Pictures: Division of Soils

Working together with acid sulfate soils

Carson Creagh

A recent conference revealed the extent and severity of acid sulfate soils worldwide and put forward some simple solutions for land managers.

Reddish gelatinous precipitates formed on the the soil surface by iron oxidising bacteria.

A cleared landscape in the Adelaide Hills. Black 'mushy' saline sulfidic soil has formed in a seepage area where rising saline-sulfatic groundwater occurs.

Linnaeus, the father of biological classification, also practised his art on the earth beneath his feet. In 1735 he described the soils of Holland's newly-reclaimed polders as *argilla mixta fusca, vitriolica salsa*: 'muddy brown class tasting of sulfuric acid salts'.

Today we refer to those acid-tasting, muddy soils as acid sulfate soils (ASS). They are found around the world, from Europe to Asia and Australasia, and have their origin in the ending of the last glaciation (see 'Preventing acid spills from farm land', *Ecos* 70).

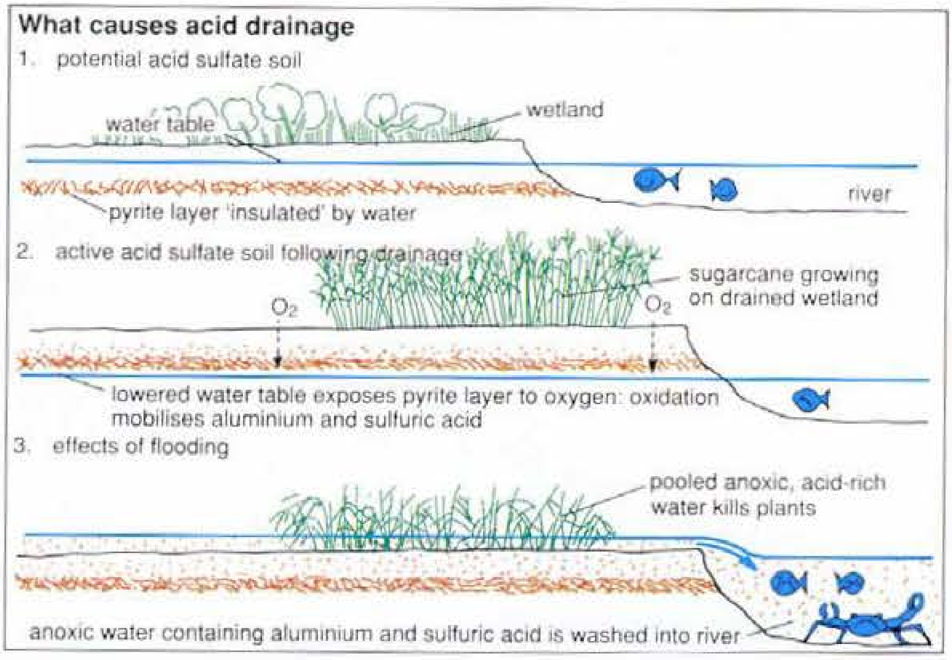
Up to about 20 000 years ago, the sea was generally 100 metres below present levels: global warming melted the ice locked in glaciers and ice caps, pushing sea levels upward and inundating low-lying land on continental margins. That process mobilised sediments and deposited them in coastal embayments, to be colonised by mangroves. The mangroves locked the sediment in place and added organic matter. In the absence of oxygen, bacteria breaking down the organic material reduced the sulfate from seawater to iron pyrite or iron sulfide, at concentrations of up to 15% in the top metre or more of the sediment profile.

While it is covered by water and thus insulated from the atmosphere, this pyritic layer is an innocuous 'potential acid sulfate soil', or PASS. When coastal land is drained or cleared for agriculture or development, however, oxygen can reach the iron sulfide and oxidise it to sulfuric acid: in some areas, acid strong enough to corrode steel and concrete.

Corrosion can be inconvenient, but the oxidation of a PASS into an actual acid sulfate soil has far-reaching consequences. In areas made susceptible by draining for dairying, sugar-cane farms or sand mining, prolonged dry spells lower the water table in low-lying areas, exposing the sulfide layer to oxygen and oxidising it to form sulfuric acid. This mobilises aluminium, present in unlimited amounts in soil clay. When the land floods after heavy summer rains, the aluminium is washed into coastal rivers and estuaries. The sudden influx of acidic water high in aluminium and iron clogs the gills of fishes, crustaceans and oysters, causing fish kills in rivers such as the Tweed and Macleay, on the north coast of New South Wales.

In June this year, Bob Smith of NSW Agriculture's Wollongbar research station near Lismore and colleagues from the Tweed Shire Council, CSIRO and other organisations, convened the first national acid sulfate soils conference. It was held at Coolangatta, on the border between NSW and Queensland (an area, like much of the north and east coast of Australia, characterised by widespread ASS).

Almost 200 people attended the conference — scientists, conservationists, local and state government representatives, farmers, professional fishermen and members of the sugar industry. Papers were presented by university and CSIRO scientists, private consultants and local and state government planners.



The problem begins when a lowering of the water table exposes 'potential acid sulfate' soil to oxygen.

Acids around the world

Concern about acid sulfate soils extends far beyond Australia. Dr David Dent, a visiting scientist with CSIRO's Division of Soils and an internationally recognised authority on the subject

Acid sulfate soils usually form in the muds that accumulate in mangrove areas such as at the Clyde River Estuary on the New South Wales south coast.

Simple solutions for cane farmers . . .

Finding ways to live with acid sulfate soils (ASS) need not be complex, even when the situation is as serious as at MacLeod's Creek in New South Wales (a tributary of the Tweed River). Here, ASS are believed to extend to a depth of 9.7 metres below the soil surface.

Acid drainage and fish kills on the Tweed River can be prevented by a simple change in cane farming practices, a research team has found. The team comprises Dr Ian Willett (formerly a soil chemist from CSIRO's Division of Soils and now a researcher with the Australian Centre for International Agricultural Research), Dr Ian White, a soil physicist from CSIRO's Centre for Environmental Mechanics, and Dr Mike Melville, a senior lecturer at the University of NSW's School of Geography.

Cane growers believe their fields must be drained continually and rapidly by floodgates emptying into adjoining waterways, and that more than three days' immersion kills cane roots and reduces productivity. But field observations by White and Melville have shown that simply leaving floodgates partially closed in cane fields with higher watertables has little effect on cane growth.

... and road builders ...

White and Melville have arrived at a similar remedy for a problem faced by the Roads and Traffic Authority (RTA) of NSW. An RTA engineer reported that water leached from a stockpile of gravel at Eungai, near Kempsey on the lower north coast of NSW, had killed nearby vegetation and that fish in a dam downstream from the stockpile had died.

He took immediate steps to arrest leaching by building interception banks (called bunds) and a containment pond, neutralising the leachate and testing for acidity. White and Melville found yellow, sulfurous material on the gravel particles, a strong odour of hydrogen sulfide and scattered mud balls up to 20 centimetres in diameter in the gravel.

Though it is unusual to find pyrite associated with gravel, White and Melville learned that the stockpile had been dredged from the bed of the Nambucca River, so ASS sediments had become mixed with the gravel. The ASS mud balls had a pyrite concentration of about 1% — meaning a sulfuric acid concentration, after oxidisation, of about 2%.

Such a concentration is environmentally dangerous, but can be neutralised efficiently. The researchers recommended that the RTA proceed with its proposal to mix, in a pug mill with the gravel, fine granite particles and lime (to cement the roadbase together), but to increase the amount of lime to ensure there is enough for complete neutralisation of the pyrite.

... and prawn farmers

Australia's growing mariculture (prawn farming) industry is carried out in low-lying coastal areas, and traditionally consists of 'tanks' that are excavated, allowed to fill with salt water, stocked with prawn fry and flushed by tidal action. The industry today employs a high degree of technology for maximum production. There lies a complex problem.

First, low-lying coastal sites close to tidal flushing and a supply of prawn fry are still used. That means ponds are still being excavated in acid sulfate soils.

Second, mariculturists use fowl manure and fertiliser to create algal blooms that provide food for the growing prawns, adding 10 tonnes of feed to produce five tonnes of prawns. This regime results in 100 tonnes of sediment over the period needed for the prawns to reach marketable size.

Third, prawns require a pH of more than seven for maximum growth, so mariculturists add lime to the water in the ponds. The addition of lime to provide this pH means the oxidation of pyrite does not mobilise aluminium, but does produce lots of soluble iron.

The sediment from intensive feeding consists largely of anaerobic matter, which allows bacteria to form black iron monosulfide. The soluble iron also oxidises to form acidity, which strips carbonate and bicarbonate from the water. These conditions clog the prawns' gills and prevent moulting (which, since prawns have external skeletons, they must undergo if they are to increase in size).

This inter-connected series of problems results in decreased productivity for mariculturists and environmental hazards for the regions in which they operate. However, White and Melville have arrived at a neat solution. After examining a prawn farm at Logan River, in southern Queensland, they have recommended that mariculturists:

- Construct ponds above ground rather than excavating them into PASS.
- Line the ponds with a layer of magnesium carbonate or calcium carbonate. If sulfuric acid comes into contact with carbonate compounds, it transforms them into magnesium sulfate (Epsom salts) or calcium sulfate. These are both essentially neutral substances that prevent the buildup of iron monosulfides, maintaining aerobic conditions that enable sediment organisms to survive and to provide an additional source of food for the growing prawns.

Expert system on the way

An expert system for identifying and managing acid sulfate soils (ASS) is being developed by Dr David Dent, Dr Greg Bowman and Warwick McDonald of CSIRO's Division of Soils.

The expert system runs on a personal computer and makes available international experience on ASS management to planners, decision makers, land managers and engineers. It is also suitable for educational use.

Several modules are being written. The first, which is already running, is an ASS identikit and work is underway on further modules for ASS hazard assessment, management and engineering.

revealed the extent of the hazard to agriculture and to the aquatic environment. Drainage of coastal wetlands has generated sulfuric acid from Sierra Leone in equatorial Africa, to Indonesia, Malaysia and Vietnam in South-East Asia, to the Orinoco Delta and Guyanas in South America.

In the wet tropics, the pyritic coastal soils have been insulated from oxygen by a covering of peat. Extreme acidity has developed as this protective layer has been cleared by drainage and burning. For example, in the Mekong Delta where pioneer Vietnamese settlement began only 300 years ago, there are still residual peat domes. But around these domes the watertable now drops below the surface during the dry season, creating aureoles of severe acidity that restrict agricultural opportunities and pollute the floodwaters of the next rainy season.

Local farmers exert some control over the watertable by using monsoonal flooding and grow rice successfully, since flooded conditions reduce iron and sulfates in the soil, removing acidity. They also employ the delta's brackish floodwaters for shrimp farming in the dry season, again keeping the lid on oxidation of pyrite. However, they depend on natural shrimp fry from the depleted coastal mangrove fringe, running the gauntlet of acid-polluted river waters to reach the inland rice-and-shrimp fields.

Many valuable lessons have been learnt about management of acid sulfate soils. In one Malaysian palm plantation, production dropped from more than 20 tonnes of fruit a hectare to almost nothing when the drains were deepened, exposing ASS. Blocking the drains to raise the watertable and flood the acid layer allowed the yields — and the plantation's managers — to recover, with production rising above the original level.

The Netherlands was uniquely lucky. Its ASS were underlain by a layer of marl, a natural source of lime. Eventually the farmers found that by ploughing deeper than usual, enough lime was turned up to neutralise the sulfuric acid. Elsewhere, lime has to be bought and added to the soil.

Agricultural lime is relatively inexpensive, but when many tonnes are needed to neutralise just one hectare of ASS, the costs quickly outweigh the benefits. For every hectare of rice-growing land on Thailand's Bangkok Plain, production increases from fewer than two tonnes to almost three tonnes when more than six tonnes of lime are added. But profitability drops from more than 1500 *baht* to about 500 *baht* a hectare.

Acids, rivers and agriculture

Jesmond Sammut, a post-graduate student from the School of Geography at the University of NSW, discussed his research into the effects of acidified water on freshwater and estuarine fish stocks. This has economic as well as environmental importance, since some 60% of commercially-harvested fish species spend at least part of their lives in estuaries.

Fish kills may be the most dramatic effect of ASS on river systems, especially where sugarcane farming and associated drainage have lowered water tables and exposed PASS to oxygen, but there are equally important sub-lethal impacts. As well as epizootic ulcerative syndrome, or 'red spot disease' (see 'Red spot disease: the acid connection', *Ecos* 70), fish suffer eye, gill and tissue damage, calcium deficiencies leading to bone deformities and egg abnormalities, reduced growth rates and increased susceptibility to fungal, bacterial and other infections.

In many circumstances, fish (which detect minor changes in water acidity) can escape 'flushes' or 'slugs' of acid water travelling downstream into their habitats, but in some eastern Australian rivers, management devices such as weirs and barrages block off such escape routes, leaving the fish effectively trapped.

Dr Rob Fitzpatrick, senior principal research scientist with the CSIRO Division of Soils in Adelaide, discussed the unique occurrence and formation of ASS in inland pasture areas affected by dryland salinity as well as ASS that occur at sites that were formerly coastal. His work has focussed on the recent soil-landscape processes (rising saline-sulfatic groundwaters associated with tree clearing since European settlement) that explain the complex transformation of fertile soils to saline sulfidic marsh soils. Fitzpatrick and his colleagues have developed proposals to show how both the Australian and international soil classification systems may be modified to describe these unique soils. He said the Multi-Function Polis site near Adelaide was underlain by ASS. This caused significant planning problems for developers.

Humans are just as affected as are fish. Mining (for example, the exploitation of the Jabiluka uranium deposits on the Kakadu floodplain see 'Preventing acid spills from farm land', *Ecos* 70) and industrial activities in ASS areas face immense problems, and residential development can only proceed if the immediate effects of sulfuric acid on the development itself as well as 'downstream' impacts are addressed at the planning stage.

Acids and development

Dr Greg Bowman, a principal research scientist with the CSIRO Division of Soils in Canberra, has devised a protocol for dealing with ASS on industrial or residential development sites.

The first stages involve investigating the extent and severity of ASS. A management strategy can then be chosen. This might involve avoiding the affected site; leaching acidity from the soil in a controlled manner; neutralising the acid with lime or, potentially, with magnesite (a mineral abundantly available and which appears more environmentally benign than lime); burying ASS in situ beneath clean fill; removal and placement into anoxic (oxygen deficient) storage beneath the water table, or hydraulic separation of the pyrite for return to anoxic storage.

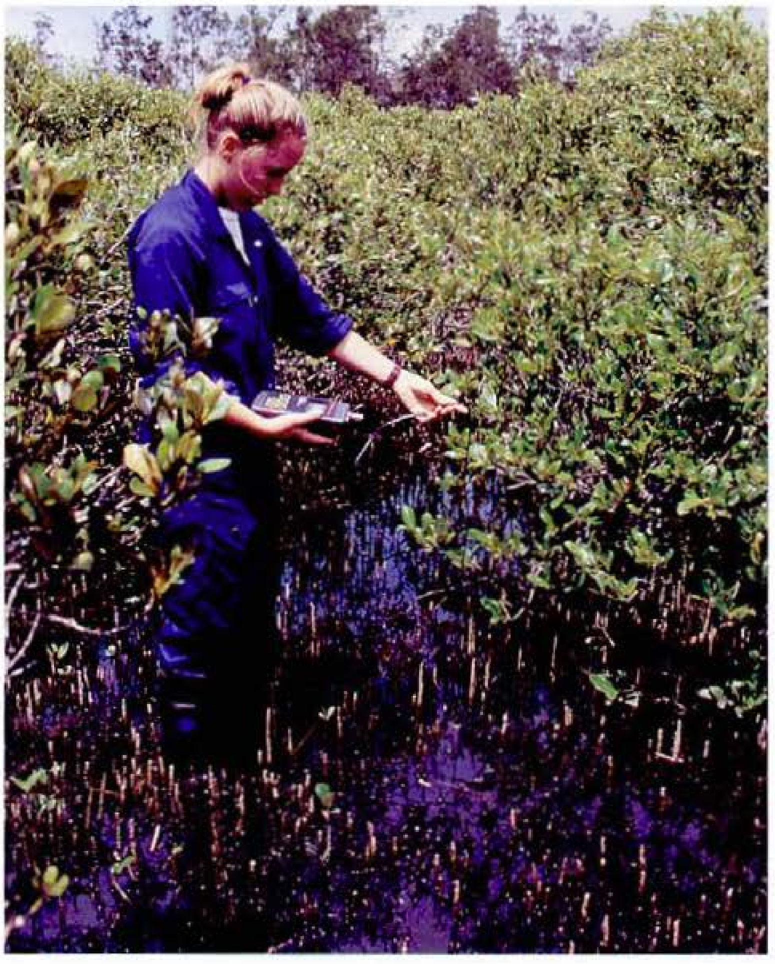
Bowman's strategies can be applied in a range of conditions, depending on costs and practicability, but assessment at the preliminary planning and environmental impact statement stages can lead to management techniques that combine avoidance with simple, cost-effective control. At Cobaki Lakes, a residential development site near Coolangatta, engineers have redesigned the entire 500 ha development to avoid ASS wherever possible and to deal with unavoidable ASS concentrations by removing the affected soil and transferring it to anoxic storage.

At Micalo Island, a proposed resort development site on the Clarence River estuary in NSW, the ASS have been acidified by drainage for sugarcane and aquaculture. On the basis of site investigations, Bowman has proposed a novel amelioration technique based on a process used in the heavy mineral sands mining industry.

During earthwork construction at Micalo, the sandy ASS will be excavated by wet dredging and the heavy pyrite grains will be separated from the bulk of the soil by pumping through hydro-cyclones or by sluicing. The pyrite will then be returned to permanent anoxic storage on the floor of the new lakes. Studies are underway to prove that the proposal will work and more research is planned to refine the separation technique and to determine the range of ASS conditions for which it is suitable.

Copies of the Acid Sulfate Soils Conference proceedings are available for $35 from Jan Edwards, Wollongbar Agricultural Institute, Bruxner Highway, Wollongbar, NSW 2477, (066) 24 0345, fax (066) 28 1744.

Excavating pits at Micalo Island so acid sulfate can be observed and sampled.



The extent and severity of acid sulfate soils is determined before choosing a management strategy.

More about acid sulfate soils

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