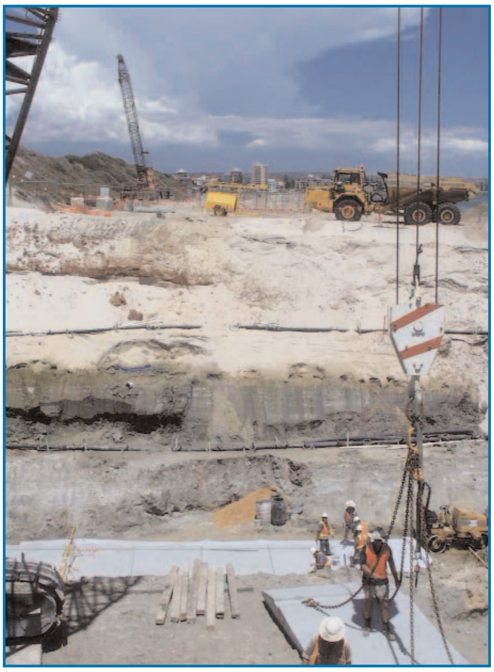
coastline

A Strategy for Implementing CPB Policies on Coastal Acid Sulfate Soils in South Australia

SOUTH AUSTRALIAN COAST PROTECTION BOARD **No 33 January 2003**



Cover photos of coastal acid sulfate soils and their impacts. Source: CSIRO

INTRODUCTION

Coastal acid sulfate soils (CASS) are potentially present throughout most low-lying coastal regions in South Australia.

The Coast Protection Board's strategy for coastal acid sulfate soils has been developed through the Coastal Acid Sulfate Soils Program (CASSP) in Environment Australia to assist South Australian government agencies, individuals and organisations in the identification and management of CASS. CSIRO and the Coast and Marine Branch (CMB) in the Department for Environment and Heritage (DEH) have been involved with the project. CSIRO has mapped CASS occurrence and analysed soil samples from high-risk areas, and CMB has prepared the Board's CASS strategy.

The strategy is detailed in three reports: 1) *Interim Strategy for Implementing CPB policies on Coastal Acid Sulfate Soils in South Australia* (CPB 2002a)*; 2) Interim Development Guidelines and Risk Assessment Criteria for Coastal Acid Sulfate Soils in South Australia* (CPB 2002b)*;* and *3) Interim Checklist for Development in Coastal Acid Sulfate Soils, South Australia* (CPB 2002c).

The strategy has been prepared in relation to the Board's Development and Hazard Policies, particularly policy 1.3 and policies 2.1 to 2.3 (CPB 2002d).

Coast Protection Board Policies Relating to Acid Sulfate Soils

Policy 1.3. The Coast Protection Board will identify specific areas of the coast that require particular management actions.

[In doing so, it will have regard to coastal flooding and erosion, acid sulfate soils, areas of conservation significance and landscape amenity values.]

The Guidelines relating to Flooding and Erosion and Acid Sulfate Soils are contained in Appendix 1 and 2, respectively of the Policy Document.

Policy 2.1. The Board will formulate hazard standards for the state of South Australia with reference to:

- Risk management approaches to hazard management using the Intergovernmental Panel on Climate Change's recommendations to policy makers, and
- Commonwealth recommended approach to management of Coastal Acid Sulfate Soils.

Policy 2.2. The Board will facilitate:

(a) the use of strategic and legally enforceable agreements to manage the risk of damage from coastal hazards on development.

(b) a program of vulnerability assessment to ensure that sufficient coastal buffer zones are provided for predicted physical processes and to accommodate public infrastructure, use and access.

[In so doing the Board will have regard to the identification of Coastal Acid Sulfate Soil areas.]

Policy 2.3. The Board will advise on development proposals within coastal areas.

[The standards to be applied to Flooding and Erosion and Acid Sulfate Soils are contained in Appendix 1 and 2, respectively of the Policy Document].

For development in areas identified as being at risk from CASS, the Board will seek from the developer the following information before providing advice to the relevant planning authority;

- specific site and watertable levels, relative to Australian Height Datum (AHD),
- soil and water sampling and analyses to determine presence of coastal acid sulfate soils contamination, and
- where CASS are confirmed seek additional information on remedial strategies to minimise soils, surface water and groundwater contamination, and a management plan for ongoing monitoring and best-practice management of the area.

WHAT ARE COASTAL ACID SULFATE SOILS?

Acid sulfate soils are naturally occurring soils or sediments that contain iron sulfide. In coastal regions they are formed during and following sea-level inundation when seawater or brackish waters containing dissolved sulfate cover organic-rich environments such as swamps, mangroves, salt marshes or tea-tree.

Under oxygen-depleted conditions, iron present within soils or sediments combines with sulfur from sulfate to form iron sulfides, in particular pyrite (FeS_2). When these sulfides are disturbed and exposed to air, oxidation occurs and sulfuric acid is produced. For every tonne of sulfidic matter that is oxidised, 1.6 tonnes of sulfuric acid is produced (NWPASS, 2000).

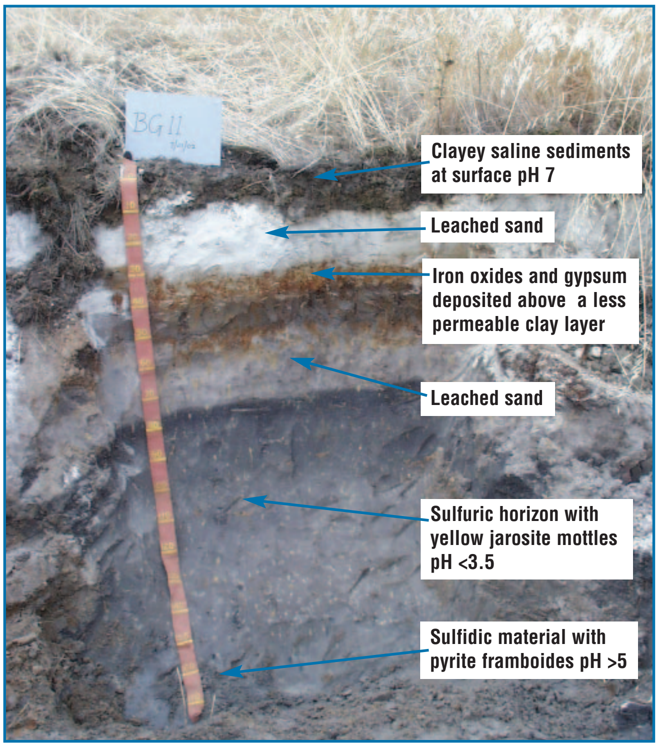
Much of the acid produced either drains into waterways or reacts with carbonates and clay minerals in soils or sediments to liberate dissolved aluminium, iron, manganese, heavy metals such as copper and arsenic, and other metal ions. If a buildup of acid or dissolved ions then occur, this can be extremely toxic to plants and animals.

Prolonged exposure of coastal acid sulfate soils to air also causes 'soil ripening' – an irreversible loss of water resulting in physical, chemical and biological changes to the soil. Soils can shrink fifty per cent or more by volume, particularly if peat topsoil is oxidised or areas are drained. This in effect causes lower elevations in drained areas compared to those that remain undrained.

Acid sulfate soils include both 'actual' and 'potential' acid sulfate soils (Figure 1). Actual acid sulfate soils (AASS) contain highly acidic soil horizons generally with pH 4 or less (sulfuric horizons). Pale yellow mottles of jarosite often confirm the presence of these soils. Potential acid sulfate soils (PASS) contain iron sulfides, known as sulfidic material, which have not been oxidised or exposed to air. Their field pH is generally pH 4 or greater.

ENVIRONMENTAL IMPACTS

The release of acid and metal ions into the environment can cause major habitat degradation and loss of biodiversity. Where the effects of actual ASS are evident, acidic scalds or drain spoils are often seen. These remain either unvegetated or are suitable only to acid-tolerant species (Figure 2a).



Photography: Rob Fitzpatrick

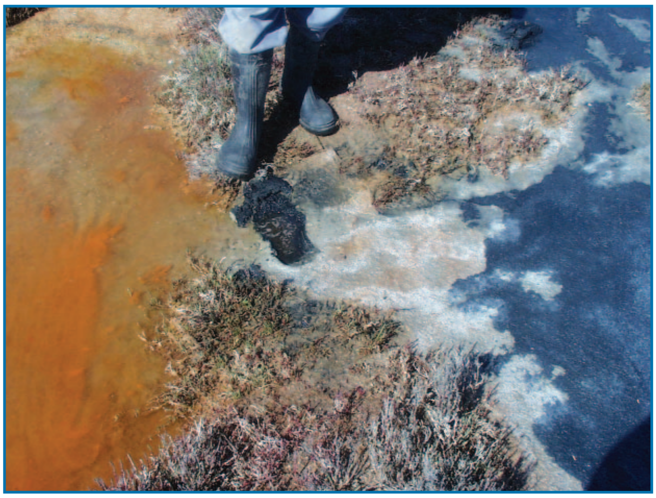
Figure 1a *Actual acid sulfate soils showing yellow streaks and mottling patterns containing jarosite (pH <4) in the grey subsoil*

Photography: Richard Merry

Figure 1b *Potential acid sulfate soils showing dark sulfidic material (pH 7)*

Photography: Brett Thomas

Figure 2a *Mangrove dieback caused by actual acid sulfate soils*



Photography: Richard Merry

Figure 2b *Iron precipitation following pH increase*

Pulses of acidic water entering estuarine and coastal environments can cause massive kills of fish, crustaceans, shellfish and other organisms. Research suggests a strong association between acidity, aluminium and gill damage in fish (NWPASS, 2000). Moreover, exposure to acidic water can damage fish skin and lead to infection by the fungus, *Aphanomyces* sp., which causes epizootic ulcerative syndrome (EUS), also known as red-spot disease. In addition, the mobilisation of black sulfidic materials can result in localised anoxic conditions in waters as oxidation proceeds to form sulfidic acid.

Acidic waters affect aquatic plants through direct exposure to acid, aluminium or manganese toxicity or smothering from iron flocs (Figure 2b). In such cases, plant communities decrease in diversity and become dominated by acid-tolerant plants. Harmful algal blooms can also be triggered by acidic water containing dissolved iron and silica.

DEVELOPMENT ISSUES

Disturbance of coastal acid sulfate soils typically results from developments that involve drainage, dewatering, excavation or filling. There are several types of development that have the potential to cause disturbance unless managed appropriately. These include:

- Infrastructure: roads, railways and bridges; port facilities and drainage works; sewage treatment works; laying of utilities such as water, sewerage and communications.
- Urban/Tourism Developments: boat harbours and marinas or canal estates and resorts.
- Mining: sand and gravel extraction.
- Agriculture/Aquaculture: either where land has been drained and works constructed such as levees, drains and floodgates or where groundwater has been extracted or lowered through the alteration of flow paths.

Most developments in coastal acid sulfate soil risk areas of South Australia have generally proceeded unchecked as acid sulfate soil disturbance was not identified as an issue until relatively recently. It is highly probable that certain developments are now under threat of deterioration or corrosion due to the release of acid either during or after their construction phase (Figure 3). Once acid sulfate soils are disturbed on a site, much of the surrounding environment is also subject to acidification by surface water or groundwater, with dissolved metals also potentially impacting the ecology of the region.

Photography: Richard Merry

Figure 3a *Concrete pipe corroded by action of acid sulfate soils*

Photography: Richard Merry

Figure 3b *Exposure of buried potential acid sulfate soils at Barcoo Outlet, which were below the watertable and under sandhills.*

RISK MAPPING

Coastal acid sulfate soils risk mapping has been undertaken to assess the probability of acid sulfate soils occurrence within the coastal regions of South Australia. Coastal saltmarsh habitat maps were used as base maps (http://www.atlas.sa.gov.au) and ten classes of acid sulfate soils risk probability were assigned to them (Table 1).

DISTRIBUTION

Actual acid sulfate soils have been identified in the Port Adelaide/Gillman region of South Australia (Figure 4b). Sulfide-containing sediments and problems associated with pyrite oxidation and export of acid leachate were first reported in the region by Harbison (1986). High concentrations of aluminium, arsenic, iron, zinc and lead have also been found in surface water and groundwater (Harbison 1986; Pavelic and Dillon 1993), and Fitzpatrick and Self (1997) identified the presence of potential and actual acid sulfate soils containing finely divided organic carbon (sapric material).

Potential acid sulfate soils are present throughout coastal regions in South Australia where low-lying coastal sediments have been deposited and/or soils formed. Evidence from fieldwork has identified several potential acid sulfate soil classes at a number of sites including Cowell (Figure 4c) and Weeroona Island (Figure 4d).

Table 1. CSIRO Acid Sulfate Soil Map Classes for South Australia (Fitzpatrick *et al*. in press)

	Map Legend	Class Description
1	(a) Actual ASS (disturbed)	**Actual acid sulfate soils** (existing AASS) Very high risk. Only found in this mapping unit in the Port Adelaide - Gillman, Barker Inlet area and in the adjacent “Other Soils” mapping unit.
	(b) Potential ASS (disturbed)	**PASS in subsoil below 20 cm (up to 1 metre thick) with surface monosulfidic black ooze (MBO), intertidal** (mainly in samphire). Moderate risk because carbonate layers usually occur above and below.
2	Potential ASS (mangrove)	**Thick PASS - mangrove soil** (potential acid sulfate soils) Mainly in mangroves with high risk.
3	Potential ASS (tidal stream)	**PASS of tidal streams** (PASS underlying tidal streams, not extensive laterally) Moderate risk.
4	Potential ASS (intertidal)	**PASS in subsoil below 20 cm (up to 1 metre thick) with surface monosulfidic black ooze (MBO), intertidal** (mainly in samphire) Moderate risk because carbonate layers usually occur above and below.
5	Potential ASS (supratidal)	**PASS in subsoil below 50 cm (up to 1 metre thick) with some surface MBO – supratidal** (Mainly in samphire, salt bush, blue bush, or saltpan associated with hyper saline soils where there is less frequent tidal inundation) Moderate to low risk.
6	Sand	**Soils of sand dunes, ridges** (No PASS and ASS within 1 metre of surface) Low risk of PASS below watertable.
7	Calcarenite	**Calcareous soils and hardpans** (No PASS, high neutralising) No or very low risk.
8	Marine Soils	**Marine soils – subtidal and intertidal marine** (PASS may be present; ASS neutralised by tides and carbonates) No or very low risk.
9	Other Soils	**Soils associated with other land uses within coastal landforms** Risk requires individual investigation; guided by adjacent mapped units.
10	Soils Not Classified	**Soils outside area of mapped coastal landforms**

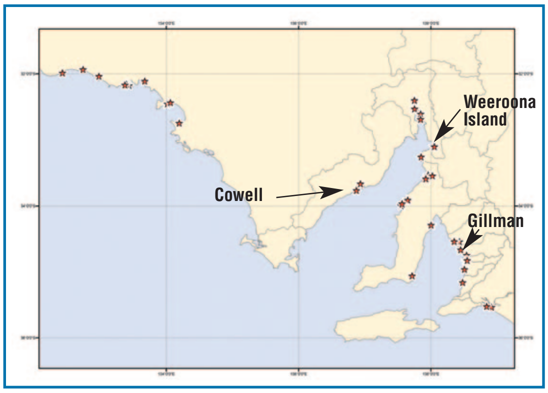


Figure 4a *Sampling locations in SA*

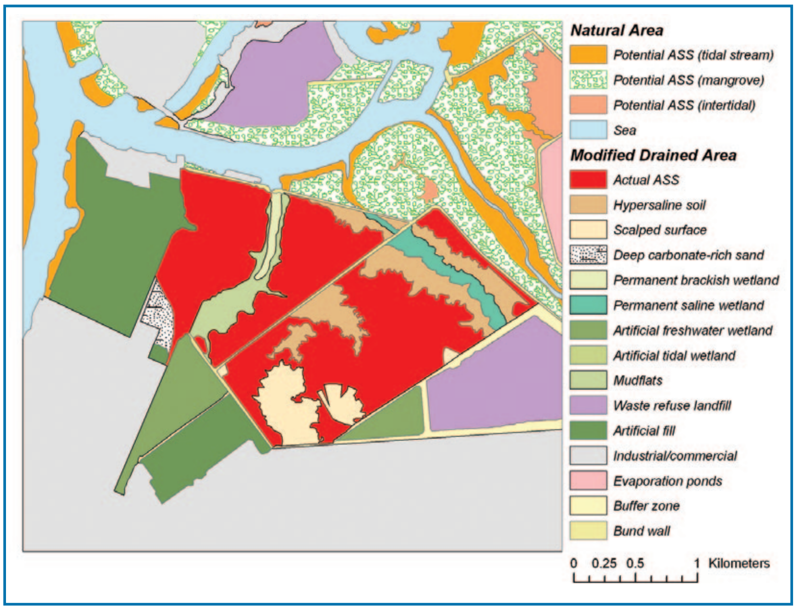


Figure 4b *Risk map showing actual acid sulfate soils at Gillman*

GILLMAN AASS

Over 2.5 km^2 of actual acid sulfate soils are present in the Gillman area. Bunds constructed more than 50 years ago across mangrove swamps cut off tidal flushing from Barker Inlet and drained areas, resulting in the formation of actual acid sulfate soils. Detailed mapping of the region as well as analyses of soils, surface water and groundwater have enabled a conceptual model of AASS formation, shown in Figure 5, to be developed.

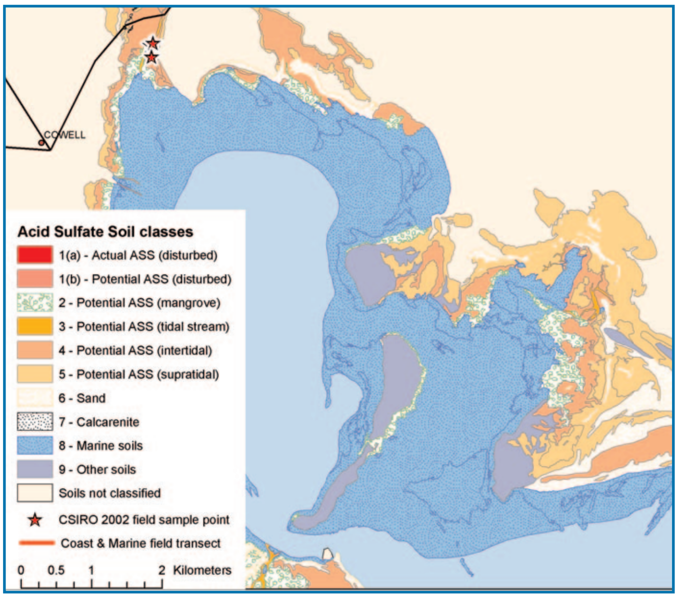


Figure 4c *CASS at Cowell*

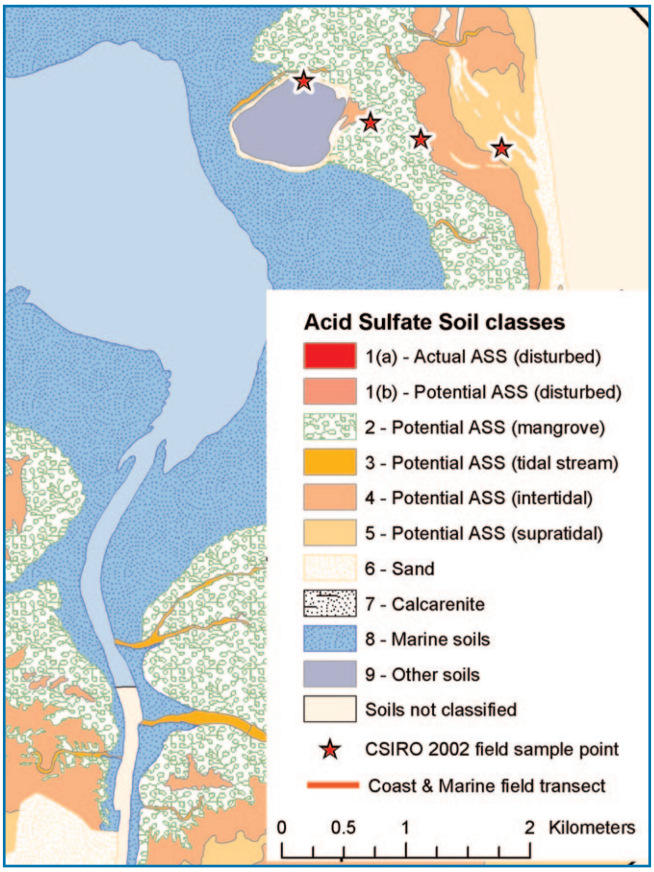


Figure 4d *CASS near Weeroona Island*

POLICY IMPLEMENTATION

In recognition of the disturbance caused by acid sulfate soils to the coastal environment, the Coast Protection Board has endorsed: 1) Policies relating to CASS; and 2) an Interim CASS Strategy, Development Guidelines and Risk Assessment Criteria, and a Checklist for Developments in coastal-zoned areas (CPB 2002a-d).

The policies are contained within the Development and Hazards sections of the Board's Endorsed Draft Policy Document (see text box, page 1), and its Interim CASS Strategy reports comprise Appendix 2 of that document. The CPB's CASS strategy statement and development guidelines are outlined in the text box on page 6.

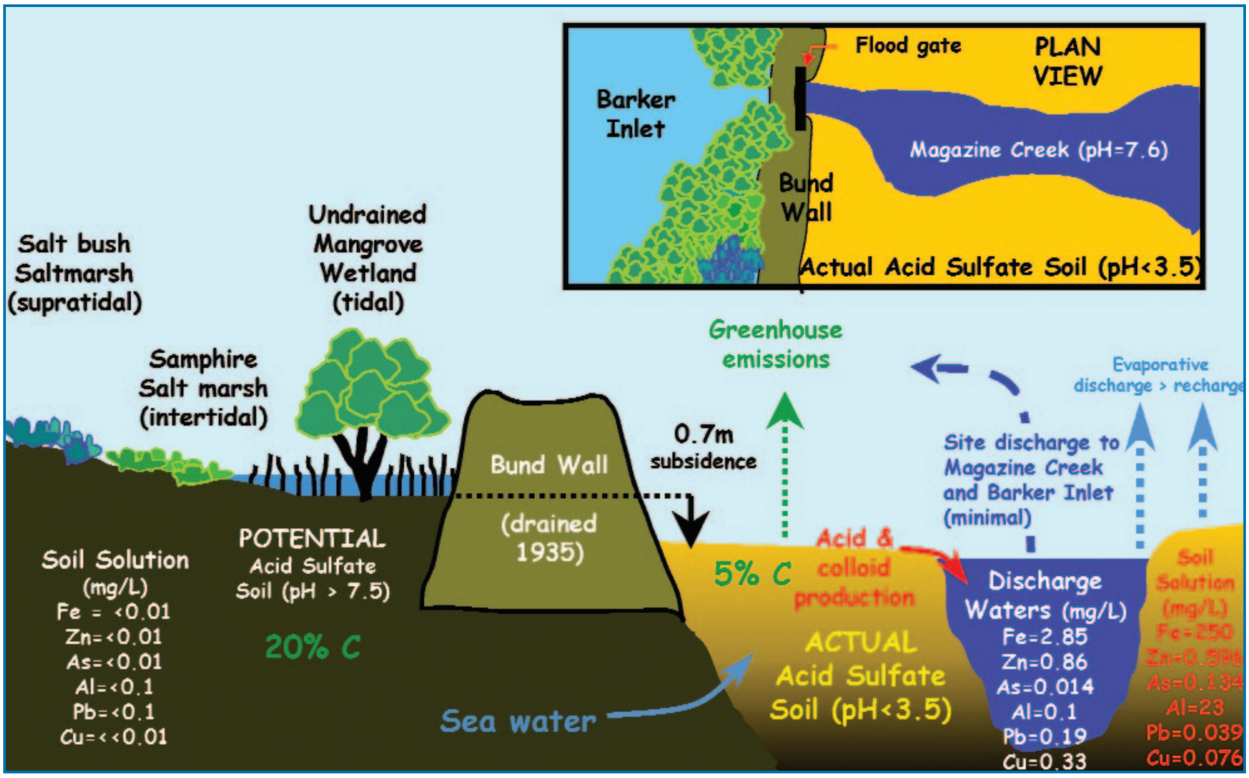


Figure 5 *Conceptual Model of actual acid sulfate soil formation at Gillman: CSIRO*

Strategy Statement

The Coast Protection Board will seek provision of the following for any proposed development in coastal acid sulfate soils areas before its advice will be provided to the Development Assessment Commission:

1. An assessment of the site including the natural ground surface relative to Australian Height Datum (AHD), and the amount of excavation or fill that is required;
2. Information on whether potential or actual coastal acid sulfate soils or groundwater are at risk of being disturbed as a result of the development;
3. Where there is a risk of acid sulfate soil disturbance:
consideration of mitigation strategies, and a standardised investigation of the soil, surface water and groundwater at the site; and
4. Where coastal acid sulfate soils are confirmed:
a management plan of ongoing monitoring and best-practice management of the area so that coastal acid sulfate soil disturbance is minimised and remediated.

Development Guidelines

For proposed developments in South Australian coastal areas:

1. Any coastal region or subsoil <5 m AHD, where the natural groundcover is less than 20 m AHD, will be subject to coastal acid sulfate soil risk assessment.
2. If acid sulfate soils (either potential or actual acid sulfate soils) are present, then acid sulfate soils provisions will apply to developments involving:
   a. extraction or removal of >100 m^3 material, or
   b. filling of >500 m^3 of material at >0.5 m average depth.
3. Any building, plumbing, drainage or operational works involving less than the relevant amount of excavation or filling is not assessable by the Coast Protection Board. However, in acid sulfate soils risk areas, standard building or works assessment criteria need to be devised.
4. ASS risk maps for South Australia will need to be consulted to determine the probability of acid sulfate soil occurrence and potential disturbance at the proposed development site. These will be available through the South Australian Coastal Atlas: www.atlas.sa.gov.au.

CASS DECISION TREE

FOR A PROPOSED DEVELOPMENT IN THE COASTAL AREA

Will the proposed development be <5 m AHD, where the natural groundcover is <20 m AHD, and involve excavation of >100 m^3 or fill >500 m^3 over 0.5 m average depth?

No

Yes

Refer to CSIRO CASS risk maps and CPB CASS risk assessment criteria (Table 2). Are coastal acid sulfate soils likely to be present at the site?

No

Yes

Provide information on the development including extent, depth and volume of proposed soil disturbance, and groundwater depths at the site.

Conduct a study of the general area including topography, geology, soil types, groundwater parameters, tidal limits, vegetation, cadastral information, roads and other infrastructure.

Undertake field sampling of elevation (AHD), soil horizon depths, pH, pH after peroxide reaction, and $Cl^-:SO_4^{2-}$ ratio. Are CASS confirmed and/or groundwater contaminated?

No

Yes

Reconsider development options such as other sites, alternative landuse, layout drainage design, groundwater usage or fill source. Will the development still proceed at this site?

No

Where the development is not likely to disturb coastal acid sulfate soils, information confirming this must be submitted in writing to the Coast Protection Board. If the Board agrees, no further action regarding acid sulfate soils is required.

Yes

BEFORE ANY DEVELOPMENT AT THE SITE:

1. Undertake detailed soil analyses, surface water and groundwater monitoring by a qualified ASS scientist.
2. Prepare a long-term CASS Management Plan that includes remedial actions at each stage of the development.
3. Conduct pilot projects and/or field trials of remediation techniques at the site.
4. Develop contingency plans in case of complications.

RISK ASSESSMENT

Acid sulfate soil risk maps can be used for planning purposes and to guide development by merging the ten classes into three main risk assessment categories depending on the probability of acid sulfate soil occurrence (Table 2).

Table 2. ASS Risk Assessment Criteria for South Australia (adapted from Stone and Hopkins 1998: Acid Sulfate Soil Model LEP)

Acid Sulfate Soil Map Class	Risk Assessment Categories	Risk Assessment Criteria
1-3	1	CPB CASS Policies applies to all developments.
4-6	2	Policies apply to developments that involve excavation or filling beyond 1 metre below natural ground surface or affect the watertable.
7-10	3	Policies apply to developments within 500 metres of adjacent Category 1or 2 land or which are likely to affect the watertable on adjacent Category 1 or 2 land.

ALTERNATIVE LANDUSES

Ideally, areas of high coastal acid sulfate soil risk should not be disturbed by development activities. The cost to the surrounding environment and inevitably to the development itself of releasing acid and metal ions into the soil and groundwater outweighs any short-term gain. Where acid sulfate soils have been disturbed in the past, structures have subsided, building materials have been corroded and agricultural or aquacultural productivity has been markedly reduced (NWPASS 2000).

To avoid disturbing coastal acid sulfate soils and the need for subsequent remedial works or rehabilitation, alternative approaches need to be considered before any earthworks are undertaken. These include:

- relocating the development to a low-risk area;
- reserving areas of high risk for environmental protection;
- redesigning site layouts to avoid CASS 'hot spots';
- designing shallow drains and floodgates to suit variable flows and reduce environmental disturbance;
- accessing water supplies other than groundwater;
- avoiding contaminated recharge to groundwater or decreasing the watertable level; and
- using only clean fill not from acid sulfate soil areas to avoid later remediation (Ahern *et al*. 1998).

If all alternatives have been considered carefully and the proposed development will still proceed, the proponent will need to submit standardised soil, surface water and groundwater analyses to the Coast Protection Board. A qualified acid sulfate soils consultant will be required to conduct a well-planned approach to the investigation and qualified laboratories will need to be used for the soil analyses. In situations where samples exceed acceptable sulfur or carbon results, a management plan for the development will be required.

SOIL, SURFACE AND GROUNDWATER ANALYSES

Analytical procedures being used by CSIRO for temperate acid sulfate soils in South Australia include:

- Total soil carbon and total sulfur by LECO furnace;
- Carbonate carbon – to determine the neutralising capacity, i.e. there is sufficient capacity to neutralise all the potential acid if the $CaCO_3$ content is 3 times that of total sulfur;
- Sulfide sulfur – to determine how much reduced sulfur is present;
- Total sulfur/sulfide sulfur – to indicate the amount of sulfate sulfur present;
- Total carbon/carbonate carbon – to estimate the amount of organic carbon present applicable as food for bacteria;
- Bulk density of soil samples to calculate mass of material in tonnes/ha; and
- Powder X-ray diffraction for detecting carbonate, sulfur-containing and layer silicate materials.

Two other methods commonly used to analyse soil samples are:

- Total oxidisable sulfur (TOS) – a low-cost screening tool used to determine sulfide levels but not acidity and generally unsuitable for soils containing sands and gravels with low levels of sulfidic material; and
- Peroxide oxidation combined acidity and sulfate (POCAS) – combined with TOS to determine the oxidisable sulfur content of soils, particularly those with pH less than 4.5. POCAS analyses provide an indication of the 'sulfur trail' and 'acid trail' of soils.

Where a clear relationship between the acid and sulfur trails can be established for a number of samples, only the POCAS acid trail need be used for the analyses.

The main water quality analyses are those of acidity, soluble iron, aluminium and heavy metal concentrations, and changes in dissolved oxygen, carbonate and bicarbonate levels. Water quality measurements should routinely include:

- pH,
- total dissolved solids or electrical conductivity (EC), and
- soluble Cl^- and SO_4^{2-} concentrations (for Cl^-: SO_4^{2-} ratio for groundwater or drain water).

Table 3 includes trigger values for several water-quality measurements. Disturbance to aquatic ecosystems is generally indicated if any measurements are not within the ranges (pH, DO, turbidity) or well in exceedence (Chl a, TP, TN) of the trigger values given.

ENVIRONMENTAL MANAGEMENT PLANS

An Environmental Management plan should consist of an integrated planning framework containing potential environmental and social impacts, performance criteria to deal with these impacts, mitigation or impact minimisation strategies, remedial measures monitored against performance criteria, implementation responsibilities, timeframes for management initiatives, reporting requirements or auditing responsibilities, periodic reviews of the plan, and corrective actions for any deviations from performance standards.

The acid sulfate soils component of an Environment Management Plan should specifically include a distribution map and/or cross-sectional diagrams of acid sulfate soil occurrence, potential on- and off-site effects of soil disturbance and groundwater levels, mitigation and treatment strategies for iron sulfide oxidation and surface water and groundwater contamination, monitoring requirements and verification testing, handling and storage of neutralising agents, and containment strategies (Queensland Government 2002).

REMEDIATION

Where developments have already occurred in coastal acid sulfate soils or where they may proceed within the coastal zone at risk of environmental or structural damage, remedial actions will be necessary to reduce any adverse impacts and rehabilitate the site and surrounding affected areas.

The main strategies for the treatment and management of coastal acid sulfate soils include:

- avoidance – by leaving CASS in an undisturbed state;
- minimisation of disturbance – by not undertaking any activity that results in the release, or accumulation and potential future release, of acid from the oxidation of undisturbed potential acid sulfate soils, and by preventing any lowering of the permanent watertable;
- neutralisation – by applying neutralising agents such as agricultural lime or bioremediating the soils so that all actual and potential acidity is neutralised;
- strategic reburial or reinterment below the watertable – by preventing oxidation of soils through long-term/permanent storage in an anoxic environment; and
- hydraulic separation techniques – by removing fine particles of pyrite and monosulfides (PASS fines). The process generally involves suspending PASS fines in a slurry and separating them from larger particles by either sluicing or cycloning (Queensland Government 2002).

CSIRO in South Australia has been conducting remediation trials at Gillman to determine the suitability of different techniques for managing actual and potential acid sulfate soils (Thomas *et al.* 2002). The main remediation techniques as illustrated in Figure 6 are: reflooding using existing freshwater and tidal wetlands and brackish water from a stormwater retention basin; bioremediation using sulfate-reducing bacteria and various organic wastes to re-establish reducing conditions and stop pyrite oxidation; lime slotting using soda by-products to treat discharges of acidic meteoric water or groundwater leachate; and tidal flushing or drainage in highly reducing, eutrophic potential acid sulfate soils at St Kilda where mangrove dieback is occurring.

The type of remediation that is applied to manage coastal acid sulfate soils depends on the specific soil types, environmental processes, the proposed development and its development plan. Particular attention will need to be paid to avoiding contamination of surface water and groundwater from coastal acid sulfate soil areas so that no acidic discharges or soluble toxic metals reach the surrounding waterways and ecosystem as a whole.

Table 3. Default trigger values for physical and chemical stressors for South Australia – low rainfall areas – for slightly disturbed ecosystems (adapted from ANZECC and ARMCANZ 2000).

Stressor	Lowland River	Estuaries	Marine
pH	6.6-9.0	6.5-9.0	8.0-8.5
Dissolved Oxygen (% saturation)	90%	90%	NA
Chlorophyll a (mg L^{-1})	NA	5	1
Total Phosphorus (mg P L^{-1})	100	100	100
Total Nitrogen (mg N L^{-1})	1000	1000	1000
Turbidity (NTU)	1-50	0.5-10	0.5-10

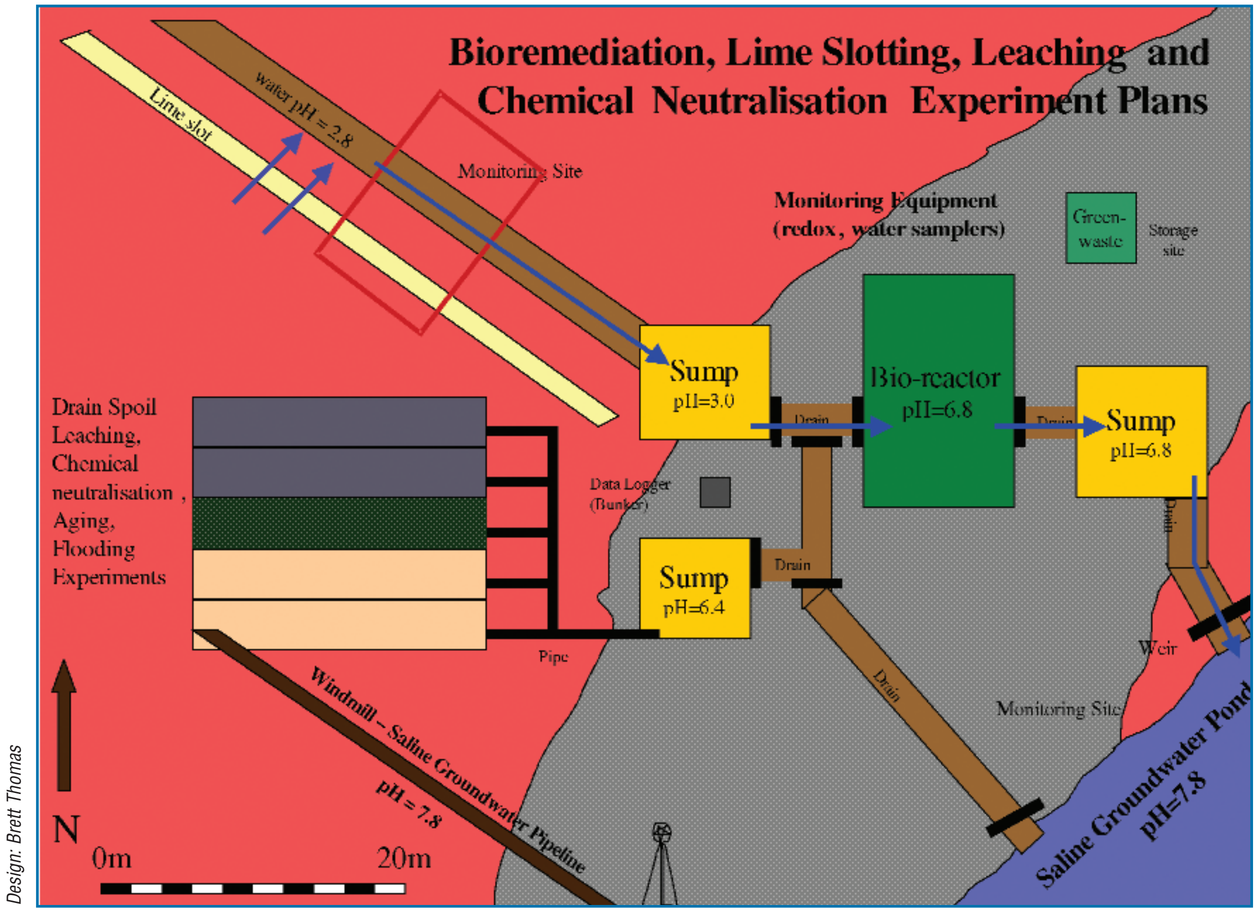


Figure 6: *Acid sulfate soil remediation trials at Gillman*

CONCLUSIONS

Where coastal acid sulfate soils are disturbed without appropriate management and remediation, they pose a significant threat to development and the natural environment. Previous disturbances in South Australia, such as at Gillman and other areas where coastal developments have proceeded unchecked, have corroded built structures and caused ecological degradation.

The Coast Protection Board's strategy for coastal acid sulfate soils applies to coastal-zoned areas and sets out actions to be taken by proponents of large-scale coastal developments to avoid, mitigate or rehabilitate areas of high risk. It is not the intention of the strategy to stop development because of coastal acid sulfate soils. Rather, the strategy has been prepared to avoid or minimise potential adverse effects of disturbance through appropriate risk assessment, treatment and management.

REFERENCES

Ahern C R, Stone Y and Blunden B, 1998. Acid Sulfate Soils Assessment Guidelines. Published by the Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.

ANZECC and ARMCANZ, 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Coast Protection Board (CPB), 2002a. *Interim Strategy for Implementing CPB Policies on Coastal Acid Sulfate Soils in South Australia*. Coast Protection Board of South Australia.

Coast Protection Board (CPB), 2002b. *Interim Development Guidelines and Risk Assessment Criteria for Coastal Acid Sulfate Soils in South Australia*. Coast Protection Board of South Australia.

Coast Protection Board (CPB), 2002c. *Interim Checklist for Development in Coastal Acid Sulfate Soils, South Australia*. Coast Protection Board of South Australia.

Coast Protection Board (CPB), 2002d. Coast Protection Board Endorsed Draft Policy Document, 30 August 2002. Coast Protection Board of South Australia.

Fitzpatrick R W and Self P G, 1997. Iron oxyhydroxides, sulfides and oxyhydroxysulfates as indicators of acid sulphate surface weathering environment, p. 227-240. In K Ayerswald, H Stanjek and J M Bigham (eds.). Soils and Environment: Soil Processes from Minerals to Landscape Scale. Advances in GeoEcology 30. *Catena* Verlag, Reiskirchen, Germany.

Fitzpatrick R W, Davies P G, Thomas B P, Merry R H, Fotheringham D G, Hicks W S and Barnett E J, in press. Properties and distribution of South Australian coastal acid sulfate soils and their environmental hazards. Australian Journal of Soil Research.

Harbison P, 1986. An Assessment of the Pollution Status of the Ponding Basin Area in the Vicinity of Magazine Creek and the North Arm. Department of Geology, University of Adelaide, South Australia.

National Working Party on Acid Sulfate Soils (NWPASS), 2000. *National Strategy for the Management of Coastal Acid Sulfate Soils*. NSW Agriculture Wollongbar Agricultural Institute, pp.39.

Queensland Government, 2002. State Planning Policy 2/02. Planning and Managing Development Involving Acid Sulfate Soils. Department of Local Government and Planning and Department of Natural Resources and Mines, Queensland.

Pavelic P and Dillon P, 1993. Gillman – Dry Creek Groundwater Study, Volume 1 and 2. Final Report to MFP Australia. Centre for Groundwater Studies Report No. 54. Collaborating Organisations: CSIRO, Flinders University of South Australia, Department for Mines and Energy and Water Supply Department.

Stone Y and Hopkins G, 1998. *Acid Sulfate Soils Planning Guidelines*. Section 1: Acid Sulfate Soil Manual. Acid Sulfate Soils Management Advisory Committee (ASSMAC), Wollongbar, NSW, Australia, pp.14.

Thomas B P, Fitzpatrick R W, Merry R H, Hicks W S and Davies P G, 2002. Approaches to remediation of acid sulfate soils in Barker Inlet, South Australia. 5th International Acid Sulfate Soils Conference, Tweed Heads, NSW, 25-30 August 2002, Extended Abstracts, p 67-68.

COAST PROTECTION BOARD

Natural Heritage Trust
Helping Communities Helping Australia
A Commonwealth Government Initiative

For further information, contact the
Coast and Marine Branch,
Natural and Cultural Heritage,
Department for Environment and Heritage.
Ph: 8124 4877; Fax 8124 4920 or
visit our web site: www.coasts.sa.gov.au