the material closer to the surface will have had an increasing fluvial influence. Walker (1970) provided an excellent early view on geomorphic/pedogenic development in the estuarine/fluvial evolution of the lower Macleay River floodplain. Dalrymple *et al.* (1992) and Roy *et al.* (2001) also provide models to explain the infilling of east coast estuarine embayments with their sand-barrier-induced, inner mud basins where sulfidic sediments accumulated initially, later to be overtopped by fluviatile sediment. The degree of estuary embayment infilling and emergence of the mud basin surface above a shallow tidal brackish lake will vary, depending on sediment input rate and the relative sea level in the estuary embayment. There are some estuary embayments that are 'mature' and completely infilled (e.g. most of the Clarence embayment) and other 'immature' embayments where significant parts have not been infilled (e.g. Cudgen Lake).

The history of the last global post-glacial sea level rise from about –125 m at 20 ka to its present position at about 6.5 ka is now well established (see Lambeck and Chappell 2001). Thom and Roy (1985) proposed their models of east coast Australian geomorphic evolution based on a constant sea level since about 6.5 ka. This is likely to be true of the sea level as controlled by the balanced inputs/outputs of a constant water volume into a globally constant ocean basin volume. However, recent research on east coast Australia shows that sea level reached a maximum at about 6.5 ka but this was up to 1–3 m above today's relative sea level. Isostatic readjustment of the lithosphere along the Australian continental margin caused coastal uplift, but the degree of this uplift varied even at locations only 100 km apart, and increased with distance inland from the coast (Lambeck and Nakada 1990). Some work suggests this uplift rate (and effective sea level fall) has been constant until the present (see Nakada and Lambeck 1989; Lambeck and Nakada 1990; Lambeck and Chappell 2001). However, Flood and Frankel (1989), Baker and Haworth (1997), and Baker *et al.* (2001) used fossil intertidal tube worm deposits stranded on coastal cliffs to infer a more prolonged, constant high relative sea level until about 2 ka, then a fall to present relative sea level. Whatever the timing of a relative sea level fall by up to 1–3 m, the magnitude and duration of this drainage base level decline is sufficient to account for much of the observed backswamp ASS oxidation, certainly where contact with tidal influence has been maintained.

The weather patterns of today are unlikely to be representative of the climate throughout the Holocene epoch (<10 ka), as can be seen in the first instance from variations in rainfall and associated flooding during the second half of European settlement. Pittock (1975) identified a 10–20% increase in mean annual rainfall over much of NSW and Queensland during the 1940s to 1970, compared with the first half of the 20th Century. W. D. Erskine and his colleagues extended this study to include records from the 19th Century and later 20th Century and proposed multi-decadal periods (about 50 years) of drought-dominated rainfall regime (about 1890–1946) and flood-dominated rainfall regime (< 1890 and 1946+), mostly with increased summer rainfall. Bell and Erskine (1981), Erskine (1986), and Erskine and Warner (1988) showed this latter increase in rainfall in the Nepean and Hunter Valleys gave an upward shift by 50–100% in the flood frequency curve. Smith and Greenway (1983) also showed an increase in flood height on the Tweed, Richmond, and Clarence Rivers after the mid 1940s. We do not have evidence of the existence of these weather patterns before European settlement, but the global 'Medieval Warm Period' (about 1100–1300) possibly had mean temperatures several degrees Celsius warmer than today. Elevated temperatures will be expressed in increased evapotranspiration, which has been shown as a major control on floodplain watertable elevation (e.g. White *et al.* 1997).

The south-eastern Australian climate of the Holocene, since present sea level was attained (about 6.5 ka), has been deduced by many researchers from lake levels and salinities, from vegetation signatures, and from aeolian dust deposit records. In general, from about 8 to 5 ka, the climate was wetter than present (Bowler 1981; Dodson 1986; Chivas *et al.* 1985, 1993; Magee *et al.* 1995; Anker *et al.* 2001). From about 5 to 2 ka, conditions were drier than present with significant changes in Tasmanian pollen spectra (Anker *et al.* 2001) and changes in inland lakes and sediments (e.g. Stanley and De Deckker 2002). Chivas *et al.* (1985) and Bowler (1981) showed that from about 2000 BP to 300 or 400 BP, Lake Keilambete in Victoria returned to perennial lake conditions. However, this return of high lake levels was not shown by Dodson (1986) for Breadalbane or Coventry and Walker (1977) at nearby Lake George, NSW. It is unclear exactly what natural vegetation changes have occurred on coastal floodplains over the past 6.5 ka in response to changes that occurred in climate and associated evapotranspiration-driven drainage; it is likely that they have been profound. The shift to drier conditions over much of the last few thousand years, compared with conditions initially experienced by landscapes accumulating sulfidic sediments, favours natural landscape drainage. This is particularly the case when base level is also lowered.

It seems to us that natural processes of landscape/hydrology evolution and pedogenesis can account for the existence and degree of much of east-coast Australia's backswamp ASS acidification. Artificial drainage systems may not have caused the acidity formation but they do provide the conduit for its enhanced export. Therefore, if any such landscapes have not been drained, any proposal to initiate their drainage should be avoided.

For those backswamps already drained, the management of the acidity export is essential and must focus on mechanisms to maximise acidity retention in the landscape, and treatment of any acidity being exported in drain systems.

Management implications

The past and current management of ASS at McLeod's Creek has involved the interception and diversion of hill-slope runoff to bypass the floodplain in major drains. Within the floodplain, management involves the containment of the acidity and other oxidation products through laser-levelling to minimise rain-fed infiltration, and minimisation of lateral drains that are the major source of acidity export. This approach also aims to minimise acidic export by reducing near-surface soil moisture, and by doing so, increasing the storage for local rainfall whilst maintaining the watertable above the potential ASS layer in order to minimise further sulfidic oxidation (Atkinson and Tulau 2000; Tulau 2002). This appears to be the only viable option for the study area, as the complete neutralisation of the existing acidity store (~50 t H_2SO_4/ha.) with lime is too expensive for broadacre agriculture (White *et al.* 1997), and reflooding with brackish river water in an attempt to return the landscape to its original state is clearly socially and economically incompatible with the current landuse.

There are several aspects to the containment strategy that will be discussed in light of the presented results, as well as the methods currently employed at the study site. The drainage system design (i.e. field drain frequency) has been shown to be of considerable importance (Yang *et al.* 2000). The results here, and other work (Smith *et al.* 2003), show that there is an extensive pool of stored acidity within these canefields, and that the current drainage network provides the conduit for exporting such oxidation products from the system. The results also suggest that a large proportion of the oxidation products being exported to field drains are doing so close to the field drain edge. However, even though it appears that drain edges are an important factor in the discharge of oxidation products from ASS, complete removal of the majority of field drains is not the panacea for estuarine degradation.

The major and minor field drains are required for the discharge of mole drains (Rittie 2000) and the storage of runoff. The drainage system managed as it is in the 100-ha farm on which this study was completed can store about 25 mm of rainfall before water enters the lowermost cane-growing surfaces. An excessive reduction in drain storage capacity would result in increased infiltration previously removed as runoff, and ponding/waterlogging in lowest landscape positions during periods of rain (White *et al.* 1997). In the absence of laser-levelling, additional infiltration would mean an increase in the volume of water passing through the acidified zone, allowing for extensive ion exchange and acidification of through-flow waters. Furthermore, the fields surrounding the study area are amongst the most productive in NSW (White *et al.* 1993), despite storing large amounts of acidity. Therefore, a balance needs to be achieved between minimising the number of field drains to contain the acidity within the cane fields, and still fulfilling the above-mentioned hydrological functions to enable the maximum growth of the sugarcane. Infilling the equivalent of about half the total length of field drains at McLeod's Creek is being carried out in an attempt to decrease the acid export from the site (Smith *et al.* 2003).

As part of the drainage system design, the depth of the field drains should also not extend into the unoxidised material (White *et al.* 1996). The results here show that the sulfidic sediment is approximately 0.4 m below the bottom of the field drain. Therefore, care should be taken if cleaning the drain not to excavate any lower than the current depth, as this will provide a new surface of oxidation when the drain water levels are reduced in low rainfall periods, and a rapid transfer path for oxidation products out of the system when local rainfall does increase (White *et al.* 1996, 1997). The application of lime to drains prior to their cleaning is also undertaken.

The final component of the acidity containment strategy is the active control of the water level in the drain system, and the watertable under the growing crop. A low watertable beneath the crop but above the sulfidic layer has the ability to store water from rainfall, removing it from the surface water system and subsequently removing it through evapotranspiration (Wilson *et al.* 1999). Watertable management has been performed at McLeod's Creek for that past 17 years, where the water level in drains is maintained at –0.6 m AHD at the outlet drain with an electric pump (Smith *et al.* 2003). This, along with the partial opening of floodgates to let brackish water (about 1/2 seawater salt concentration) enter the drains during drier periods, has ensured that the watertable has remained above the sulfidic layer whilst ensuring maximum storage capacity for local rainfall (Smith *et al.* 2003), as can be seen in the reported data (Fig. 6).

This strongly brackish water is allowed into the 100-ha farm drainage system during very dry periods to ensure that monosulfidic drain-bottom sediments remain saturated. These sediments store acidity, dissolved metals, and other pollutants so that they can later be safely removed and lime-treated before spreading on adjacent cane paddocks. The input of this brackish water is carefully managed so that it does not enter mole drains where it would greatly impact the salt-sensitive cane crop. That such salty water input into the drains is possible clearly shows that the lateral hydraulic conductivity is very small in most of the sulfuric and all of the sulfidic layers of these ASS. This management technique has also been used in other Tweed cane-growing areas but its general application depends on a careful hydraulic assessment of each area.

White *et al.* (1993) showed from movement of Tweed brackish water up McLeod's Creek during dry conditions that there was some connection between crop evapotranspiration and the drainwater. Nevertheless, as Wilson *et al.* (1999) showed, this linkage is not strong, so that the crop depends on rain storage from vertical infiltration at the immediate site. Groundwater from adjacent hills is excluded from the crop by the depth ($\sim$10 m) of sulfidic gel beneath the crop, acting as an aquaclude.

The large variability in rainfall at the study site means that the acidity containment strategy described here may occasionally fall short of preventing large discharges of acidity from occurring. There is therefore the potential for neutralising the discharge waters at such times with lime (agricultural, hydrated or dolomitic) via a Calibrated Reagent Applicating Blender (CRAB) (Desmier *et al.* 2003) after any significant discharge events. Also, as the results show that a large proportion of the acidity and oxidation products is coming from only a small portion of the canefield, the strategic application of lime to canefield headlands, field drain banks, and their mole drain exit points would be effective in targeting the highest areas of acidity release, compared with the general application of lime across an entire canefield.

Whilst these suggestions may be applicable to areas with similar depths to sulfidic sediments and climatic conditions, they may not translate to all areas affected by ASS under sugarcane cropping. The management of acidic discharges from broad-scale, low-value landuses other than sugarcane remains problematic. The specific parameters of individual sites need to be taken into consideration before detailed management strategies are implemented.

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From conflicts to wise practice agreement and national strategy: cooperative learning and coastal stewardship in estuarine floodplain management, Tweed River, eastern Australia

Ian White [a,*], Mike Melville [b], Ben Macdonald [a], Robert Quirk [c], Robert Hawken [c], Mark Tunks [d], Don Buckley [d], Rick Beattie [e], John Williams [f], Lance Heath [a]

[a] *Centre for Resource and Environmental Studies, Australian National University, Canberra, ACT 0200, Australia*
[b] *School of Biological, Earth and Environmental Sciences, University of NSW, NSW 2057, Australia*
[c] *NSW Canegrowers Association, Condong Sugar Mill, Condong, NSW 2484, Australia*
[d] *Tweed Shire Council, PO Box 816, Murwillumbah, NSW 2482, Australia*
[e] *NSW Sugar Milling Co-operative Limited, 117 Pacific Highway, Broadwater, NSW 2472, Australia*
[f] *NSW Agriculture, Wollongbar Research Centre, Wollongbar, NSW 2466, Australia*

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Abstract

Appropriate information, participatory processes and wise practice agreements are key elements in reducing conflicts over the use and management of coastal resources. In this work we describe the evolution of a cooperative learning approach to coastal floodplain management, incorporating these elements. Government-encouraged drainage of coastal floodplains in eastern Australia caused accelerated oxidation of acid sulfate soils and export of diffuse acidic drainage into streams. Major impacts on infrastructure, ecology, fisheries and aquaculture resulted. In the Tweed River estuary, in 1987, all gilled organisms were killed by acid discharge from floodplain canelands. This generated major conflicts between fishers, environmentalists and sugarcane producers. The cooperative learning partnership that evolved, involving cane farmers, local government, and researchers, has produced better strategies for managing sulfidic estuarine areas and mitigating impacts on downstream ecosystems. These underpinned mandatory best practice management guidelines for the NSW sugar industry. Increases in productivity and decreases in acid discharge have resulted. Fish kills on the Tweed and elsewhere also generated broader, parallel whole-of-government approaches that led to Australia's national strategy for managing coastal acid sulfate soils and the rapid adoption of information and strategies across Australia.

Keywords: Coastal floodplain management; Acid sulfate soils; Cooperative learning; Wise practice agreements; Acidic discharge; Diffuse source pollution

1. Introduction

1.1. Global challenges of coastal zone management

The annual value of the world's coastal goods and ecosystem services has been estimated to be about US$24 trillion, compared with a global gross domestic product of around US$18 trillion [1]. While the former figure is questionable, coastal ecosystems are both immensely valuable and valued by communities. Coastal regions and estuaries are distinctive because they involve so many different sectors of society that claim right of access and use of resources. This often results in lengthy, expensive and counterproductive conflicts [2].

Despite their importance, coastal areas continue to degrade through both natural and human-induced changes [3]. Of the human pressures, cropping and grazing and mega cities in coastal catchments have the largest impacts [4]. Increased diffuse source discharges of nitrogen, carbon and sediment, as

* Corresponding author. Tel.: +61 2 6125 0660; fax: +61 2 6125 0757.
E-mail address: ian.white@anu.edu.au (I. White).

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a result of changes in coastal land and water regimes, are major concerns [5]. Studies of nutrient processes in near shore areas suggest that population density and percentage of land under crops in coastal catchments provide useful proxy measures of coastal disturbance [6]. Trigger values for identifying regions of highly disturbed coastal catchments have been set at densities as low as 60 persons/km^2 and 10% of catchment cleared [3,6].

Although examples of localised coastal improvement exist, sustainable resource use and maintaining coastal systems functions remain vital global tasks. Some of the key challenges include [5]: improving the availability and accessibility of resource and environmental information; fostering participatory approaches to coastal zone management; developing wise use options and agreements (best management practices); ensuring that planning and management cope with change; and developing policies that take into account risks and vulnerability.

1.2. Information, participation and coastal stewardship

Some, concerned by continued environmental degradation, believe that it is not possible to wait while the knowledge gaps in complex, coastal ecosystems are researched. Instead, action learning or adaptive management has been proposed as a practical response to the difficulties of managing complex situations [7,8]. It is argued that, in an adaptive process, mistakes due to incorrect information can be easily identified through rigorous monitoring and be corrected. Adaptive management, however, assumes linear processes where the consequences of erroneous actions can be reversed readily. Systems such as estuaries, however, appear to behave in a non-linear, hysteretic manner, exhibiting dramatic collapses that are not easily reversed [9].

Information on coastal ecosystem functions is patchy, even in intensively managed areas [10]. The general paucity of data is also evident in Australia. Relatively little research has been undertaken on the processes, consequences of environmental change or impacts of human activities in coastal eastern Australia, despite the concentration of population there [11]. The psychology of change management suggests change is more readily embraced when the underlying reasons for change are understood [12]. Appropriate, reliable information, communicated in a relevant way, is an important catalyst for change. The challenge is to collect and transmit that information in ways that are trusted by conflicting sectors.

Experience indicates that the first step in resolving conflict is to describe its nature and cause [2]. The next step is identifying and bringing together all stakeholders in a participatory manner, to try and build consensus and reach compromise agreements [13]. To reach agreement, there needs to be a process or mechanism in which the conflicting parties have confidence, and where they are able to address and resolve conflicts. Independent, impartial, outside parties, such as universities have been found to be very useful in developing higher quality agreements [2]. Problems in the management of coastal resources in eastern Australia have flowed from the plethora of top-down, conflicting visions and disparate goals between protection, rehabilitation, economic development and regional employment growth, as well as the inheritance of past legislation and administrative goals [11]. Governments are frequently reluctant to embark on participatory processes, as they are very time-consuming, and often use them as a last resort in solving conflicts.

Coastal stewardship has been proposed as one way of reducing conflicts by promoting ownership and pride in a country's heritage. It involves voluntary compliance, strong commitment and willing participation in the sustainable use of coastal resources and the development of wise practices [14]. The challenges in coastal stewardship are to inform, educate, motivate and empower communities to become managers and custodians of their environment. There are concerns, however, that without strong underpinning regulations, voluntary compliance agreements contain no effective mechanisms to address persistent breaches.

In this paper we examine the use of information, participation, and coastal stewardship in resolving serious conflicts over coastal floodplain management, stemming from fish kills, and in developing wise practice agreements for coastal floodplains in eastern Australia. We describe a cooperative learning partnership that has evolved over the last 15 years, which included local government, cane farmers and their industry, and academic institutions. This approach has successfully addressed some of the important challenges outlined above. We also describe the parallel institutional changes at the State level that flowed from the fish kills and eventually led to the production of a national strategy for the management of coastal acid sulfate soils and the rapid adoption of information and strategies across Australia. We first outline issues concerned with coastal zone development in Australia.

2. Coastal zone development in eastern Australia

About 80% of Australians live in the coastal zone, and about 66% of these are concentrated around large urban centres on estuaries and inlets. In the period 1971 to 1991 the population of the non-metropolitan coastal zone grew by 95%, from 2.1 to 4.1 million people, compared with a 32% growth for all of Australia. About 25–30% of the coast is subject to increasing development, most of this concentrated in the south eastern section of the country. In South Australia, more than half the land is cleared in 86% of estuaries. In Victoria the figure is 60% and in New South Wales 37% [15].

There are clear indications that coastal developments are changing the coastal, estuarine and marine ecology. For example, the dramatic decline in Australia's seagrass beds, up to 85% in some areas, due to nutrient outputs in the south east and sediment loads in the north east, is but one indicator of land-based impacts [15]. Given their fundamental importance in the marine food chain, disappearing seagrasses and their slow rate of recovery are major concerns.

2.1. Floodplain development

Eastern coastal floodplains in Australia were the first areas developed for agriculture following European settlement, due to their favourable temperatures, plentiful soil water and young, fertile soils [16]. Their plentiful soil water was associated with

DURANBAH DRAINAGE SWAMP UNION
C/- Crowe Horwath
PO Box 459 Murwillumbah NSW 2484
P: 02 6670 9350

16 April 2015

Mr Troy Green
General Manager
Tweed Shire Council

BY EMAIL

Dear Councillors, General Manager and Directors

The Board of the Duranbah Swamp Drainage Union has viewed with concern the draft plan for the management of Bruce Chick Park. As the draft plan states, drainage is very important to the farm land that drains through Ledday's Creek, McLeod's and Stott's Channels. The removal of fallen trees over the last thirty years has been conducted under an approval from Tweed Shire Council and all relevant Government departments.

The global best practice for acid sulphate soil management has been developed and implemented in the McLeod Creek basin with 12 PHD studies being completed in that area. This work has reduced the fish kills and acid discharges to almost nil. One of the findings of the studies is that poor drainage will increase the amount of acid discharged into Stott's channel and result in further fish kills. The studies have shown that the acid is still in the landscape but current efficient drainage practices and the sugar cane are holding the acid in the landscape.

Any reduction in the Drainage Union's ability to maintain this drainage will decrease the quality of the water entering the Tweed River.

In addition to the remediation of acid sulphate discharge is the issue of flood mitigation. The Tumbulgum, Eviron and Stott's Creek areas are particularly prone to severe inundation over extended periods and the efficacy of Stott's Channel is vital to this flood mitigation. Any restrictions on the Duranbah Swamp Drainage Union to carry on basic maintenance of these waterways would be both environmentally and commercially detrimental.

Yours sincerely

Duranbah Drainage Swamp Union

Keith Moon - Secretary

Duranbah Swamp Drainage Union
C/- Mrs H Grippo
PO Box 36
CONDONG NSW 2484

18th June 2015

The General Manager
Tweed Shire Council,
PO Box 816
MURWILLUMBAH NSW 2484

Dear Sir,

RE: MANAGEMENT OF BRUCE CHICK CONSERVATION PARK

Please find attached a combined submission from Duranbah Swamp Drainage Union, Condong Drainage Union and the Tweed River Branch of the Cane Growers Association concerning the Management of Bruce Chick Conservation Park.

If you require any further information please do not hesitate to contact Mr Robert Hawken on 0458 483 365.

Yours faithfully
DURANBAH SWAMP DRAINAGE UNION
CONDONG DRAINAGE UNION
TWED RIVER BRANCH OF THE CANE GROWERS ASSOCIATION

Per:
Helen Grippo
Secretary
Ph: 0412 780 117
Email: questfield1952@bigpond.com

Submission to Tweed Shire Council on the Management of Bruce Chick Conservation Park

Introduction

Good drainage is essential for successful sugar cane production and water quality management. In most years the Condong mill area produces 500,000 to 600,000 tonnes of cane. In the three wet years from 2011, annual production dropped to just over 300,000 tonnes.

Several researchers have quantified the yield loss in sugar cane due to water logging. Gosnell (1971) showed yield losses of 63 per cent and 35 per cent where the water table was maintained at 250 mm and 500 mm respectively. Both Rudd and Chardon (1977) and McGuire (1982) demonstrated that cane losses were approximately 0.5 tonnes/ha/day for each day the soil is water logged. By monitoring a range of sites during a growing season McGuire showed that 70% of the yield reduction was due to the water table elevation. Ridge and Reghenzani (2000) stated that, "Poor aeration is the main cause of depressed [cane] growth in waterlogged soils. Root function is adversely affected by the lower oxygen levels and raised carbon dioxide levels, and the root system is shallower."

Farmers accept that flooding and extended periods of water logging have a negative effect on cane growth which is unavoidable on a flood plain. To mitigate the effects of flooding farmers and drainage unions have installed an extensive drainage network. Anything that affects the efficiency of the drainage network has a negative impact on crop growth and water quality. Losses incurred as a result of the January 2013 flood were estimated at $2.29M. This demonstrates the importance of drainage to the industry. Over the last three decades farmers have worked in collaboration with staff from Tweed Shire Council and state government to manage the drainage network to improve water quality and fish habitat. Any restriction on managing the drainage network would have a negative impact on both issues.

Possible impacts on drainage of cane land

There are approximately 2,260 ha of cane land serviced by the Condong and Duranbah Swamp Drainage Unions. This includes some of Condong Mill's the most productive land and normally produces around 180,000 tonnes of cane which represents one third of the mill's throughput.

During floods, water from the Condong area flows overland towards Stott's Ck. Any restrictions to the outlets at McLeod's Ck and Ledday's Ck will result in longer inundation times for cane on farms in the Stott's Island area. Restrictions here will also slow the drainage of water from the Condong area.

Local cane farmers are concerned that any restrictions placed on the removal of fallen vegetation obstructing water flows along the outlets of McLeod's , Ledday's Creeks and Stott's Channel, will reduce the effectiveness of the drainage system with subsequent impacts on crop production and water quality.

The drainage union has been operating under an existing permit to clear the channel of obstructions for over 20 years. All work has been done to minimize impacts on surrounding vegetation. Removal of this permit would not only impact on farm drainage and water quality but also the integrity of Stott's Island through the eventual formation of land bridges to the mainland.

NSW GOVERNMENT | Department of Primary Industries

Natural Disaster Preparedness

Flood Ready Cane Farming Strategic Plan for the North Coast Region of NSW

Building on resilience through better preparedness

www.dpi.nsw.gov.au

Published by the NSW Department of Primary Industries

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More information

Rik Whitehead, Project Manager, NSW Department of Primary Industries, Wollongbar

Selina Stillman, Project Officer, NSW Department of Primary Industries, Wollongbar

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Chairperson and Project Manager	Rik Whitehead
Project Support	Selina Stillman, Jenny McInnes
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Other photo's by: NSW Sugar Milling Coop and Dr Natalie Moore, NSW DPI.

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Jobtrack 13367

Foreword

The coastal floodplains of the NSW North Coast are well suited to cane production though flood risk, drainage management, acid sulphate soils and urban encroachment are challenges for the industry.

Flood risk in particular creates unique challenges particularly when consecutive floods occur which impact on infrastructure, productivity and farm recovery. None the less, the industry is resilient to floods and this project is aimed towards strengthening the capacity of the sector and its people to adequately manage flood risk.

The Flood Ready Cane Farming project seeks to increase the resilience of the sugar cane industry by improving the ability of cane farmers and the milling sector to better prepare and plan for the risk of flooding as well as to respond effectively and hasten recovery from the impact of flooding.

The goal is to maintain the sustainability of the sugar cane industry in NSW, maintain the productivity and profitability of production systems and ensure the security of cane supply to the local mills and the sugar refinery at Harwood. It is hoped that the pathways towards increased resilience to natural disasters created by the project will provide a framework that other industry sectors can follow in preparing themselves for the challenges and opportunities ahead.

This Plan is not the end of the story for the Flood Ready Cane farming project but is a reference document to encourage the continuation of dialogue, collaboration and local connections for building on the capacity, innovation and strengths within the cane industry.

Rik Whitehead
Chairperson – Flood Ready Cane Farming Steering Group

Contents

1. Introduction to Flood Ready Cane Farming

About the NSW North Coast Sugar Cane Industry

Sugar cane production has dominated the floodplains of the Far North Coast of NSW from the Clarence valley to the Tweed valley for over 100 years. Spanning an area of 32,000 hectares it is a $230 million industry and a major employer across the region employing some 2,200 people including growers, harvesters, haulers, and mill and refinery workers[1].

Currently there are 550 growers[2] producing cane for three sugar mills; Condong (Tweed River), Broadwater (Richmond River) and Harwood (Clarence River) (Table 1). A regional farmer's cooperative, NSW Sugar Milling Cooperative owns the three mills and also operates the Manildra Harwood Sugar refinery of which it has a half share ownership.

Collectively the region has the capacity to produce 270,000 tonnes of raw sugar derived from 2.5 million tonnes of sugar cane annually. By-products include molasses and bagasse[3].

Snapshot of NSW Sugar Cane Production

Table 1: Average Sugar Cane Farm Production

No of growers	Average hectares per farm	Average production per farm	Average Commercial Cane Sugar (CCS)
550	56	4,000 tonnes	11 - 12

Sugar cane on the North Coast is primarily grown in a two year cycle due to the sub-tropical climate and environmental conditions. Between 65-70% of tonnage harvested is two-year cane. Typically Condong farmers will harvest 67% of their farm each year, with Broadwater and Harwood Farmers harvesting around 50-55% of their farm annually[4]. The main planting months are August – September (Condong) and September – October (Broadwater and Harwood). Harvesting occurs from mid-June to late November or early December.

Why the project was initiated

The North Coast region has experienced annual flooding since 2009. The cumulative flood events have had a significant impact with some catchments estimated to be operating at around 35% of production levels.

Table 2 illustrates the individual and collective sugar cane production for the 2011 and 2012 harvesting seasons across the three milling areas. The total 2011 harvest tonnage was only 66% of capacity and in 2012 this was further reduced to 36% of capacity[5].

Annual Cane and Sugar production 2011 and 2012

Table 2: Sugar and Cane Production 2011 & 2012

Mill Area	Tonnes of Cane		Tonnes of Sugar IPS		Commercial Cane Sugar (CCS)		Hectares Harvested	
	2011	2012	2011	2012	2011	2012	2011	2012
Condong	312,852	301,984	35,287	36,307	12.42	12.27	3,635	4,308
Broadwater	714,956	376,921	79,484	44,560	12.12	12.15	5,395	4,277
Harwood	585,659	236,122	65,938	26,977	12.10	11.64	4,537	2,868
Total	1,613,467	915,027	180,709	107,844	12.17	12.06	13,567	11,453

In early 2013 three significant rainfall events in relative succession caused extensive flooding across the NSW North Coast. The Clarence River reached record height and the Tweed and Richmond Rivers experienced extended periods of elevated river levels.

Regional damage to the cane industry was reported as approximately $69 million, $29 million of which was within the growing sector and the remaining $40 million in milling and refining production[6]. Approximately 3,500 hectares were either destroyed or severely damaged. The forecast loss of sugar cane is 1.4m tonnes (60% of normal production). It is estimated that even without additional flood events in coming years, full capacity will not be reached until 2018 due to the cumulative effects of annual flood events[7] and the 2-year cropping cycle.

Impacts on Sugar Cane and Soy Bean Production 2013

Table 3: 2013 Cane and Soy Bean loss[7]

	Sugar Cane			Soy Bean		
	loss/damage (ha)	Replant Costs	Loss to industry	loss/ damage (ha)	Loss to industry	Total Loss
Condong	457	$1 m	$2.07m	535	$214,400	$3.29m
Broadwater	579	$735,000	$2.58m	607	$910,500	$4.22m
Harwood	1,315	$2.9m	$5.86m	1,156	$1.7m	$10.46m

This Project has been initiated in recognition of the high costs of flooding across the cane industry in relation to damages, loss of production and cost of recovery, and the need for greater preparedness and resilience. The Project aims to identify opportunities which enable industry and floodplain managers and stakeholders to work together to find solutions through collaboration and dialogue.

In a survey conducted following the 2013 floods, 85% of respondent farmers[8] indicated a critical issue was the increased flood impact they were experiencing across the floodplains as a consequence of inadequate or poorly maintained infrastructure. This had contributed to increased damage to crops. Areas of concern included:

- On and off farm drainage
- Bottlenecks and blockages in the flow of water
- Other obstructions and impediments

Following the successive flood events on the North Coast, sugar cane farmers and other stakeholders were keen to reflect on what had occurred and identify strengths, weaknesses, opportunities and future risks to improve resilience and sustainability of individual farms and the industry as a whole.

About the Project

Funding provided under the joint State and Commonwealth Natural Disaster Resilience Program provided an opportunity to establish the Flood Ready Cane project to identify strategies for building on industry resilience to meet the challenges of floods. Co-funding and in-kind contributions were provided by NSW Cane Growers, NSW Sugar Milling Cooperative and NSW Department of Primary Industries and a small working group consisting of a representative from each of these organisations have been responsible for managing the project.

A steering group comprising grower representatives from the three cane growing areas (Tweed, Richmond & Clarence) provided the strategic direction and priorities for the project. Other organisations such as local government, local flood plain authorities, SES and Local Land Services were consulted as required. Consultants were engaged for specific components of the project to enhance the work undertaken.

Opportunities for reducing the impact of flooding on the sugar cane sector were identified throughout the consultation process including:

1. Development of a Flood Ready Plan that has industry ownership and adoption thereof

2. Dialogue between industry, floodplain authorities and stakeholders regarding drainage systems and networks

3. Implementation of highest value practices, at all levels of the supply chain, to address flood risks, including risks to productivity, infrastructure, machinery, personal property, business continuity, financial viability and personal well-being.

4. Continuation of on-farm and community initiatives that have proven effective in building and maintaining resilience and reducing the impacts of flood events.

2. Aim

The purpose of the project is to increase the capacity and capability of the sugar cane industry sector on the north coast to mitigate, prepare for, respond to and recover from the risk and impact of floods in order to maintain the long term productivity and sustainability of the sector.

Specifically, the project aims to identify a model farm-level flood plan and other tools that set priorities and practical actions for managing and reducing the impacts of floods on farm enterprises as well as the supply chain.

About this plan

This plan identifies and addresses key vulnerabilities, risks, opportunities and the management strategies and practices that can be used to better prepare farm enterprises, farm families as well as the supply chain for the impacts of floods to increase overall resilience.

It provides a pathway to achieving the vision and represents the partnership and the commitment from farmers, industry, local emergency groups and key government service providers to addressing the issues identified throughout the dialogue of the project.

The plan adopts the following set of principles of resilience as developed by the Coalition of Australian Governments - COAG (2011)^ and applied to the National Disaster Strategy:

Understand the hazards and risks

Anticipate floods, prevent and prepare

Work together to coordinate effort, use strengths

1. Work in partnership with agencies and authorities
2. Make Emergency Management Plans that build resilience
3. Be flexible in response
4. Volunteer
5. Reduce risks
6. Restore satisfactory functioning quickly

Vision

NSW sugar cane industry continues to thrive and develop through the adoption of collaborative and resilient practices, flood preparedness and the management of risks across all stages of production from the farm to the mill.

These principles acknowledge the four phases of disaster management: prevention, preparedness, response and recovery (Figure 1).

Prevention of impacts includes considering ways of working with environment, water flow, and infrastructure to prevent or mitigate flood progress.

Preparedness is a process of risk management and planning to anticipate floods and limit adverse impacts.

Response is the immediate action taken once a flood is present to ensure safety and limit impacts.

Recovery is the work done to restore people, farm and industry operations and communities back to everyday functioning and includes reviewing and learning from the flood events.

The concept of a disaster management cycle is important because every experience of flood builds experience and learning to be even more effective before during and after floods in the future. It reminds us that we are always somewhere on the cycle and often dealing with a couple of phases at once such as recovery and preparedness.

This is resilience:
to be able to learn from the past,
act more wisely, collaboratively and effectively over time.

Flood Ready Cane Farming builds resilience through developing connections at the local and regional level. Nearly every strategy in this plan and its implementation is dependent upon effective leverage of these connections through the four phases of disaster management to:

- obtain and disseminate information, experience and know how including the establishment of a resource hub;
- plan and work together to respond confidently to floods to protect people, crops, property and farm resources;
- cooperate to promptly address obstacles and maximise farm continuity;
- support farmers, their families, their employees and their communities at all times; and,
- influence decision makers and floodplain service providers to consider the particular needs of and proposals from the sector

3. Who benefits

The beneficiaries of Flood Ready Cane Farming and application of strategies based on the principles of resilience include many stakeholders:

Cane farmers and their community can benefit from:

✓ A plan designed to reduce the impacts of floods on the farm business, crops, its assets (including natural assets) and the people that live and work on the farm.

✓ The sharing of knowledge, experience and the building of skills through connections with other cane farmers, industry organisations and support agencies.

Millers and Refiners can benefit from:

✓ Working collaboratively with suppliers and key agencies to reduce the impacts of floods on production, farm operations and the people involved.

Consumers and community can benefit from:

✓ The continued viability of the North Coast Sugar Industry ensuring supplies to the domestic and export market are maintained.

✓ The continued viability of the North Coast Sugar Industry ensuring ongoing employment of local people and the significant contribution the industry makes to the economies of the North Coast.

✓ The ongoing environmental stewardship of the floodplains by the cane farmers and in particular the world leading management of acid sulfate soils and black water.

The Sugar Industry as a whole can benefit from:

✓ Cane farmers having confidence to go forward and manage risks which improve the industry position and increase the sustainability of the sector.

✓ Cane farmers having a better understanding of what support services are available.

Government agencies and emergency services can benefit from:

✓ Understanding the issues and priorities for the sugar cane industry in the preparedness, response and recovery phases of floods to enable more targeted and effective support services.

It is anticipated that benefits will extend beyond the core of the sugar industry to other community stakeholders such as emergency management bodies, local governments and the wider community through stronger networks, cooperation and partnerships.

4. Key flood issues for sugar cane productivity

A range of consultation forums were held across the region for industry representatives, local government and floodplain agencies. The forums offered an opportunity to identify local and regional flood issues and priorities and provide the platform for the Strategic Plan[9, 10, 11].

Themes identified in consultation forums

	Industry	Floodplain Managers	Government Entities
Drainage	Maintenance of on-farm and off-farm infrastructure has an impact on crop damage and flood water inundation	River heights can exceed drainage levels resulting in longer periods of inundation. Rising sea levels and climate change will continue to impact on this.	The Drainage System is integral to the entire floodplain and natural resource management including management of: • Acid sulphate soils • Blackwater • Fish habitats
Funding	There is insufficient funding for installation, upgrade and maintenance of drainage works	Funding is insufficient to enable all priorities to be met. Focus tends toward urban flood mitigation works	Funding is insufficient for all competing natural resource management and floodplain priorities
Ownership and Tenure	There is a need for greater clarity regarding off-farm ownership including what exists, who owns and manages it, the current condition and capacity	Need to identify ownership and responsibility of drainage infrastructure. NB: Audits are currently or have been undertaken for this	Government entities do not have management of or responsibility for drainage maintenance and works.
Regulatory environment	Regulatory requirements are arduous and restrict capacity to undertake on-farm land and drainage management activities	Maintenance of hydraulic functions of drainage need to be balanced with environmental requirements and objectives.	Regulations serve to provide protection of the environment and enhance hydraulic capability.
Planning	There is a need for on-farm flood preparedness and recovery planning which incorporate local knowledge and experience	Authorities have responsibility for planning for the entire floodplain across the local and regional levels	Government entities provide the framework for floodplain management and rely upon authorities and other delegates to manage
Communication	There is a need for greater dialogue and communication between industry, floodplain managers and government regarding floodplain priorities. Continued Industry representation on Floodplain Management Committees will provide a forum for working and planning together for flood events. Farmers require information pre and post flood events to better prepare and reduce impacts		

5. Strategy for increasing resilience to floods

Flood Ready Cane Farming requires identification, analysis and treatment of risks at 3 levels:

1. ***The Farm level,***
2. ***Local industry and community level*** and
3. ***The sector as a whole at the regional level.***

The tables on the following pages have used a risk management approach to identify desired outcomes, strategies for action and options against identified risks at the farm level, local level and regional level. Not all risks will be evident or present at each level in all cases so the tables serve to capture possible strategies and actions that may be useful to reduce flood impact.

An important approach is that farmers and industry participants are empowered, encouraged and supported to take an active and influential role in being flood ready based on what is in their influence. Focussing on issues that are outside our sphere of influence can create undue stress and frustration with little gain.

Key strategies for being flood ready at all levels can involve farmers and other stakeholders to:

• Plan	• Support	• Be informed
• Participate	• Connect	• Synthesise
• Communicate	• Improve	• Consult
• Know who	• Share	• Represent
• Know how	• Prioritise	• Lobby
• Coordinate	• Report	• Clarify
• Assess	• Empower	• Encourage
• Be proactive	• Network	• Negotiate
• Use tools	• Evaluate	• Volunteer
• Assist	• Advocate	• Influence

The above Table identifies a range of pro-active strategic approaches that encourage participants to work together in managing risks. They are based on "actions" which are available to, and can be readily applied by all stakeholders in floodplain management.

The Strategies presented in the following pages utilise these actions to provide Options for flood readiness at the farm level and across the local and regional plains. The Options have been derived as examples of practices which enable engagement, collaboration and highest value outcomes. It is important to remember that the Options serve as a guide and are not prescriptive. Farmers, floodplain managers and government entities are encouraged to identify and adopt measures which best reflect their risks, hazards, priorities, needs and resources.

Table 1: Farm level strategies for Flood Ready Cane Farming

Risk	Desired Outcome	Strategy	Options
Farming communities are unprepared for the impacts of flood events.	Farming communities have sufficient knowledge to prepare for, respond to and recover from flood events.	**Plan** Farmers have well developed plans which identify on-farm risks and options for mitigation, response and recovery activities and continuity. **Connect and participate** Farmers share local knowledge and experiences to further the understanding of emergency management practices within the sector.	Farmers are aware of and have access to Risk Management Planning Tools to analyse flood risk, and identify preparedness and recovery options. Farmers incorporate flood management and continuity in their Business Plans. Opportunities are provided to farming communities to participate in emergency planning activities.
Communication and early warning systems do not allow for early preparedness measures.	Adequate warning is provided to farming communities to enable preparation for flooding and reduce impacts.	**Communicate** Communication structures enhance dissemination of early warning messages and information during flood event's	Farmers understand and have access to weather warning technology and early warning systems e.g. BoM and SES website, ABC Radio.
Loss of productivity and increased damage to crops as a result of inundation.	On-farm and external drainage systems enable timely removal of flood waters.	**Evaluate** The drainage system is well understood by all parties and responsibilities upheld. **Network** Farmers, industry and government entities work in collaboration to review legislative and regulatory obligations and identify best practice.	Industry engages with farmers to enhance understanding of the drainage system, owner responsibilities and legislative requirements. Farmers conduct optimal and best practices in managing and maintaining on-farm drainage assets. Farm asset management systems used to record and support asset maintenance works.
On-farm recovery is impeded due to financial constraints	Farmers are adequately covered by insurance and/ or have access to financial reserves. Farmers have access to external assistance through government grants, donations and philanthropy.	**Plan** Financial planning is a key element in farm business and risk management plans. **Know who** Farmers are aware of available financial assistance and have an understanding of application processes and requirements.	Farmers incorporate financial planning in Business Plans. Farmers identify appropriate insurance options. Farmers are aware of how to access information regarding financial assistance, assessment requirements and application processes.

Risk	Desired Outcome	Strategy	Options
Farmer and personal health and well-being are negatively impacted by increased stress and physical health risks associated with flood waters.	Farmers have access to personal and industry based support services during flood recovery.	**Know who and Plan** Health and well-being support measures for farmers and farming communities are identified and incorporated into on-farm, local and regional Emergency Management Plans. **Communicate** Information is available and disseminated to farmers affected by flood waters in relation to health and well-being impacts.	Farmers are aware of and have access to health risks associated with stagnant and flood waters through information from authorised health agencies and services. Farmers have access to information in relation to safe clean-up methods and practices. Farmers are aware of and have access to personal support services through Industry's Employee Assistance Program, as well as introduced recovery activities and programs. Rural support networks are established for identified vulnerable and at risk persons. Information regarding Employee Assistance Program is readily available and included in employee induction and training.
Farmers, their families and visiting persons sustain injury on farms affected by flood waters.	Recovery and clean-up are conducted using safe farming practices and visiting persons are safe from hazardous materials and other damaged objects.	**Be proactive** Recovery and clean-up activities are undertaken utilising safe farm work practices. **Be informed** Farmers, their families and visiting persons are aware of the inherent dangers of flood impacted properties.	Farmers identify safety as the highest priority during recovery operations. Farmers are aware of and have access to information regarding safe farm practices e.g. hazardous materials, disposal of damaged good's PPE is available to all persons involved in recovery activities and clean up. Visitors are made aware of safety issues.
Natural resources are further damaged during recovery operations.	Compounding impacts on natural resources are considered during recovery operation and risks minimised.	**Know how** Farmers and employees undertake recovery activities in an effort to minimise additional damage to natural resources on and off-farm.	Farmers and workers are aware of and have access to information and resources that minimise additional damage to natural resources e.g. soil compaction, exposure of acid sulfate soils.

Table 2: Local level strategies for Flood Ready Cane Farming

Risk	Desired Outcome	Strategy	Options
Drainage infrastructure impedes removal of flood waters and increases impacts of inundation.	Local drainage systems have the capacity to quickly reduce water inundation levels.	**Evaluate** The drainage system is well understood by all parties and responsibilities upheld. **Network and Communicate** Farmers, industry, floodplain managers and government entities maintain open dialogue and work together to achieve highest value outcomes.	Opportunities are provided for open dialogue between key parties with interests across the drainage system to share flood studies and modelling, work together on developing maintenance schedules and clarify the purpose of infrastructure. Industry engages with key groups and agencies to support optimal practice, whole of farm management and manage environmental risks. Guidance is provided regarding owner responsibilities and legislative requirements. Avenues for funding and dialogue with government are sought to support drainage maintenance and upgrade. Industry is an active member on Floodplain Management Committees which facilitates awareness of whole of catchment values.
Cane supply networks are disrupted due to road closures and loss of transport networks.	Road infrastructure can quickly recover from inundation.	**Evaluate** Impacts of new local road infrastructure upon floodplains are assessed at the design and build stages providing industry with an opportunity for comment. **Plan** Potential impacts are communicated to farmers to enable planning and preparedness activities.	Risks to cane supply networks are identified and incorporated into farming and sugar milling emergency management plans. As funding is available critical roads to industry are prioritised for works. Farmers have access to websites and radio information regarding road and transport impacts (e.g. SES, My Road, ABC Radio).

Risk	Desired Outcome	Strategy	Options
Insufficient information for measuring and assessing impacts results in delays in release of relief package and assistance.	Impacts and damage are reported in a timely manner.	**Coordinate** Damage assessment is coordinated through local networks and regional arrangements.	Farmers and industry have access to and are familiar with key websites providing information regarding financial assistance, assessment requirements and application processes. Industry is connected to Recovery Committees and structures following flood events.
Recovery initiatives do not consider and reflect needs of sugar cane industry.	Recovery activities recognise priority needs of sugar cane industry and incorporate tailored programs in Recovery Action Plans.	**Advocate** Industry issues are identified in local Recovery Plans and other recovery activities. **Communicate** Industry engages in dialogue with recovery managers to ensure industry issues remain at the forefront of recovery considerations.	Industry participates in recovery planning and operational activities in line with established NSW Recovery arrangements. Sugar Cane Industry flood issues are recognised by Local and Regional Emergency Management Committees through Agricultural Services Functional Area representation. Local and Regional Emergency Management Plans identify issues and options for sugar cane industry in risk assessments and operational plans. Industry continues to collate timely damage reports and provide to NSW DPI.

Table 3: Regional level strategies for Flood Ready Cane Farming

Risk	Desired Outcome	Strategy	Options
Complexities of off farm infrastructure ownership and obligations impede effective management of drainage systems and transport networks.	Off farm floodplain infrastructure is managed for effective and efficient operation according to the purpose of structures and reduces flooding impacts through ongoing maintenance and innovative upgrades and practices consistent across growing areas.	**Advocate and negotiate** Industry, floodplain management authorities and government work together to reduce perceived complexities of legislation and regulations regarding tenure, ownership and management.	Opportunities are sought for open dialogue between all parties with interests across the drainage system. Opportunities to work together with Floodplain Management Committees to raise awareness around infrastructure, regulations and funding capability are sought.
Drainage system efficiency is impeded by inconsistent practices.	Drainage system management is consistent and applicable across cane growing areas.	**Synthesise** Drainage management is well understood and where possible streamlined across cane growing areas.	Stakeholders work towards identifying opportunities for streamlining and reconciling current drainage management infrastructure and develop strategic management plan. Industry is an active member on local and regional Floodplain Management Committees. Committee Induction training is provided to Industry representatives on multi-agency Committees.

Risk	Desired Outcome	Strategy	Options
Insufficient warning is provided to enable preparedness activities.	Timely and accurate information is provided to inform early warning messaging.	**Use tools** Where available, flood gauges provide information for monitoring and predicting water level changes Farmers are aware of sources for accessing information regarding changing water levels. **Communicate** Communication systems are identified as key methods for dissemination of messages and information during flood events.	Farmers and Industry are familiar with early warning systems and have access to websites and radio information regarding water level changes and flood predictions (e.g. SES, BoM, ABC Radio). Industry and emergency managers regularly communicate to ensure awareness of risks to farmers and cane production prior to and after flood events.
Reduced regional economic viability and loss of business.	Local and regional business can withstand interruption to farming production.	**Plan** Continuity plans are developed for local business likely to be affected by fluctuations in farming production.	Industry and other stakeholders incorporate flood and continuity risks into their Business Plans.
Unemployment increases due to loss of opportunities on farm and in mill and refinery sectors.	Production is maintained to a level which ensures ongoing employment within the industry.	**Participate** Employees are trained and have skills in alternative practices and recovery actions. **Empower** Employees are provided access to support and social programs.	Employees are multi-skilled and provided training opportunities. Employees and farmers are encouraged to access the Employee Assistance Program provided through Industry.

Risk	Desired Outcome	Strategy	Options
Industry is unable to withstand cumulative effects of annual and multiple flood events.	Industry encourages and supports innovative practices.	**Improve** Opportunities to develop innovative farming, milling and refining practices are provided. **Encourage** Continue to support practices and activities which encourage collaboration, innovation and resilience.	Utilise the expertise within Sugar Research Australia and Ag Services Group to achieve gains in farming practices. Build on and showcase resilient practices. Risk of farming low level areas is fully identified and recognised by industry. Seek opportunities and funding for Industry, floodplain managers and government to work together. Continue positive culture within the industry towards tackling challenges and cooperation.

6. Future direction

Success will be the achievement of the desired outcomes of this Plan. Along the way will be indicators that progress is being made for example:

- Industry and farmers are proactive in sourcing flood information from a range of avenues including: websites, gauges, communication with emergency managers
- Farmers are more confident and proactive in engaging in dialogue with key agencies to manage risks and planning for and preparing for floods
- Cooperative groups are established at regional and local levels to carry out the roles set-out in this plan
- Industry participants are communicating often about their roles in the 4 phases of disaster management and carrying them out in cooperation with each other
- Other primary industry sectors are adopting some of the ideas from this plan.

While there is considerable good-will and collaboration in ensuring strategies and actions are progressed, it is suggested that some more formal mechanisms be incorporated to track and promote progress of the Flood Ready Cane Farming Strategic Plan.

To ensure success, it is suggested that the following steps be taken:

a. Establish a mechanism to monitor progress
e.g. working group, sponsorship and agreed processes

b. Identify indicators for each of the outcomes

c. Identify risks and potential barriers to success

d. Address the barriers

e. Gather data and/or qualitative information to assess progress as defined by the indicators

f. Foster industry "Champions" to lead initiatives and promote active engagement

"Responsibility" for Flood Ready Cane Farming is a shared role. Success and progress will rely on continued dialogue and interaction on the strategies identified within the plan but also allowing for flexibility in accordance with the principles of resilience.

It is recognised that among other things, climate change poses a risk to primary industries. For the cane industry these risks include rising sea level, coastal erosion, increased frequency and severity of storms and floods, and increased incidents of cyclonic weather and east coast lows. The impacts of such events could result in increased storm surges, prolonged inundation of flood waters and reduced recovery time between events.

This Plan does not intend to specifically address issues of climate change risk to the NSW sugar cane industry though flood preparedness measures and aspects of the plan will go some way towards promoting dialogue and planning with regard to climate variability and climate change. The focus of the plan is on current land use activities, infrastructure, farm level flood readiness and the identification of local and regional level strategies for moving forward within the current risk context. However, understanding and awareness of the extent of risks and timeframes associated with climate change scenarios would assist to inform and prepare for the predicted future influences of a changing climate.

7. References & Resources

1. **Sunshine Sugar – Industry Brochure -**
http://www.nswsugar.com.au/images/nswsugarDocs/files/2013_Sunshine_Sugar_Docs/Sunshine_Sugar_Info.pdf

2. **Richmond River Cane Growers -**
http://richmondrivercanegrowers.com.au/sample-page/cane-farming/

3. **Sunshine Sugar –Cane Farming Brochure**
http://www.nswsugar.com.au/images/nswsugarDocs/files/2013_Sunshine_Sugar_Docs/Cane_farming.pdf

4. **Sunshine Sugar – Information for New Farmers -**
http://www.nswsugar.com.au/images/nswsugarDocs/files/Info_for_Growers/Information_for_new_farmers_2013_1.pdf

5. **Canegrowers Annual Report 2012/2013-**
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7. **Geolink, 2013, "Increasing Agricultural Production Resilience on the Coastal Floodplain: Sugar Cane Engagement with Northern Rivers Local Floodplain Infrastructure Authorities**

8. **Beattie, R. 2013, "Flooding and Drainage Impacts on the NSW Sugar Industry", Sunshine Sugar,**

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11. **Michelle Walker, Curious Minds Co, Aug 2013, Forum Report "Flood Resilience in the Sugar Cane Industry**

12. **Australian Cane Grower Magazine, 2013, Issue 31, "Drainage Feature" -**
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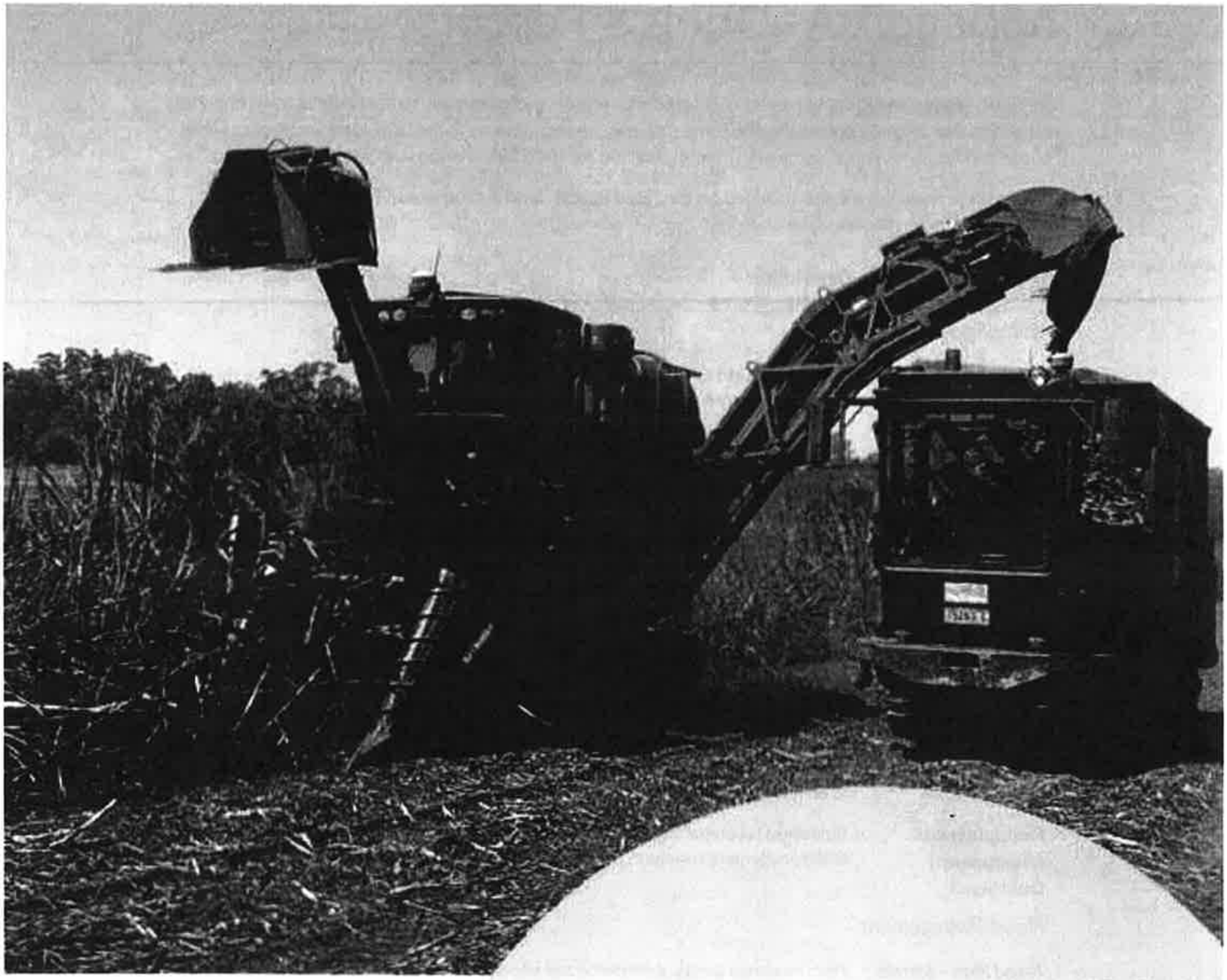
14. **DECC, 2007, Floodplain Risk Management Guideline -**
http://www.environment.nsw.gov.au/floodplains/StandardFloodplainRiskManagement.htm

15. **Canegrowers, SmartCane Principles of Best Management Practice -**
http://www.canegrowers.com.au/icms_docs/70456_BMP_Principles_of_BMP.pdf

16. **BSES, Managing Flood Damaged Cane -**
http://www.canegrowers.com.au/icms_docs/147481_BSES_Managing_flood_damaged_cane.pdf



Appendix A – Tools & Resources

The Flood Ready Cane Farming project uncovered a diverse array of potentially useful material, tools, checklists and guides that all could potentially play some role in increasing capacity at the farm, local and regional level. For use and future reference, some of the tools identified are listed below along with where to find them.

Links to these resources are also provided on the Flood Ready Cane Farming website at www.dpi.nsw.gov.au/floodreadycanefarming .

Tool	Description	Where to find it (links)
Planning Tools		
Farm Emergency Preparedness Plan (checklist)	One page easy to follow checklist for farms by the Centre for Food Security & Public Health; Iowa State University	Farm emergency checklist from IowaSU
NSW SES Floodsafe Business Plan Template	• Available on-line – can be downloaded and/ or printed • assists a farmer to write a farm level flood plan: - potential impacts - triggers for action before, during and after a flood - detailed action plan before, during and after - staff contact list - emergency contact list	SES Floodsafe Business Toolkit
Risk Management Framework	• Managing flood risks using The Risk Management Process and the Risk Evaluation Tool (grid). Framed as a step-by-step tool for farmers and communities to use.	NSW DPI Flood Ready Cane Farming Website
Farm Management System	A tool for Sugar Cane growers to identify and manage risks to on farm production	SmartCane Modules
Floodplain Risk Management Guideline[14]	Guidelines for preparing FRM Plans including Committees and management structures	Floodplain Risk Management Guideline
Flood Management		
Flood Plan – Simple Outline	Farm mud map (physical property) and key questions	
Managing Flood Damaged Cane[16]	Information Sheet for assessing flood impacts and waterlogging tolerance	BSES
Electricity and Safety during Floods	• One-page guide from Essential Energy - includes contact numbers	Safety During Floods
What to do Before, During and After a Flood	• 28 page handbook issued by Emergency Management Australia for use by general public	Flood Handbook from EMA

Tool	Description	Where to find it (links)
Farming Practice		
SmartCane Principles of Best Management Practice[15]	Provides information regarding land, soil and water management and practices for improving sugar cane production	Principles of Best Management Practice
NSW Sugar Industry Farming Code of Practice	Provides information for undertaking best practice including drainage	Sunshine Sugar
Information for New Farmers	Provides overview of sugar cane farming best practice and relevant contacts	Sunshine Sugar
QCANESelect™	Information and decision support for growers on variety selection, block recommendations and whole of farm planning.	see URL at end of doc
Health and Well being		
Building Emotional Resilience - GRDC	• Farmer Health Fact Sheet from Grains Research and Development Corporation (GRDC) • highlights strategies for strengthening emotional resilience at an individual level Touches on depression, helping others and resource organisations/websites	Grain Research and Development Corporation website
How Disaster Affects Everyone	'Fact Sheet' from Disaster Assist setting out common human reactions to disaster:	How disaster affects every one
NSW DPI training	List of online courses available including 'Managing climate risk on farm'	NSW DPI Profarm Training Website
Contact people and their organisations	A list of some of the main stakeholder organisations, groups, acronyms, roles, resources and Web links relevant to flood preparedness response and recovery	NSW DPI Rural Resilience Program
Tips for looking after yourself	'Fact Sheet' from Disaster Assist setting out practical strategies for coping.	Tips for looking after yourself
Communication		
Contact people and their organisations	A list of people and their organisations/interests that are invested in maximising the resilience of the cane industry. This list is provided to encourage collaboration and co-operation. Continually being updated	NSW DPI Rural Resilience Program

QCANESelect™ link -

https://tools.sugarresearch.com.au/QCANESelect/Security/WebLogin.aspx?ReturnUrl=%2fQCANESelect%2fDefault.aspx

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NSW GOVERNMENT
Department of Primary Industries

Submission to Tweed Shire Council on the Management of Bruce Chick Conservation Park

Introduction

Good drainage is essential for successful sugar cane production and water quality management. In most years the Condong mill area produces 500,000 to 600,000 tonnes of cane. In the three wet years from 2011, annual production dropped to just over 300,000 tonnes.

Farmers accept that flooding and extended periods of water logging have a negative effect on cane growth which is unavoidable on a flood plain. To mitigate the effects of flooding farmers and drainage unions have installed an extensive drainage network. Anything that affects the efficiency of the drainage network has a negative impact on crop growth and water quality. Losses incurred as a result of the January 2013 flood were estimated at $2.29M. This demonstrates the importance of drainage to the industry. Over the last three decades farmers have worked in collaboration with staff from Tweed Shire Council and state government to manage the drainage network to improve water quality and fish habitat. Any restriction on managing the drainage network would have a negative impact on both issues.

Possible impacts on drainage of cane land

There are approximately 2,260 ha of cane land serviced by the Condong and Duranbah Swamp Drainage Unions. This includes some of Condong Mill's the most productive land and normally produces around 180,000 tonnes of cane which represents one third of the mill's throughput.

During floods, water from the Condong area flows overland towards Stott's Ck. Any restrictions to the outlets at McLeod's Ck and Ledday's Ck will result in longer inundation times for cane on farms in the Stott's Island area. Restrictions here will also slow the drainage of water from the Condong area.

Local cane farmers are concerned that any restrictions placed on the removal of fallen vegetation obstructing water flows along the outlets of McLeod's , Ledday's Creeks and Stotts Channel, will reduce the effectiveness of the drainage system with subsequent impacts on crop production and water quality.
The drainage union has been operating an exciting permit to clear the channel of obstructions for over 20 year. All work has been done to minimize impact on surrounding vegetation ,a removal of this permit would not only impact farm drainage and water quality but also the integrity of Stott,s 1sland through the eventual formation of land bridges to the mainland.

Cathey Philip

From: [redacted]
Sent: Monday, 22 June 2015 12:27 PM
To: Corporate Email
Subject: Bruce Chick Park Plan Of Management

To the General Manager Mr Troy Green,

In respect to the exhibited Bruce Chick Park Plan Of Management we note that O'Keeffe family properties owned in the Stotts Creek area have and will require drainage of flood and normal rainfall events via Leddays Creek, McLeods Creek and Stotts Channel to the Tweed River. Efficient drainage is critical to the growing of crops and other land uses on the Tweed River floodplain.

Yours sincerely

Paul O'Keeffe
for GR & KD OKeeffe Pty Ltd and K.D. O'Keeffe

Cathey Philip

From: [redacted]
Sent: Monday, 22 June 2015 12:37 PM
To: Corporate Email
Subject: Bruce Chick Park Draft Plan of Management exhibition

Attention to the General Manager Mr Troy Green

In respect to the exhibited Bruce Chick Park Draft Plan of Management I note the O'Keeffe family properties in the Stotts Creek area rely on drainage of flood and rain water via Leddays Creek, McLeods Creek and Stotts Channel to the Tweed River. It is critical to the growing of crops on the Tweed river floodplain that drainage is efficient. The Bruce Chick Park Draft Plan of Management should maintain or ideally improve water flows through these water courses.

Yours sincerely

Paul O'Keeffe for

GR & KD O'Keeffe Pty Ltd and K.D. O'Keeffe