



National Strategy *for the* Management of Coastal Acid Sulfate Soils

AGRICULTURAL AND RESOURCE
MANAGEMENT COUNCIL OF
AUSTRALIA AND NEW ZEALAND

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Cover photograph: Hastings River, New South Wales, showing acidic plume. Mike Dove, University of New South Wales.

Foreword

Acid sulfate soils (ASS) occur throughout Australia. The focus of this paper is coastal and estuarine ASS. Coastal ASS have formed through natural processes and are generally overlain by other soils. However, when coastal ASS are exposed to air by drainage or excavation and then rewetted, acid drainage water is produced. Past government policies, the high demand for living on the coast and the extensive agriculture along the coastal strip have led to disturbance and increased exposure of ASS. These have resulted in large-scale acid generation and runoff.

Acid runoff causes a range of adverse impacts to the environment, coastal development, fishing and agricultural industries where it is inadequately neutralised by the receiving environment. Costs to local and regional communities may be measured in terms of:

- Poor water quality with attendant loss of amenity, damage to estuarine environments and reduction of wetland biodiversity.
- The need for rehabilitation of disturbed areas to improve water quality and minimise impacts.
- Loss of fisheries and agricultural production.
- Additional maintenance of community infrastructure affected by acid corrosion.

The *National Strategy for the Management of Coastal Acid Sulfate Soils* proposes a holistic and comprehensive approach to define the problem, prevent it from increasing and encourage remedial actions to reduce existing acid water runoff. In the absence of the National Strategy a piecemeal, cost ineffective response to this problem is likely. Future remedial actions can be expected to be much more expensive.

The benefits of the National Strategy are expected to be:

- Improving understanding of the problem.
- Preventing the problem increasing.
- Improving water quality and environmental outcomes over time.
- Avoiding/reducing future remedial costs by implementing preventive measures as soon as possible.

The National Strategy is critical to resolving ASS issues affecting industrial, environmental, agricultural and residential developments.

The challenge now is for government, industry and the community to implement the National Strategy to improve the prospects for sustainable coastal development and primary industries by ensuring proper management of ASS.

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Terms of Reference

As given by the Standing Committee on Agriculture and Resource Management (SCARM):

Prepare a national strategy on the management and use of ASS in consultation with industry and community interests.

The national policy will consider:

- The implication of existing practices in the absence of policies or strategies to control development.
- Economic, social, environmental, and technical issues requiring a national approach for their resolution.
- Roles and responsibilities of various levels of government and the community, and areas for cooperation.
- Resources required for implementation; and Australian ASS research requirements.

Scope of the National Strategy

In addressing the Terms of Reference, the National Strategy for the Management of Coastal Acid Sulfate Soils:

1. Introduces the problem of acid sulfate soils, identifies the nature of impacts past and future, and outlines the benefits of a national strategy. The document does not provide in depth technical material that can be found in the references listed for further reading.
2. Provides a flexible, broad based Australia-wide strategy and a hierarchy of national objectives and management options for implementation. The document does not provide action plans for states, regions or specific sites.
3. Recognises a pressing need to address problems in coastal areas. The National Strategy does not address ASS of inland

Australia or acid drainage from acid mine spoils.

4. Recognises the importance of the environment and ecologically sustainable management of our land and water resources by all stakeholders. The National Strategy has been framed within a number of major natural resource management policies. These include: the *National Strategy for Ecologically Sustainable Development*, the *National Water Quality Management Strategy*, the *National Strategy for the Conservation of Australia's Biological Diversity*, the *Intergovernmental Agreement on the Environment*, the *Decade of Landcare Plan*, and the *Wetlands Policy of the Federal Government of Australia* and more recently *Australia's Oceans Policy*.

Executive Summary

Although acid sulfate soils (ASS) occur throughout Australia, this paper is concerned with coastal and estuarine ASS. Acid sulfate soils are environmentally unfriendly if disturbed by drainage or excavation. They are widely distributed around the eastern, northern and northwestern Australian coastline. ASS underlie coastal estuaries, embayments and floodplains on which the majority of the Australian population and urban development is located. They also underlie significant fish nursery areas and coastal agricultural industries such as sugar cane, dairying, beef and tea tree oil production.

Left undisturbed ASS are benign, but disturbance by excavation or drainage exposes sulfidic compounds in the soil to air, producing large quantities of sulfuric acid. Studies on the Richmond River in northern New South Wales estimated over 1,000 tonnes of sulfuric acid, 450 tonnes of aluminium and 300 tonnes of iron were released from a 4,000 ha catchment following a major flood in 1994. This acidified a 90 km reach of the river for seven weeks with pH falling to as low as 2.6.

Nationally there is an estimated 40,000 km² of coastal ASS containing over one billion tonnes of sulfidic compounds ie. iron sulfide minerals (pyrite). When fully oxidised each tonne of pyrite produces 1.6 tonnes of sulfuric acid.

Acid runoff causes adverse impacts to the environment and to coastal development, fishing and agricultural industries. Costs to local and regional communities may be measured in terms of:

1. Poor water quality with attendant loss of amenity, damage to estuarine environments and reduction of wetland biodiversity.
2. Loss of fisheries and agricultural production.
3. Additional maintenance of community infrastructure, particularly where affected by acid corrosion.

4. The need for rehabilitation of disturbed areas to improve water quality and minimise impacts.

Major environmental impacts include kills of fish and oysters, fish disease and destruction of fish nursery habitat as well as loss of aquatic biodiversity. These arise from the deleterious effects of acid drainage water that also contains high concentrations of toxic metals, especially aluminium and iron.

Economic impacts are broad and substantial. ASS impacts threaten coastal development, driven by the high value of waterfront investment, and associated infrastructure worth over \$10 billion Australia-wide. The cost of treating and rehabilitating ASS associated with urban development and infrastructure projects total many millions of dollars. As a consequence, many projects have stalled and some have been abandoned. Millions of dollars worth of infrastructure corroded by acid water has had to be replaced. Millions of dollars of oysters, prawns and fish have been destroyed, nursery areas have been decimated and poor ASS management has degraded large areas of land. Acid drainage and poor water quality also pose considerable threats to coastal tourism and communities reliant on good quality estuarine water to attract visitors.

Acid outflows have caused conflict between stakeholders in the coastal region, including farmers, fishers, aquaculturalists, property developers and environmentalists. The fishing and oyster industries are seeking action from government, landowners and developers to correct the acid impacts which cause them serious economic loss.

Agricultural industries have indicated they are not prepared to shoulder the responsibility alone, noting that government funded drainage and flood mitigation schemes often were the initial cause of over-drainage of flood plains. Further,

many landowners cannot afford the capital investment required to reduce the problem. Landowners also raise an equity issue, querying why they should invest in works, eg. liming the banks of drains, which do not improve agricultural productivity.

The impacts of ASS are too serious to ignore. Governments and communities must respond to this problem. Governments at all levels, must work with industries and local communities to support projects and initiatives which address the significant social, economic and environmental issues arising from ASS.

This National Strategy aims to:

- Improve the management and use of coastal ASS in Australia to protect and improve water quality in coastal floodplains and embayments.
- Assist governments, industry and the community in identifying and undertaking their roles in managing coastal ASS.

To achieve these overriding aims the National Strategy establishes four principal objectives:

1. Identify and define coastal ASS in Australia

The national distribution and extent of ASS needs to be established at both catchment and property levels. Risk maps showing potential distribution and depth of ASS have proven beneficial in NSW and southern Queensland and similar predictive tools would assist in other catchments with existing agriculture or under development pressure.

A reliable property assessment method together with an accurate environmental hazard assessment process at a catchment level will also advance our ability to improve water quality and productivity from ASS. Similarly, nationally uniform definitions, standards and analytical methods are required for effective management.

2. Avoid disturbance of coastal ASS

Undisturbed ASS pose little problem for the environment. They should not be drained or excavated and land management practices should be modified accordingly.

Measures suggested to prevent the problem becoming worse include:

- Awareness: key land managers and developers must be aware of the problem, including the nature and distribution of ASS as well as its potential adverse impacts.
- Education: land managers and developers must understand and apply best practice principles and technologies.
- Planning and development controls: planning controls must be tailored to minimise the risk of disturbing ASS and provide appropriate preventive measures without excessive cost. These may be linked with areas mapped as ASS risk.

The investment of time and effort in measures that avoid or prevent disturbance of ASS will provide a much greater return than measures designed to treat or rehabilitate areas after disturbance.

3. Mitigate impacts when ASS disturbance is unavoidable

If development must occur on ASS, then it should be undertaken in a manner that ensures there is no resultant increase in acid water discharge into streams and waterways. Current treatment technologies are not readily applicable as cost effective options for agriculture. Research into best management practice for drain maintenance and water table management is essential to fill critical knowledge gaps. Affordable treatment technologies must be refined and extended to industry for adoption into routine practice.

4. Rehabilitate disturbed ASS and acid drainage

Areas of disturbed ASS contain a large reservoir of sulfuric acid that will drain into waterways after inundation or heavy rain. Cost effective technologies to rehabilitate these areas need to be developed, tested and proven effective in broad scale situations.

Much of the acid water originating from ASS comes from major floodplain drainage schemes. Rehabilitation of these lands will require substantial investment. Incentives must be introduced to encourage private investment in rehabilitation works. However without the assistance of public funds progress will be slow. Successful management of ASS requires coordinated input across the spectrum of community, industry and governments.

Achievement of the four objectives listed above will result in the following benefits:

- Improved understanding of the problem.
- Prevention of the problem increasing.
- Improved water quality and environmental outcomes over time.
- Avoiding/reducing future rehabilitation community costs otherwise associated with doing nothing.

Achievement of the objectives

The National Strategy identifies key responsibilities and interrelationships at all stakeholder levels. Principal tasks at the local level are awareness, education and adoption of best management practices. At the state level, policy implementation, extension, regulation and coordination are the prime responsibilities. At the Federal level, policy direction, research, strategic coordination and funding are the essential issues to be addressed. The National Strategy considers the roles and responsibilities for each of these sectors.

Resources essential to a successful outcome of the National Strategy include:

- Risk maps that indicate the distribution and depth of ASS in coastal catchments with

existing agriculture and/or under significant development pressure.

- Informed land owners and developers who are willing to change land management practices such that further disturbance of ASS is avoided or existing problems are treated to minimise acid outflows.
- Informed councils and local communities that support these initiatives with planning development controls appropriate to the risk of disturbing ASS.
- State works departments, Council service departments, excavators and floodplain drainage authorities that are trained in ASS identification and avoidance, and that treat or rehabilitate ASS which are disturbed.
- A coordinated whole-of-government approach to policy and action which fosters industry and community participation and provides clear goals and responsibilities for the relevant authorities.
- Research into improved methods of field and environmental hazard assessment, validation of treatment and rehabilitation technologies, and economic studies into the options of reserving, disturbing or managing ASS.
- Incentive schemes to encourage private and community investment in rehabilitation of the environment and the natural resource base.
- Expert technical support to land owners and resource managers who are changing land use practices to address the causes of acid generation and runoff.
- Demonstration sites to encourage adoption of best practice and monitoring of new technologies.

The National Strategy is an important step in the national recognition, coordination and management of resources to ensure ASS are managed in a responsible manner. A coordinated Federal/state response, implemented at local and catchment levels, could result in most ASS problems being addressed to some degree within a decade. This response would benefit fishing, aquaculture, recreation, tourism, agriculture industries as well as urban development and the communities in coastal Australia.

1. Introduction

1.1 Acid sulfate soils

Acid sulfate soil (ASS) is the common name given to naturally occurring soil and sediment containing iron sulfides, principally the mineral iron pyrite, or containing acidic products of the oxidation of sulfides. When sulfides are exposed to air, oxidation takes place and sulfuric acid is ultimately produced when the soil's capacity to neutralise the acidity is exceeded. As long as the sulfide soils remain under the water table, oxidation cannot occur and the soils are quite harmless and can remain so indefinitely.

ASS were identified in the Netherlands nearly 260 years ago. These soils have since been found to occur worldwide and occupy over one million square kilometres, with major occurrences in Asia, Australia, Africa and Latin America. It has been estimated conservatively that Australia has over 40,000 km² of ASS, containing in excess of one billion tonnes of pyrite.

Their presence in Australia was recognised only 45 years ago. They were mainly ignored until a massive fish kill in 1987 decimated 23 km of the Tweed River in northern New South Wales and focused attention on the impacts of these soils.

1.2 Distribution in Australia

Coastal ASS occur in every Australian state and the Northern Territory. Using information on conditions necessary for the formation of ASS, together with the known geomorphology of the Australian coastline, it can be predicted that ASS should be found in coastal embayments and estuarine back swamps, with surface elevations less than about 10 m above mean sea level (10 m AHD). Extensive occurrences of ASS are found along the eastern and northern coastline of Australia with smaller areas in southern Western Australia, South Australia, Victoria and Tasmania (Figure 1).

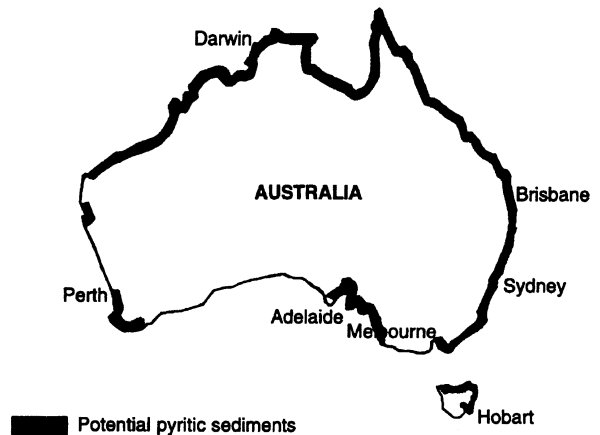


Figure 1. Indicative distribution of coastal acid sulfate soils in Australia.

At present only areas of New South Wales and Queensland have been mapped. The NSW Department of Land and Water Conservation has produced maps of coastal catchments with a high and low probability of sulfidic sediments. This work showed New South Wales has 4,000 km² of high risk ASS and these occur in every estuary (Appendix 3).

An overview study by the Queensland Department of Natural Resources has estimated that ASS occupy about 23,000 km² in Queensland (Appendix 4). Detailed mapping in Queensland to identify areas of acid generation was initiated in late 1995 to investigate ASS on the southeast coastline, the area under greatest development pressure.

1.3 Implications of past practices

When exposed to air, the sulfides in ASS oxidise. Oxidation involves the eventual conversion of solid pyrite to sulfuric acid and red-brown iron oxide flocs. For every tonne of pyrite completely oxidised, 1.6 tonnes of sulfuric acid are produced. This acid production can cause soil and ground water pH to fall below 3.

The processes involved are identical to those in acid mine drainage from sulfidic mine dumps. In order to use estuarine flood plain areas for coastal development and agricultural production, flood mitigation and drainage schemes have been constructed. These works intersected ASS which exposed them to air, producing large quantities of acid in the soil profile. Engineered drainage schemes straightened meandering drainage lines, reducing the time taken to export acid water from around 100 days to less than five days. This has resulted in the efficient export of huge quantities of acid into major streams and waterways.

Under traditional management, floodgates may hamper the neutralisation of acid outflows by preventing tidal inflows of buffering estuarine water. They may also promote the storage of acid upstream. In dry times, large floodgates can impound acid water for many months. This acid may be released as a damaging slug in subsequent flood events.

Measurements on the Richmond River in northern New South Wales have revealed that in a major flood event in 1994, over 1,000 tonnes of sulfuric acid, 450 tonnes of aluminium and 300 tonnes of iron were released from a 4,000 ha subcatchment. The released acid was swept backwards and forwards by the tide as an acid slug with pH sometimes as low as 2.6, for more than seven weeks, resulting in dramatic changes to in-stream ecology and decreases in biodiversity. Over 90 km of the river was acidified.

The current rate of sulfuric acid production from drained back swamps in southeastern Australia is estimated to be between 100 and 300 kg per hectare per year. At that rate it will take in the order of 1,000 years to remove all sulfides from these soils. The potential acidity contained in Australia's ASS is over 10,000 times that in all existing acid mine dumps.

1.4 Land use of coastal ASS

The current principal uses of ASS areas include:

Agriculture:

- sugar cane,
- dairying,
- tea tree,
- grazing,
- cropping.

Urban development:

- housing,
- resorts,
- marinas/canal estates.

Infrastructure:

- roads,
- railways,
- bridges,
- port facilities,
- flood gates,
- dredging.

Aquaculture:

- prawns,
- oysters,
- fin fish.

Mining:

- sand extraction,
- gravel extraction,
- dredging.

Natural areas:

- mangrove swamps,
- salt marshes,
- national, state and local parks and reserves,
- coastal wetlands,
- coastal lakes.

These land uses generate significant regional employment. However, developments on ASS particularly large scale drainage and flood mitigation schemes, can lead to widespread acidification of land and streams and subsequent economic loss onsite or in adjacent areas. The total area of ASS in coastal Australia with potential for acid production approaches the area of land affected by dryland salinity in Australia. Collectively, Australian Government policies, initiatives and resources have been focused on the development and application of management solutions to the increasing threat of salinity. They need to address ASS in the same way.

1.5 Context of the National Strategy

The *National Strategy for the Management of Coastal Acid Sulfate Soils* is an important step in the recognition, coordination and management of resources at the national level to ensure coastal ASS are assessed and managed responsibly.

Several major natural resource management initiatives have provided the strategic framework in developing the National Strategy. These include the: *National Strategy for Ecologically Sustainable Development*, the *National Water*

Quality Management Strategy, the *National Strategy for the Conservation of Australia's Biological Diversity*, the *Intergovernmental Agreement on the Environment*, the *Decade of Landcare Plan*, and the *Wetlands Policy of the Federal Government of Australia* and more recently *Australia's Oceans Policy*. These strategic documents have guided the development of the National Strategy and all have a common set of principles that recognise the importance of the environment and the ecologically sustainable management of our land and water resources by all relevant stakeholders.

2. Environmental, Social and Economic Impacts

2.1 Introduction

Acidification impacts reduce the conservation, commercial and recreational values of tidal streams and estuaries. Major environmental impacts within waterways include fish kills, fish diseases, habitat degradation and changes to aquatic plant communities. There is also some evidence of impacts on waterfowl habitats.

A number of Australian researchers are investigating the environmental and economic impacts of ASS disturbance. White et al. (1996) and Sammut et al. (1995) have published reviews of recent work. The information that follows is drawn from these sources and is gratefully acknowledged.

2.2 Environmental impacts

2.2.1 Fish kills and fish disease

The most obvious and damaging impacts of coastal ASS have been on fish and other organisms in estuaries. Massive kills of fish, crustacean and oysters have been reported in Australia.

One major flood in northern New South Wales resulted in the death of all fish, Crustacea and Annelid worms. Because of their lack of mobility, crustaceans and shellfish such as oysters are more vulnerable to acid run-off than fish. For many coastal fish kills it has been difficult to investigate within the short time frame required to determine the cause. Acid and aluminium are the most implicated factors in these circumstances.

Field investigations and experimental work have recorded a strong association between high acidity, aluminium and gill damage. Fish with gill damage behave as if exposed to low dissolved oxygen, even though levels are

acceptable. Behaviour includes gulping for air with erratic gill movement.

Exposure to acidified water also damages fish skin and increases the susceptibility of fish to infection by *Aphanomyces* sp., the ulcer-causing fungus of epizootic ulcerative syndrome (EUS). EUS, also known as *red spot disease* or *Bundaberg disease*, is a skin disease of fish characterised by large red lesions that leave fish unsaleable and may cause fish deaths. Outbreaks of EUS can affect up to 80 per cent of the fish catch in acidified waters.

2.2.2 Habitat degradation and loss of biodiversity

Habitat degradation and loss of biodiversity are possibly the most significant impacts of acidification. On the Richmond River of northern New South Wales, there are over 200 floodgates that have converted well buffered, brackish water to poorly buffered, fresh water. These engineered river reaches are more susceptible to repetitive acidification and may generate and contain acid for many years. Because floodgates can isolate acidic water from the acid neutralising waters of tidal reaches, these closed areas of water act as acid reservoirs that periodically release acid downstream.

Habitat is also fragmented vertically by stratification of the water body. Fish can utilise the pH-neutral or near-neutral, lower stratum, allowing their passage through acidified systems but the waters may later destratify and fish kills result. Similarly, the movement of fish through the lower stratum may increase periodic sub-lethal exposure to acid, which may increase susceptibility to disease. The clarified upper stratum also exposes fish in the lower stratum to increased UVB radiation, which may cause skin damage.

Acidic water destroys food resources, displaces organisms to other areas, precipitates iron that smothers vegetation and microhabitats, and alters the chemical and physical properties of the water. In tidal reaches, mud flats are often smothered by iron flocs many kilometres away from the source of acid. Slugs of acid water also affect access to habitats by restricting passage of fish through the estuary; this disrupts reproduction and the survival of juvenile fish.

After an acid event, when water quality begins to improve, there is normally a lag in the recovery of the biota due to different rates of recruitment. In many river tributaries, these recovery processes are interrupted by further periodic acidification.

Fish have an inherent ability to sense and avoid acid and, unless trapped, will not normally enter acidic reaches. Exceptions are some acid-tolerant populations of *Hypseleotris* gudgeons. The introduced and noxious Mosquito fish (*Gambusia holbrooki*) also has acid-tolerant populations in the Richmond River.

Research has suggested also that harmful algal blooms may be triggered in waterways by acidic drainage water containing dissolved iron and silica.

Aquatic plants

Aquatic plants exposed to acidified waters may be affected by aluminium and manganese toxicity, smothering from iron flocs or the direct toxic effects of acid. Under long-term acidity, changes in aquatic plant communities have been observed, species numbers have decreased and a few acid-tolerant species dominate, belonging mainly to the genera *Nymphaea* (waterlily) and *Eleocharis* (spike rush). Plants from these genera can complete life cycles at pHs of less than 3 without any apparent negative impacts. In most cases propagation is enhanced by acidic conditions, possibly because of increased water clarity, low competition and reduction in grazing activity.

The introduced Cape water lily (*Nymphaea caerulea* spp. *zanzibarensis*) is acid-tolerant and grows abundantly at pH less than 3 in clarified, aluminium-rich waters. Its invasion of acidified drains is rapid and it should be recognised as an aquatic weed. Flocculation of sediment has increased water clarity in acidified drains and enabled this species to live at greater depths than normal. The Cape waterlily influences water quality by reducing wind shear driven mixing, thereby minimising destratification in drains. It also saturates the water with dissolved oxygen due to its increased capacity for photosynthesis in clear water. These conditions are not normal habitats for the native flora and fauna.

The native waterlily (*Nymphaea gigantea*) is also acid-tolerant, but is less competitive than the Cape waterlily and tends to be displaced or reduced at locations where the two species occur together. When pH rises and is again suitable for native species, the Cape waterlily is already well established and limits recruitment of other species.

Unfortunately, profusion of acid-tolerant aquatic plants, unusually clear or green-tinged water and schools of acid-tolerant fish, often give the false impression of a healthy system.

Terrestrial fauna and flora

There are no published studies on the effects of ASS on terrestrial native fauna. It is probable that there are negative impacts that are yet to be identified. For instance the eggs of frogs only survive in pH-neutral waters.

In a number of coastal swamps, acidic spoil heaped along drain banks and acidic bare areas (scalds) have remained unvegetated for years and low lying land drained for farming is infested by vegetation such as acid-tolerant *Polygonum* spp. Such conditions are unattractive to waterfowl. A recent survey of the acidified reaches of the Tuckean Swamp in northern New South Wales shows a significant decline in waterfowl numbers.

The effects of acid on terrestrial flora will vary with the depth to acid soil, the behaviour of the water table, the concentrations of metal and sulfate present and the duration of surface water acidification.

Land and water degradation

The soil in large areas of coastal backswamps has become highly acidic following drainage. Once the oxidation process commences, acid accumulates in the soil in quantities that are lethal to most commercial plant species and crops. This acidification trend is very difficult and expensive to reverse. It is the source of acid outflows into waterways.

Pumping of groundwater in coastal areas containing ASS or sulfidic sediments can cause widespread acidification of the aquifer. Lowering water tables through pumping of groundwater can also initiate oxidation of ASS and result in acidification of the groundwater. In these situations the acidified groundwater may also contain high concentrations of dissolved iron and other metals.

2.3 Social issues

2.3.1 Social conflict

Coastal flood plains have the longest record of productive agricultural use of any region in Australia. Successive Australian governments, at all levels, have encouraged their development, particularly through drainage and flood mitigation initiatives. The schemes have re-engineered many coastal flood plains and streams and their hydrology. In ASS areas, they have resulted in major conflicts between farmers, fishers and aquaculturalists, and generated complaints to local and state governments.

In some prestigious canal estates, residents have complained to authorities of foul smelling, iron stained waters in canals for several weeks following heavy rain. This is a little recognised consequence of up-stream ASS disturbance resulting in acidified water accumulating in the canals.

As understanding of ASS has improved, local fishing and oyster industries have identified sources of acid water discharge, which have adversely affected their livelihoods. These fishers are seeking action from government and landowners to correct these impacts which cause them serious economic hardship. Left unresolved, these effects will act as an ongoing source of conflict between waterway users and users of ASS.

Agricultural industries have indicated they are not prepared to shoulder the responsibility for acid drainage water alone, noting that the government funded drainage and flood mitigation schemes often were the cause of over drainage of the flood plain. Landowners raise an equity issue, questioning why they should invest in environmental works that do not produce an economic return to fund such investment. Many cannot afford the massive capital investment that will be required in most areas to improve water quality. They also seek assurance that changes to land use practices, which they may introduce, will result in improved quality of drainage water.

Under these circumstances landowners can be expected to seek support and incentives from government. Similarly, the fishing and water-based industries will continue to demand tangible action to stop further acid water discharge into streams and waterways. Government response must be sensitive to these different expectations and an effective communication strategy will be essential. It is clear that all levels of government must work with industries and the local community to support projects and initiatives that will address these social conflicts, as well as economic and environmental issues.

2.3.2 Human and animal health

The health status of farming communities living in Asia on ASS and drinking acidified water is notably poor. Aluminium rich waters may have significant impacts on human and animal health. These impacts could include stunted growth, poor health and mental impairment.

Because highly acid, aluminium rich waters can be exceptionally clear due to sediment flocculation, there is a danger that they may be considered fit for consumption. However, in most Australian estuaries, waters tend to be brackish and are not often used for drinking or stock watering. Indeed stock often refuse to drink acidic waters. Some cases of industrial dermatitis, caused by the handling or inadvertent contact of skin with acid soil materials, have been reported. Epidermal absorption of heavy metals is also a possibility.

In addition to these direct health impacts, there are indirect acid drainage impacts on human and animal health. For example, it is known that certain species of disease carrying mosquito actively seek out acid drainage for breeding.

2.4 Economic impacts

ASS underlie significant areas of coastal Australia where the majority of Australians reside. Substantial developments, including urbanisation, industrialisation, infrastructure and utility supply, agriculture, aquaculture, sand and gravel extraction as well as dredging in these areas have disturbed ASS.

ASS impacts now economically threaten these industries, whose total value is conservatively estimated at \$10 billion, in the following ways:

2.4.1 Avoidance costs

Economic losses can be incurred in the transfer of developments to non-ASS areas. These costs accrue in the form of decreased land values, increased transport costs as well as loss of income from foregone expansion of industries such as sugar cane and tea tree oil production as well as loss of amenities.

2.4.2 Treatment and rehabilitation costs

Corrosion

Drainage waters from ASS corrode iron, steel, aluminum and concrete. Acid waters chemically

attack aluminum boats. The Tweed Shire Council in northern New South Wales has recently spent nearly \$4million replacing iron water pipes corroded by acid ground water in ASS areas.

Concrete structures are also corroded by acid effluent from ASS. This results in the expansion and weakening of the concrete and its eventual exfoliation and dissolution together with rusting of the steel reinforcing.

Etching of concrete and exposure of aggregate are typical early signs of the attack by acidic water. Concrete corrosion of road and rail bridges and other structures has been observed from Kiama in southern New South Wales to Cairns in north Queensland.

Subsidence

Many ASS are gel-like with low load bearing capacity. As a consequence, foundations or earthworks built on these materials may settle or subside unevenly, albeit slowly since it involves dewatering of the unconsolidated materials. The pumping action of passing traffic tends to exacerbate settling problems in roadways. Many surface structures may require either extensive piles or the laying of an extensive load spreading membrane, thereby increasing construction costs.

Prevention of acid discharge

Coastal urban development, such as housing, resorts, marinas and canal estates, together with the provision of their services and infrastructure, are likely to disturb ASS.

In 1996, developments worth over \$2 billion were proposed on ASS in Queensland. On the Gold Coast in southern Queensland, 90 per cent of development applications were required to consider ASS in their environmental management plans. Treatment technologies to avoid or prevent the formation of acid drainage associated with these developments in Queensland are estimated to cost in excess of \$100 million annually.

2.4.3 Loss of product

Fishing and aquaculture losses

Fishing and oyster industries have reported substantial financial losses after fish kill events, both through loss of saleable product and loss of consumer confidence in the quality of their product. In 1995 over \$1 million of sea mullet was discarded by New South Wales commercial fishers because of *Epizootic Ulcerative Syndrome*. Losses in production of Sydney rock oysters from ASS impacts were estimated at \$7 million over the last six years.

Reduced agricultural productivity

The soil water in ASS or drainage from exposed ASS materials can limit plant production in several ways. Firstly, certain compounds, metals and ions in the soil-water including hydrogen sulfide, aluminium, iron, manganese and hydrogen are directly toxic to plants. Aluminium is considered particularly harmful.

Secondly, toxic metals liberated from ASS may reduce plant growth by inducing deficiency in plant base minerals such as calcium, magnesium and potassium, or a deficiency in the availability of plant nutrients, particularly phosphorus.

Thirdly, ASS cause an increase in attack of plant pathogens and a decrease in soil microbes, particularly those responsible for nitrogen fixation. In addition, ASS can cause direct physiological damage, such as the stunting of roots. This can produce plant water stress in situations where the plant appears to have adequate water.

The net result is that in many locations ASS have degraded farmland by reducing pasture quality. Very few pasture plants can withstand the toxic effects of high acidity and high concentrations of toxic metals. Sugar cane and tea tree are notable and productive exceptions. In a number of coastal swamps, acidic drain spoil and scalds have remained unvegetated for many years. Dust from acid sulfate scalds has caused visibility

problems for vehicles travelling on the Pacific Highway near Kempsey in New South Wales.

2.5 Technical coordination

Long-term impacts of ASS are still not fully understood and the technology for dealing with current problems is still in the early stages of development. Though many countries have had problems associated with the treatment and management of ASS, each instance tends to be unique and the treatment peculiar to the situation. As a consequence the transfer of some research results undertaken in other countries to Australian circumstances may not be practical. Local technical expertise is essential if critical problems are to be addressed on the basis of the best available information and resources are not to be wasted.

In New South Wales and Queensland, ASS management advisory committees have been formed within the last five years to provide advice to government and facilitate a coordinated government response. These committees contain representation from key stakeholder groups, particularly industry and state government agencies.

The committees are each supported by a technical group which provides expertise on issues such as implementing strategies to reduce acid outflows and to remediate acidified lands. The technical groups are also establishing uniform methods for site assessment and laboratory analysis. They monitor research developments and coordinate expertise in addressing local area problems.

2.6 Management options

The environmental, social, economic and technical problems arising from ASS indicate three main approaches to their management:

- Wherever possible ASS should be left in an undisturbed state to avoid acid formation.
- If ASS must be disturbed then the development should be in accordance with the level of risk of acid formation and with

appropriate management practices to mitigate the impacts of any acid produced. Cost benefit analysis may determine the feasibility of development in such circumstances.

- If ASS are already acidified by past disturbance, remedial measures need to be developed and adopted to reduce the volume and frequency of acid water outflows.

For these options to be successfully implemented there needs to be:

- Coordination of government policy and resources at all levels.
- Effective planning and development controls.
- Effective treatment techniques.
- Regulation by government and compliance by industry.

3. Benefits of a National Strategy

The framework set out in this National Strategy provides significant advantages across several sectors including governments, landholders and industry.

Benefits will be realised at the national and local level, over both the short and long term. They will accrue across environmental, economic, social, technical and operational areas.

The more important benefits are expected to be:

1. Better understanding of the problem by key stakeholders.
2. Stopping the problem getting worse.
3. Improving water quality and environmental outcomes over time.
4. Avoiding/reducing future rehabilitation costs to the community otherwise associated with doing nothing.
5. Establishing a framework for national communication.

6. Identifying priorities and options for action and funding at national, state and local levels.
7. Creating a consistent interface between ASS management and related national initiatives.

The most important benefit will be recognition, coordination and management of coastal ASS issues and problems at the national level. The National Strategy recognises ASS as an urgent issue requiring greater understanding and immediate action, paralleling those implemented to manage salinity in inland catchments.

In the absence of the National Strategy a piecemeal, cost-ineffective response to this problem is highly likely. Future remedial actions can be expected to be much more expensive.

An approach which addresses the key issues and helps the community move towards ecologically sustainable use of ASS is detailed in the following sections.

4. Principal Aims and Objectives in the Management of Coastal Acid Sulfate Soils

This National Strategy aims to:

1. Improve the management and use of coastal ASS in Australia to protect and improve water quality in coastal floodplains and embayments.
2. Assist governments, industry and the community in identifying and undertaking their roles in managing coastal ASS.

To achieve these overriding aims the National Strategy establishes four principal objectives:

4.1 Identify and define coastal ASS in Australia

Landowners and coastal resource managers need to know the local distribution and extent of ASS. This information is equally required at national, catchment and property levels. National uniform definitions, standards, analytical methods and assessment protocols are essential to implement effective management.

4.2 Avoid disturbance of coastal ASS

Once the distribution of ASS is known, this information needs to be used to prevent or avoid activities that may expose ASS to air. Prevention of environmentally detrimental activities will prove less expensive than remedial works or rehabilitation and will be achieved through a combination of education programs, well considered development planning controls and promotion of best management practices.

4.3 Mitigate impacts when ASS disturbance is unavoidable

If development has to occur on these soils, it should be undertaken in a manner that ensures there is no increased resultant acid water

discharge into streams and waterways.

Expensive treatment technologies have enabled some major developments to occur, but are not well suited to agricultural activities.

4.4 Rehabilitate disturbed ASS and acid drainage

Past land use practices such as excavation and over-drainage have disturbed considerable areas of coastal ASS. Where they have not been recognised and treated they constitute large reservoirs of acid that drain into waterways after inundation or heavy rain. These sites cause conflict between land based and aquatic industries because of their impacts. Works to rehabilitate the worst areas, together with improved land management techniques, will be necessary to improve water quality and mitigate adverse impacts.

Each of the four objectives must be addressed concurrently if significant improvement in water quality is to be made. Strategies to achieve each objective appear in the following section.

Many stakeholders must contribute to the strategies if they are to succeed in identifying and managing ASS. They are indicated by code at the end of each strategy according to the following legend:

Fed	Federal government,
ST	state/territory governments,
LG	local governments/statutory authorities,
Ind	industry organisations,
Com	community catchment groups,
LO	individual landowners.

Objective 1

To identify and define coastal ASS in Australia

Recommended strategies

4.1.1 Map the distribution of ASS

4.1.1.1 Prepare standardised risk maps of ASS in coastal catchments on a priority basis at a scale useable at a local government level and identify potential problem areas (Fed, ST).

4.1.1.2 Make ASS risk maps available publicly at minimal cost (Fed, ST).

4.1.1.3 Test and develop remote sensing techniques to locate/identify ASS nationally (Fed, ST).

4.1.1.4 Standardise nationally and improve mapping, definitions, sampling and procedures for ASS analysis (Fed, ST).

4.1.1.5 Develop improved methods of field assessment of ASS (Fed, ST).

4.1.1.6 Encourage assessment and testing at a property level to reliably identify and confirm the extent and distribution of ASS (Fed, ST, LG, Ind, Com, LO).

4.1.2 Understand the nature of ASS and their impacts

4.1.2.1 Undertake coordinated, comprehensive comparative studies of ASS development in contrasting Australian catchments to provide more accurate environmental hazard assessment (Fed, ST).

4.1.2.2 Promote and undertake research into the formation and degradation processes operating in Australian ASS (Fed, ST, Ind).

4.1.2.3 Determine human health impacts of exposure to acid waters, especially those containing high concentrations of aluminium and iron (Fed, ST).

4.1.2.4 Identify indicator flora and fauna species associated with acid drainage water (Fed, ST).

4.1.2.5 Document impacts (environmental, economic and social) of ASS on industry and the community (Fed, ST, LG, Ind, LO).

4.1.2.6 Develop standard procedures for monitoring acid water discharges from ASS (Fed, ST).

4.1.3 Desired outcomes

- The possible distribution of ASS is mapped for each priority coastal catchment under pressure from development, agriculture or drainage works.
- ASS risk maps are used in association with statutory planning instruments.
- An accurate assessment of environmental and health hazards posed by ASS can be made for priority catchments and sub-catchments.
- Recommendations concerning consumption and/or treatment of acid water will be available to people who source drinking water directly from dams, wells, bores or streams on ASS floodplains.
- A reliable field assessment method to provide practical cost effective assessments of acid generation will be available to land owners and resource managers.
- Long term benefits for habitats, water quality, fauna and flora diversity accrue as ASS management is undertaken.

- | | |
|--|--|
| <ul style="list-style-type: none">• Assessment and monitoring procedures for ASS are standardised. | <ul style="list-style-type: none">• Bio-indicators are determined for ASS problem areas. |
|--|--|

Objective 2

To avoid disturbance of coastal ASS

Recommended strategies

4.2.1 Awareness: improve awareness of key groups about the nature and potential impacts of ASS

- 4.2.1.1 Undertake programs to make landowners, developers, industry, local government and the community aware of ASS and their impacts (Fed, ST, LG, Ind, Com).
- 4.2.1.2 Extend the ASS newsletter (ASSAY) to a national distribution and promote it as the national vehicle to update coastal resource managers on ASS issues (Fed, ST, LG, Ind, Com).
- 4.2.1.3 Distribute ASS awareness publications to all coastal councils, peak industry and environmental bodies and state and federal government agencies that participate in decisions on coastal development (Fed, ST).
- 4.2.1.4 Involve key industry organisations in preparation of ASS management training courses for coastal planners (ST, Ind).

4.2.2 Education: educate landowners, resource managers and key industry groups in management practices which avoid ASS disturbance and encourage compliance with industry best practice and regulatory requirements

- 4.2.2.1 Develop, promote and extend nationally, best practice principles and guidelines for ASS management to minimise acid generation and runoff (Fed, ST, LG, Ind, Com).

- 4.2.2.2 Educate industry and land owners in best management practices which avoid, minimise and mitigate disturbance of ASS (ST, LO).

- 4.2.2.3 Provide details of relevant legislation including incentive options available to encourage adoption of best land management practice (ST, LG, Ind).

- 4.2.2.4 Improve the knowledge and skills of planners, consultants, advisers, excavators and utility service providers (ST, LG).

- 4.2.2.5 Support land owners and industry with a well trained and adequately resourced extension network, active in education, training and development programs (ST, LG, Ind).

- 4.2.2.6 Encourage industry, community catchment groups and local government networks to sponsor, facilitate and promote education and training activities at a local level (ST, LG, Ind).

- 4.2.2.7 Promote development of school and TAFE based curricula relating to the identification and management of ASS (Fed, ST).

4.2.3 Development Planning Controls: introduce planning controls which manage the risk of disturbing ASS

- 4.2.3.1 Develop appropriate planning policies and instruments to manage ASS areas in accordance with the risk of disturbing these soils (ST, LG, Ind).

4.2.3.2 Integrate planning and development controls with education and awareness programs (ST, LG, Ind).

4.2.3.3 Encourage land holder and industry input to develop planning controls relating to both development and rehabilitation of ASS high risk areas (ST, LG, Ind).

4.2.4 Regulatory controls

4.2.4.1 Review legislation nationally to identify that which supports and/or conflicts with the National Strategy objectives and amend if needed (ST, LG).

4.2.5 Desired outcomes

- Industry, government agencies and community have sufficient knowledge base to avoid disturbance of ASS and manage them sustainably.
- Assessment of drainage and excavation works is undertaken with reference to ASS risk maps.

- Appropriate planning controls and mechanisms are established for coastal developments and agricultural enterprises on ASS.
- Planning and development control instruments are supported by appropriate use of other regulatory tools.
- Land owners, coastal resource managers, developers and planners become aware of the properties and impacts of ASS on water quality, aquatic ecosystems and capital infrastructure, as well as relevant legislation and penalties.
- Coastal resource managers have access to training and technical information so they may provide competent investigation, analysis and advice to clients.
- Local land holders and industry implement best management practice for ASS and avoid or mitigate water quality problems.
- Planning controls are integrated with education and awareness programs.

Objective 3

To mitigate impacts when ASS disturbance is unavoidable

Recommended strategies

4.3.1 Management: manage disturbance of ASS in a manner which addresses potential problems

- 4.3.1.1 Create a national framework which provides advice on existing ASS management programs/strategies and integrates these with other natural resource management programs and strategies (Fed, ST).
- 4.3.1.2 Develop consistent and relevant policies for the management of ASS and implement these in close working association with major stakeholders (ST, LG, Ind, Com).
- 4.3.1.3 Establish mechanisms at a state /territory level to provide a coordinated whole-of-government approach to managing ASS issues in conjunction with relevant industries and communities (ST).
- 4.3.1.4 Develop best management practices for future development on coastal ASS (ST, LG, Ind, Com, LO).
- 4.3.1.5 Establish a balanced regulatory policy of incentives and standards to improve management of ASS areas (ST, LG, Ind).
- 4.3.1.6 Develop appropriate responses for non-compliance with industry codes, best practice or existing regulations (ST, LG, Ind).
- 4.3.1.7 Encourage catchment management committees and local government to monitor land use activities and water

quality to identify inappropriate practices in ASS areas (ST, Com, LO).

4.3.2 Treatment: treat disturbed ASS to neutralise acid formation or prevent oxidation of sulfidic materials

- 4.3.2.1 Develop national principles and technologies for treatment of disturbed ASS (Fed, ST, LG, Ind).
- 4.3.2.2 Work with industry to ensure that disturbed ASS are treated to minimise discharge of acid water (ST, LG, Ind).
- 4.3.2.3 Monitor the effectiveness of treatment programs in developments that have disturbed ASS areas (ST, LG).

4.3.3 Research: improve treatment and best management technologies through applied research

- 4.3.3.1 Develop, trial and validate the various management and remediation techniques proposed for treating ASS and acid runoff (Fed, ST).
- 4.3.3.2 Undertake studies into the comparative costs and benefits of reserving, disturbing and managing ASS (Fed, ST).
- 4.3.3.3 Investigate and develop best management practices for sustainable agricultural production on ASS (Fed, ST, Ind).
- 4.3.3.4 Encourage research and development agencies and the Australian Research Council to include ASS research and restoration initiatives in their

environmental strategies and funding allocations (Fed, ST, Ind).

4.3.3.5 Encourage the inclusion of ASS management as a priority issue in partnership agreements for natural resource management related programs (Fed, ST, LG, Ind, Com).

4.3.3.6 Promote extension and technology transfer of results of research projects designed to improve management of ASS (Fed, ST, LG, Ind, Com).

4.3.3.7 Encourage input, participation and funding endorsement by catchment management committees for local monitoring and research projects (ST, LG).

4.3.4 Desired outcomes

- Effective policies in place to manage developments on ASS in a manner which prevents adverse impacts on water quality.
- Proven management technologies are available for inclusion in best management practices.
- Remediation measures implemented in future developments that disturb ASS.
- New remediation technologies under active research, development and extension.
- Equitable disbursement of cost of remediation projects across industry, community and government.
- Appropriate responses in operation for non-compliance with industry codes, best practice and/or existing regulations.
- Land holders, industry, local government and state government departments begin actively monitoring high-risk ASS areas to identify inappropriate practices in these areas.

Objective 4

To rehabilitate disturbed ASS and acid drainage

Recommended strategies

4.4.1 Management: introduce works and land use practices that rehabilitate areas of disturbed ASS and reduce acid drainage

- 4.4.1.1 Work with local land holders, industry and community groups to identify high environmental impact sites for rehabilitation, from which significant environmental and economic benefits would accrue (Fed, ST, LG).
- 4.4.1.2 Encourage local action groups such as Coastcare, Landcare etc. to design, implement and seek funding for rehabilitation projects (Fed, ST, LG, Ind, Com).
- 4.4.1.3 Form a national technical committee network to support rehabilitation programs with coordination of expert advice and research (Fed, ST).
- 4.4.1.4 Provide training to agencies, local government and industry so people skilled in rehabilitation technologies are available at the local level (ST, LG, Ind).
- 4.4.1.5 Establish local projects and trials to demonstrate proven remediation /rehabilitation technology at selected sites (Fed, SG, LG, Ind, Com, LO).
- 4.4.1.6 Evaluate rehabilitation projects, including water quality monitoring before and after remedial works (Fed, SG, LG, Ind, Com, LO).
- 4.4.1.7 Adequately resource rehabilitation projects by government, industry and

the community (Fed, ST, LG, Ind, Com, LO).

- 4.4.1.8 Develop contingencies, protocols and plans for government and industry to respond to ASS emergency incidents such as fish kills (ST, LG, Ind).

4.4.2 Research: undertake research to develop technologies that reduce acid drainage and rehabilitate disturbed ASS

- 4.4.2.1 Develop, trial, monitor, validate and promote the various management and remediation techniques and technologies proposed for rehabilitating ASS (Fed, ST, LG, Ind).
- 4.4.2.2 Undertake studies into the comparative costs and benefits of reserving, disturbing, rehabilitating and managing ASS (Fed, ST).
- 4.4.2.3 Develop field calibrated ASS models capable of predicting rates of acid production, acidification and leachate generation for Australian conditions (Fed, ST).
- 4.4.2.4 Give priority to ASS remediation technology in government and industry research funding programs (Fed, ST, Ind).
- 4.4.2.5 Establish a dedicated funding program for ASS research (Fed, ST, Ind).

4.4.3 Incentives: encourage investment in environmental works which have significant community and industry benefit

4.4.3.1 Identify and actively develop incentive schemes for environmental works of public benefit, especially in agricultural situations for environmental rehabilitation and management projects/practices (Fed, ST, LG, Ind).

4.4.4 Desired outcomes

- Local landholders supportive of initiatives to attract funding for rehabilitation projects and active in fostering private and government support for local projects.
- Rehabilitation techniques trialed and implemented as appropriate to local problems.
- New rehabilitation techniques researched, developed and extended to coastal resource managers, industry and landowners.

- Programs implemented to improve water quality from known high environmental impact sites.
- Local community becomes actively involved in rehabilitation projects.
- Emergence of incentive driven rehabilitation of ASS areas.
- Greater coordination of restoration and rehabilitation activities.
- Costs and benefits of undertaking management and rehabilitation of ASS are determined.
- Evaluation mechanisms implemented which enable all stakeholders to appreciate the results of rehabilitation and changes in management.

5. Implementation of the National Strategy

Roles and responsibilities are different but interrelated across the spectrum of stakeholders at the local, state and national levels. At the local level the emphasis is on awareness, management action and implementation of planning controls. At the state level, the key is coordination, policy development and implementation, regulation, risk mapping and production of information for dissemination. Nationally, the main responsibilities are policy direction, strategic coordination, and research. Funding is an important role for all levels of government.

The National Strategy will only be effective when the parties identified in this document, develop and implement action plans in their areas of responsibility. The body with overall responsibility for implementation of the National Strategy should be the Standing Committee for Agriculture and Resource Management (SCARM). SCARM consists of all Departmental Heads/ CEO's of Federal, State/Territory and New Zealand government agencies responsible for agriculture and natural resource management which includes: soil, water and rural adjustment policy issues, as well as the CSIRO and the Bureau of Meteorology.

The National Strategy identifies many agencies and various disciplines with responsibilities for implementing recommended strategies. Agencies should report annually to SCARM on the progress of implementation through the Sustainable Land and Water Resource Management Committee (SLWRMC). The success of the National Strategy should be assessed against the achievement of the desired outcomes identified for each objective. The National Strategy should be reviewed by SLWRMC within five years of its endorsement and further refined.

The roles and responsibilities for each party are summarised as follows:

5.1 Federal government

- Continue to assist in developing a nationally coordinated approach by governments and industry to improve management of ASS through participation in a national working group under the aegis of the SLWRMC of ARMCANZ.
- In conjunction with the States and Territories develop policies and programs consistent with best management practice for ASS.
- In conjunction with the States and Territories, develop cost sharing agreement for funding research and remediation programs.
- Develop with other stakeholders a balanced program of incentives for investment in rehabilitation of high priority ASS areas.
- Coordinate development of nationally uniform definitions of ASS and standard methods for the field and laboratory analyses of ASS.
- Fund research and related information initiatives to increase awareness and understanding of:
 - environmental and health hazards posed by these soils across catchments,
 - leachate chemistry and rates of acid production, acidification and acid drainage under Australian conditions,
 - reliable field assessment methods and best management practices,
 - validation of treatment and rehabilitation technologies,
 - bio-indicators of ASS.
- Encourage research funding bodies such as Research and Development Corporations to include ASS remediation research in their environmental priorities and funding allocations.
- Fund catalytic high priority rehabilitation projects, especially on-ground works.

- Support the mapping of ASS in priority catchments under significant development pressure.
- Undertake studies into the comparative costs and benefits of purchasing, reserving, disturbing, treating or rehabilitating ASS areas, including incentive schemes for landowners.
- Coordinate a review of national and State legislation to identify statutes that support or conflict with national objectives and recommend appropriate amendments.

5.2 State and Territory governments

- Identify a lead agency to coordinate state government services.
- Establish an advisory committee to provide a whole-of-government approach with membership drawn from agencies, local government, industry and community.
- In conjunction with the Federal Government, develop cost sharing agreement for funding research and remediation programs.
- Prepare strategic plans for the management of ASS at a state level.
- Include ASS considerations in formulating land and water resource policies and programs.
- Identify ASS as a priority issue for consideration in partnership agreements under resource management related programs.
- Establish regulatory and planning development controls appropriate to the risk of disturbing ASS.
- Provide effective extension services and specialist technical support to assist councils, county councils, industry and the community.
- Coordinate and where appropriate, conduct training/education programs directed at raising awareness, changing attitudes and skilling landholders to better manage ASS.
- Conduct research into ASS identification and assessment, particularly in environments where little is known about distribution and impact of ASS.

- Undertake ASS risk mapping programs and encourage local planning instruments to manage development in high-risk areas.

5.3 Local governments/statutory authorities

In conjunction with relevant State and Territory agencies:

- Prepare local planning instruments that incorporate ASS issues into environmental assessment processes and development controls.
- Provide leadership in addressing ASS impacts at a local level and assist with the coordination of community activities.
- Cooperate with local industry and community groups to rehabilitate problem areas.
- Train office and field staff in ASS issues and safe management following disturbance of ASS in accordance with a statewide training manual.
- Participate in incentive schemes for landowners to improve land use practices that directly improve drainage water quality.
- Work with agencies to develop mechanisms for rapid response to ASS ‘emergencies’, eg. fish kills.
- Effectively manage the provision of services, utilities and flood protection mechanisms on the floodplain to minimise acid water outflows.

5.4 Industry organisations

- Cooperate with agencies to develop best management practices and ASS land use guidelines that will help attain the Principal Objectives of the National Strategy.
- Conduct training and promotional activities to ensure members are knowledgeable of the risks and appropriate avoidance and/or management actions for dealing with ASS.
- Encourage treatment of disturbed ASS to prevent acid water discharge.

- Sponsor and participate in the further development of treatment and rehabilitation technologies.
- Influence research priorities of Research and Development Corporations and encourage industry funding of ASS management and remediation.
- Consult with governments on land use assessments and ASS management plans.
- Undertake local sampling associated with new industry expansion or urban development proposals.

5.5 Community catchment groups

- Sponsor the formation of local action groups to facilitate resolution of ASS management issues.
- Facilitate and support local education and awareness programs.
- Encourage and endorse funding submissions for local research, monitoring, rehabilitation projects and ASS mapping.

- Participate in the development of planning controls at a local level.
- Monitor water quality in local waterways.

5.6 Individual land owners

- Adopt and promote best management practices for ASS.
 - Participate in education and training programs to improve knowledge of the cause/effect relationships that apply to the management of ASS on their property.
 - Become actively involved in local ASS action groups.
 - Integrate social and environmental values as well as economic considerations in managing ASS on their land.
 - Support and cooperate in relevant development planning control activities.
- Participate in local research, monitoring and rehabilitation programs.

6. Resources to Achieve Desired Outcomes

6.1 Informed stakeholders

The state of knowledge about the management of ASS is generally quite poor. Programs to date have created an awareness of the problem by focusing on negative environmental impacts. This has successfully raised the profile of ASS but training and education programs are now necessary to give people the skills and knowledge to better manage ASS areas. Key target audiences include agricultural landowners, excavators, utility service providers, councils, developers and consultants to the development industry. These groups require understanding to avoid disturbance of ASS and, if this is not possible, information about land use practices to prevent acid drainage water and how to factor in the costs. They also require information on the rehabilitation of areas already disturbed by past practices or drainage.

Local management of ASS will also be improved by knowing the distribution of ASS in a catchment. Risk based maps have proven successful in New South Wales and Queensland in providing this initial information.. The NSW sugar cane industry is now supplementing this with more detailed field based sampling at an individual property level.

6.2 Coordinated government participation

6.2.1 Land use planning and development controls

New developments

Planning instruments are an important tool in preventing future disturbance of ASS. Local development controls such as Local Environment Plans (LEPs) and Development Control Plans (DCPs) have been drafted in New South Wales to assist local Councils to introduce controls which are appropriate to the risk of ASS

being disturbed, especially by drain construction and maintenance works.

Rehabilitation works

A potential conflict can arise between environmental planning controls and ASS rehabilitation projects which cannot be guaranteed to avoid acid discharges at all times. It is important that planners and regulators acknowledge that it might not be possible to completely prevent acid drainage following rehabilitation, especially after flooding. Unless these difficulties are accepted the current environmental protection provisions may mitigate against rehabilitation works being attempted.

The participation of landowners in rehabilitation projects will be limited if lands are zoned as wetlands or habitat protection after rehabilitation works are complete. These issues need to be considered and resolved in a manner that encourages landowner participation.

Rehabilitation of land which is intended to be used for a community benefit, eg. as wetlands or habitat reserve, needs to be funded equitably with appropriate contributions from government and the community for its redevelopment.

6.2.2 Whole of government, industry and community coordination

Achievement of water quality objectives will require a whole-of-government, coordinated approach across all appropriate agencies, industry and community. Mechanisms to achieve this in the form of acid sulfate soil management advisory committees have been established in New South Wales and Queensland. Similar mechanisms may be required in those other states and the Northern Territory with significant developments in ASS areas. This whole-of-government approach facilitates the creation of a common vision, complementary policies and

uniform direction, as well as coordinating the commitment of resources across agencies. Interdepartmental management committees also provide a platform for consultation and technical liaison with industry and the community. Ideally, governments will establish such mechanisms early in their response to ASS management and acid drainage.

The four principal objectives proposed under this National Strategy must be addressed concurrently. Strategies and mechanisms must be put into operation simultaneously to identify the distribution of ASS, to prevent disturbance of ASS wherever possible, to ensure treatment of ASS which is disturbed, and to rehabilitate ASS which have been disturbed by past activities.

6.3 Incentives for rehabilitation

Remedial works to treat disturbed ASS are expensive and have been economically feasible only in large coastal developments (canal estates, resorts, etc.) or infrastructure projects eg. bridge construction. They are not generally economically feasible for agricultural industries. This is because large areas may be involved, the private capital base to fund these works is limited and the returns from agricultural activities/development are usually insufficient to fund the capital works and treatment technologies required.

Many works, which have over-drained coastal floodplains, were originally initiated and undertaken by government and then handed over to landowners to maintain. Rehabilitation works to improve water quality are now needed, eg. liming drain banks, but are unlikely to enhance agricultural productivity, although the fishing industry will benefit. This provides little incentive to the landowner to invest in these programs. Furthermore, returns from coastal agricultural industries are presently at low levels and landowners have little capital to invest. Similarly, it is difficult to hold individual landowners personally liable for the environmental impacts of past drainage works undertaken by government. These factors mitigate against financial participation by

agricultural producers in the management and rehabilitation strategies.

To overcome these barriers, a range of incentive options to facilitate participation by agricultural landowners should be considered, including:

Taxation deductions

Tax deductibility of 150 per cent for environmental works of community benefit (eg. liming drain banks) would encourage investment in activities that provide no direct private benefit or economic return but indirectly benefit the fishing and tourism industries. This incentive could be given a limited life to encourage early participation by landowners in improved management practices and rehabilitation projects.

Water quality incentive payments

Water quality incentive payments could be introduced to encourage landowners to make changes that improve the quality of drainage water. The community could pay for these incentives in negotiation with the tourism and fishing industries as beneficiaries of the improved water quality. Alternatively, a portion of fishing licenses could be used to create this fund, or private environmental trusts established, similar to those operating overseas.

Rate relief

Exemption from rates on land that is managed solely for environmental purposes and has been taken out of economic production should be considered. Local government will need to receive some supporting funding from state and/or Federal governments, as appropriate to the specific circumstances, for this scheme to work.

Catalytic funding for on-ground works

Government funding of on-ground works is essential if major progress is to be made. This funding will encourage landowners to participate

in rehabilitation schemes and adopt best management practices.

Environmental levies

Local councils could be encouraged to impose a levy on development applications to create a pool of funds to support local environmental rehabilitation projects. These funds could be used to fund activities with substantial community benefit.

Land purchase and reservation

In a limited number of instances, land purchase and reservation for environmental use may be the most appropriate social, economic, technical and environmental solution. It is not suggested as a routine option as it may create expectations of land purchase. However, a mechanism to purchase limited, critical areas needs to be established.

6.4 Technical resources

Proven technologies

Landowners and industry require proven management and rehabilitation technologies before changes to existing management practices can become widespread. Research to develop new technologies and establish best management practices is essential to the successful implementation of the National Strategy.

Technical advice

Industry will require competent advice on ASS management. The formation of an ASS specialist team with expertise in soil science, hydrology, soil and water chemistry, drainage and extension would assist industry, especially agricultural industries, to undertake works, management

changes and other projects essential to achieve the National Strategy's principal aims.

A national database on ASS would facilitate free and open exchange of information. Technical specialists require access to the latest information if they are to offer competent advice. A national newsletter, conference and workshops could augment this.

6.5 Regulation

The National Working Party did not consider it appropriate for legal action or penalties to be imposed on landowners or industries whose ASS areas had been disturbed by drainage works undertaken before ASS problems were recognised and understood. In these instances, a cooperative approach between government and industry is preferred to encourage self-reliance and adoption of best practice.

However, punitive action may be appropriate for future developments that cause acid outflows to waterways. Industry should be given an opportunity to become better educated and introduce self-regulation through best management practices, with prosecution of individuals who fail to comply.

A national review of legislation to identify statutes that conflict with National Strategy objectives is considered both necessary and beneficial. The review should also suggest amendments to existing legislation to improve management of ASS.

6.6 Web Site

A web site should be established to provide ASS information, particularly technical, management and funding information.

7. Research Requirements

Over recent years, more stringent guidelines for environmental impact statements (EIS) for coastal development proposals have led to a marked increase in ASS investigations in eastern Australia. However, most of these EIS studies are site specific, of limited scope and rarely address important scientific questions pertaining to Australian ASS. At the same time fundamental scientific research into the properties, processes, environmental impacts and remediation of ASS has been restricted, mostly because of inadequate funding by government research agencies and industry. Consequently, there is a lack of comprehensive scientific information about Australian ASS, particularly in the tropics where they occur most extensively and probably pose the most severe hazards.

Many important issues relating to Australian ASS still require a significant research effort. These include:

7.1 Distribution

Risk mapping of ASS has been completed in NSW and is underway for parts of southeast Queensland. It is unlikely that conventional field mapping will be cost effective or appropriate for the remainder of the Australian coast.

Consequently, there is a need for research into the application of advanced remote sensing technologies to identify potentially ASS. Electromagnetic or radiometric sensing and the development of appropriate algorithms need to be investigated. Identification of bio-indicators may also facilitate mapping.

7.2 Identification

Field tests and sampling techniques for potential ASS are useful but often unreliable with results unsuitable for making comparisons.

Development of improved field assessment methods would benefit both industry and the environment.

7.3 Monitoring ASS properties and processes

Fundamental information is required on the formation and degradation processes in Australian ASS. Better information is needed on soil solution and leachate chemistry, and mineral transformations. There is also a need for comprehensive comparative studies of ASS development in contrasting Australian coastal environments so that differences in soil properties, processes and acidification products can be quantified, allowing more accurate environmental hazard assessments to be made.

7.4 Biological impacts

Considerable scope still exists for research into the biological impact of ASS, especially the biological response to aluminium toxicity. If experience in parts of southeast Asia is indicative, there is potential for Australian ASS to create human health problems. No research has yet been undertaken on this issue in Australia.

7.5 Treatment

Rigorous and comprehensive research is urgently needed to develop trial and validate many of the management and remediation techniques proposed for treating ASS. Techniques such as water table management would probably be more relevant for extensive agricultural applications, whereas others, such as anoxic storage, would be more suitable for capital intensive situations. However, the cost effectiveness and environmental consequences of these and many other proposed ASS treatments have yet to be rigorously established. There is also scope for comprehensive studies into the comparative costs and benefits of reserving, disturbing or managing ASS areas.

7.6 Simulation modeling for management

The only comprehensive ASS simulation model currently available is from the Netherlands. This would need considerable development if it is to provide a predictive environmental management tool appropriate for Australian conditions. There is an urgent need for field calibrated ASS models capable of predicting rates of oxidation, acidification and leachate generation applicable to Australian conditions.

7.7 Sustainable agriculture

The effectiveness of best management practice in agricultural production systems in ASS areas has yet to be strenuously tested and monitored across a range of soils, climates and tidal regimes. Comparisons of yields, productivity, acid generation and export are needed for various drainage, liming and irrigation strategies. Comprehensive work is needed on the national implications of ASS for sustainable agricultural development within the Australian coastal zone.

7.8 Social and economic research

The social and economic aspects of ASS disturbance need to be investigated so that the

full range of impacts (both positive and negative) can be assessed. This may be achieved through selected case studies. The awareness and knowledge of ASS in coastal communities and among land managers are unknown. Similarly the economic impacts of ASS on land users, affected industries and local communities have not been studied in detail, despite their probable significance. In particular, quantification of the full economic impact on the fishing industry is needed.

7.9 Funding

Since the research and development effort and cost to remedy current problems is substantial, a strategic approach is needed to set priorities for research and to indicate when issues can be addressed. It is essential that federal and state governments liaise and coordinate their funding programs for the research and monitoring works being undertaken on ASS. Management advisory and technical support committees need to establish effective communication networks, share information and adapt findings from Australian and overseas research where applicable.

8. Glossary of Terms and Acronyms

AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment Consultative Committee
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASS	acid sulfate soils
ASSAY	acid sulfate soils newsletter
EIS	Environmental Impact Statement
ESD	ecologically sustainable development
EUS	Epizootic Ulcerative Syndrome
National Strategy	National Strategy for the Management of Coastal Acid Sulfate Soils
NSW	New South Wales
Pyrite	an iron sulfide mineral
Qld	Queensland
Recruitment	the number of individuals surviving arbitrary periods of time after settlement into a habitat.
SCARM	Standing Committee on Agriculture and Resource Management
SLWRMC	Sustainable Land and Water Resource Management Committee

9. Recommended Reading List

Comprehensive publications

These publications cover identification, assessment, chemistry, hydrology, planning, land use, impacts and treatment of acid sulfate soils.

Bush, R (ed) (1993) *Proceedings of the National Conference on Acid Sulfate Soils*, Coolangatta Queensland, June 1993. NSW Department of Agriculture, Wollongbar, NSW.

Dent D (1986) *Acid sulfate soils: a baseline for research and development*. Publication 39. International Institute for Land Reclamation and Improvement/ILRI, Wageningen, The Netherlands.

NSW EPA (1995) *Assessing and managing acid sulfate soils: Guidelines for land management in NSW coastal areas*. EPA 95/41. Environmental Protection Authority, Chatsworth, NSW.

Smith, RJ and Ahern, CR (1996) 'Acid sulfate soils a constraint to Queensland coastal developments?' In: *Land Management for Urban Development*. (ed. SA Waring), pp 55-69. Australian Society of Soil Science Incorporated, Queensland Branch.

Smith RJ and Smith, HJ.(eds) (1996) *Proceedings of the 2nd National Conference of Acid Sulfate Soils*, held at Coffs Harbour 5-6 September 1996. Published by Robert J Smith and Associates and ASSMAC.

Stone, Y, Ahern CR, and Blunden B (1998). *Acid Sulfate Soils Manual 1998*. Acid Sulfate Soil Management Advisory Committee, Wollongbar, NSW, Australia.

White, I and Melville, MD with Sammut, J, van Oploo, P, Wilson, PB and Yang, X (1996) *Acid Sulfate Soils – facing the challenges*. Earth Foundation Australia Monograph 1. Millers Point, NSW.

Additional significant papers

Acid Sulfate Soils' Management Advisory Committee (Technical Committee) (unpublished) *Acid sulfate soils laboratory methods*, November 1997 (unpublished) NSW Agriculture, Wollongbar, NSW.

Ahern, CR and Ahern M (unpublished) *Sampling and Analysis Procedure for lowland Acid Sulfate Soils (ASS) in Queensland*. Queensland Acid Sulfate Investigation Team, Queensland Department of Natural Resources, Brisbane, QLD.

Naylor, SD, Chapman, GA, Atkinson, G, Murphy, CL, Tulau, MJ, Flewin, TC, Milford, HB and Morand, DT (1995) *Guidelines for the use of acid sulfate soils risk maps*. NSW Soil Conservation Service, New South Wales Department of Land and Water Conservation, Sydney.

Sammut, J, Melville, MD, Callinan, RD and Fraser, GC (1995), 'Estuarine acidification: impacts on aquatic biota of draining acid sulfate soils'. In: *Australian Geographical Studies*, 33: 89-100.

White, I, Melville, MD, Sammut, J, Wilson, BP and Bowman, GM (1996). *Downstream impacts from acid sulfate soils*. In: Eyles, A, Hunter, H and Rayment G (eds), *Downstream Effects*. pp. 165-172. Queensland Department of Natural Resources, Brisbane, QLD.

White, I, Melville, MD, Wilson, BP and Sammut, J (1997) 'Reducing acidic discharges from coastal wetlands in eastern Australia'. In: *Wetlands Ecology and Management*. 5: 55-72. W J Streever (ed). Wetland Rehabilitation Australia. Kluwer Academic Publishers, Netherlands.

Note: for further information on obtaining these papers, contact Acid Sulfate Soils' Information Officers on: telephone (07) 3896 9819 ~ Queensland Department of Natural Resources or telephone (02) 6626 1344 ~ New South Wales Agriculture

NWP-ASS Membership

*National Working Party on Acid Sulfate Soils**

Standing Committee on Agriculture & Resource Management

- Mr John Williams
NSW Agriculture (Chairman)
- Mr Bernie Powell
Qld Department of Natural Resources

Ministerial Council on Forestry, Fisheries & Aquaculture

- Dr John Beumer
Qld Department of Primary Industries
- Mr Rob Williams
NSW Fisheries

Australian Seafood Industry Council

- Mr Stephen Tapsall *
Qld Commercial Fishermen's Organisation

CSIRO

- Dr Greg Bowman *
CSIRO Land and Water

Australian & New Zealand Environment Conservation Council

- Mr Peter Bek
Qld Department of Environment
- Professor Ian White *
CSIRO

National Farmers' Federation

- Mr Jeffrey Champion

Federal Government

- Mr Lionel Wood
Department of Agriculture, Fisheries and Forestry Australia

Queensland Canegrowers

- Mr Grahame Colley

Secretary

- Ms Jennifer Grant
NSW Agriculture

* Since the formation of the National Working Party on Acid Sulfate Soils, several members have changed agencies but have remained members of the committee. The above listing reflects the original affiliation of members.

- Mr Stephen Tapsall now with Qld Department of Primary Industries.
- Dr Greg Bowman now with NSW Department of Land and Water Conservation.
- Prof Ian White now with Australian National University.

Properties of Coastal Acid Sulfate Soils

1. Formation of ASS

ASS have formed and been oxidised throughout geologic time as part of the global sulfur cycle. Those soils of most concern in coastal Australia are sulfidic sediments that were deposited during the last 10,000 years (the Holocene period). Sea level rise, following the end of the last Ice Age, drowned coastal embayments and sediment blocked off coastal lagoons. During and following the sea level rise, which ended about 6,500 years ago, sea water or brackish water, containing dissolved sulfate, covered organic debris from swamp vegetation, such as mangroves, tea trees and salt marsh. Combined with iron from the sediments, under generally air-free conditions this produced iron sulfides.

Five conditions are necessary for the formation of iron sulfides. These are:

1. a supply of dissolved sulfate, with concentration greater than 10 mg/L,
2. a supply of readily decomposed organic matter,
3. an adequate source of iron,
4. generally oxygen-free conditions, and
5. tidal flushing to remove soluble reaction products.

Such conditions occur in wave-protected mangrove and salt marshes, outer barrier tidal lakes, and back swamps; areas that can accumulate large amounts of organic debris and contain oxygen-free sediments. In Australia, ASS occur in soils ranging from thick deposits (>10 m) of unconsolidated estuarine mud to thin bands in the coarse sands of outer barrier systems and in gravels in coastal riverbeds. Many are covered by a variable thickness of more recent river alluvium or aeolian sands.

Sulfides are still being produced in mangrove swamps, salt marshes, coastal lakes and in sea and estuarine bottom sediments. Because fresh river water is low in dissolved sulfate, significant

ASS deposits are not usually found in freshwater alluvium or in estuarine river systems with outflows much larger than the tidal exchange.

2. Unique properties of ASS

The unique properties of ASS arise from their sulfide content. Sulfide concentrations (as iron pyrite FeS_2) range from about 0.01 per cent to as high as 15 per cent.

Not all acid produced by oxidation of sulfides is released into streams because the acid soil water can react partly or even completely with the sediments in which it was produced. The reaction between acid and soil constituents, mainly clay minerals, liberates dissolved aluminium, iron, manganese, heavy metals such as arsenic and copper, and other metal ions into soil and drainage waters. These ions remain dissolved, provided the solution remains acid (pH generally less than 4.5), and can be extremely toxic to plants and gilled organisms.

The reaction of acid with the soil also brings about permanent change to the soil itself in a process called soil ripening. Many of the unconsolidated, back swamp, sulfidic sediments are essentially gels containing up to 80 per cent water and they have a very small capacity to transmit water. Ripening flocculates these gels, producing soils with lower water contents and higher hydraulic conductivities. Ripening also can cause the soils to shrink by up to 50 per cent of their volume. Shrinkage is further enhanced if peat topsoil is oxidised and/or back swamps are drained. The net result is that soil surface elevations in drained back swamp areas are lower than in the undrained state.

2.1 Rates of acid production

The rate of oxidation of ASS is critical to their management, since it determines the persistence and magnitude of acidic outflows. This rate depends on:

- how fast oxygen in the air can move into the soil,
- the amount and distribution of sulfides in the soil,
- the distribution of soil water,
- soil temperature and soil pH, and
- soil composition.

In areas with vigorous crops or native vegetation and where the unoxidised sediments have low hydraulic conductivity, evapotranspiration can withdraw water faster than it is supplied by inflow from drains or creeks. This evapotranspiration lowers water tables below the position of the unoxidised sulfides and exposes them to air. Even in present-day, undrained mangrove communities, oxidation of the newly formed sulfides to sulfuric acid occurs at every low tide, although the acid is neutralised by the subsequent high tide.

2.2 Fish kills as indicators of acidification

Fish kills are not necessarily indicators of the onset of acidification nor do they reliably determine the duration and extent of acidification. Firstly, fish kills may not occur during acidification of a site because fish populations may already have been depleted at the location by previous acid events. For example, tributaries of the lower Richmond River in northern New South Wales were repeatedly affected by acid between 1993 and 1995 preventing most fish from recolonising affected reaches. Secondly, fish may successfully avoid acid, particularly in tidal reaches where fish can more effectively find refuge. Thirdly, many fish kills are not monitored nor reported properly and there are few occasions where fish kills have been unequivocally linked to acid events. Many fish kills are reported or monitored some time after the mortalities occur, when water quality has improved or returned to normal. Spikes of acid can be missed, thus the toxic event may pass before a kill is reported. In many cases, dead fish submitted for analysis are unsuitable for pathological work because of rapid deterioration of fish tissue. Similarly, poor handling and

fixation of specimens may cause artefacts that complicate histological interpretation.

2.3 Phytotoxicity of ASS

The toxicity of ASS to plants appears to be related to the change in balance of metal ions caused by the additional aluminium ions and the ionic species of aluminium present.

There are wide variations in the tolerance of plant species, and of varieties within species, to toxicities produced by ASS. For example, oats and maize seem more tolerant to aluminium than mustard or sugar. Rubber trees, oil palms, coconuts, bananas, cassava and sugar cane seem to be able to tolerate surface soil pH as low as 4. Pineapples can tolerate pH even lower than 4.

The effects of ASS on plant production may be reduced when there are sediments of peat or alluvium overlying the ASS. Under these conditions plant roots may be restricted to the surface layer and plant production less affected. Soil buffering capacity will also affect plant response to acid soil-water. In climates with pronounced dry periods the impacts are more severe than in those with more regular rainfall.

2.4 Corrosion of concrete structures

Unless concrete structures are very dense (low porosity), acid can react with the calcium carbonate and calcium hydroxide present to form gypsum (calcium sulfate). Gypsum reacts with calcium aluminates in the concrete to form ettringite. Both gypsum and particularly ettringite formation cause an increase in the volume of the affected concrete. This results in the expansion and weakening of the concrete and its eventual exfoliation and dissolution. Etching of cement and exposure of aggregate are typical early signs of the attack of acidic effluent on concrete.

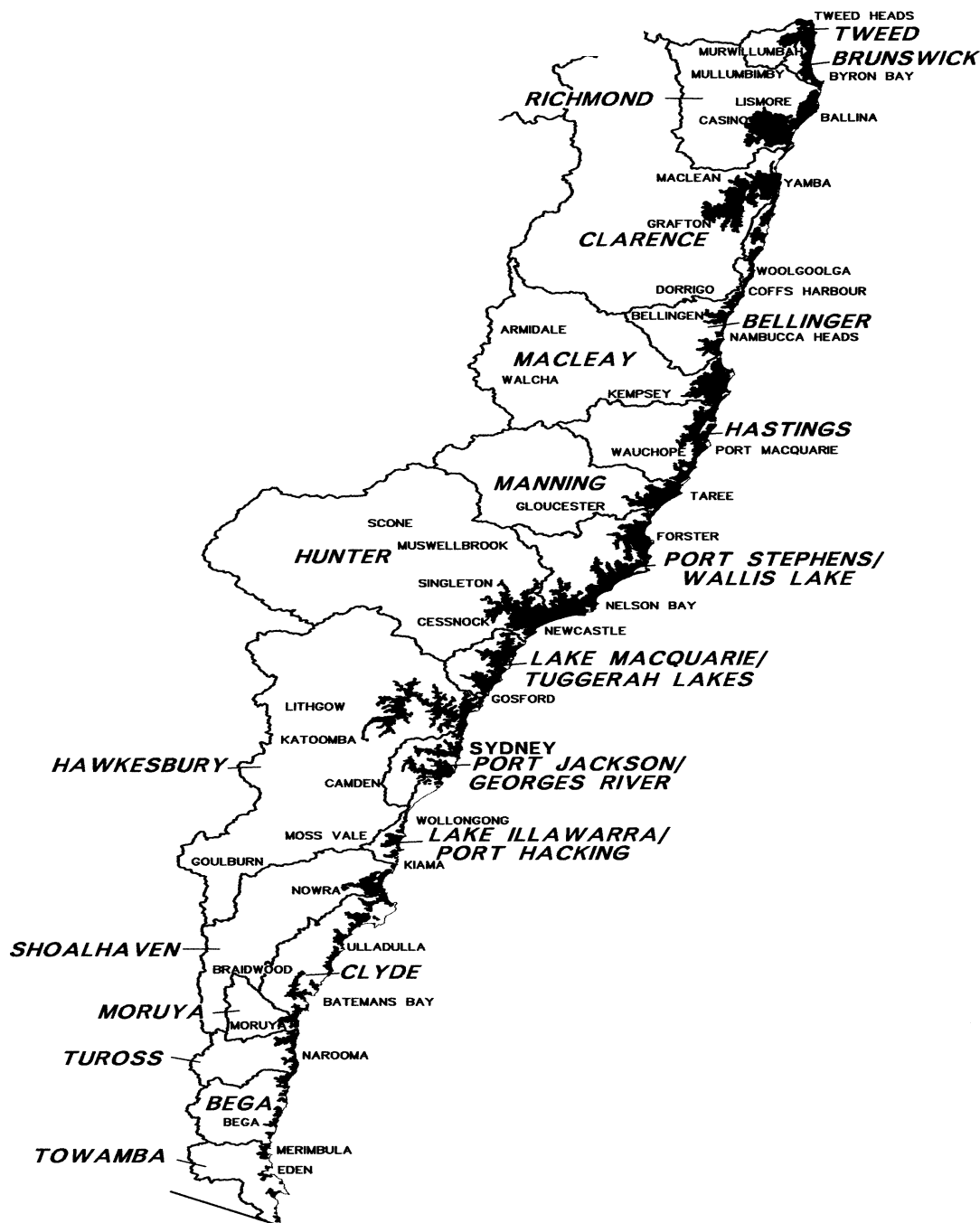
2.5 Clogging of aquifers and water wells

Another engineering consequence of ASS is the blocking or impairment of drain systems by precipitation of red-brown, iron hydroxide and

iron oxide flocs, when fresh or neutral pH water meets acid iron-rich water. Groundwater pumping from coastal aquifers, in which significant pyritic oxidation has occurred, can cause the landward incursion of seawater into the aquifer. When the well-buffered seawater encounters acidic iron-rich waters, precipitation of ferric hydroxide/oxides can occur clogging

the aquifer. If this takes place, seawater intrusions may be 'frozen' in place with little likelihood of being displaced seaward. Iron rich waters can also clog water wells, drains and pumps, due to iron hydroxide/oxide floc precipitation upon oxidation. Trapping of filamentous bacteria and matting iron can have the same effect.

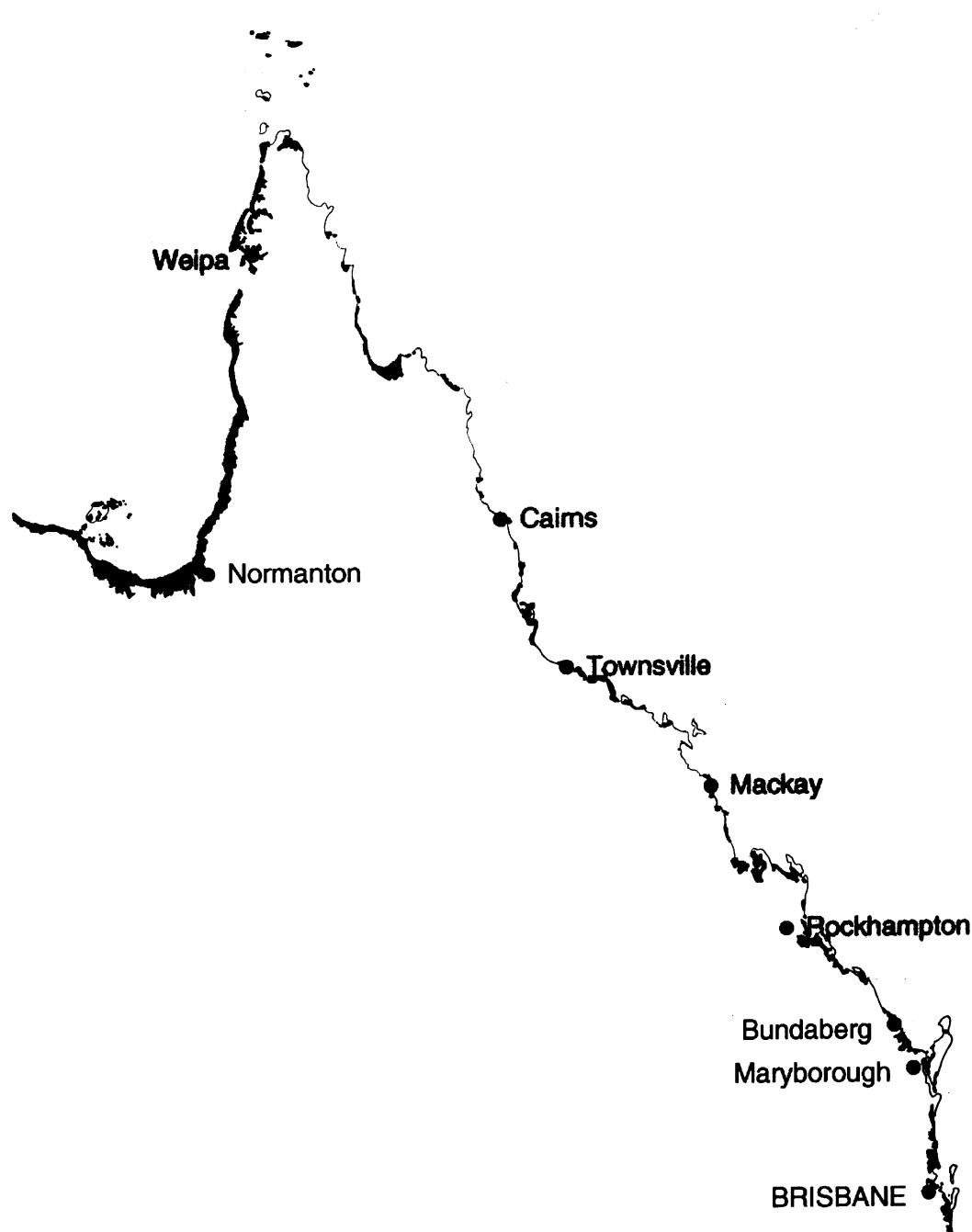
Coastal ASS in New South Wales



Indicative distribution of coastal and estuarine ASS in New South Wales.

Source: New South Wales Department of Land and Water Conservation.

Coastal ASS in Queensland



Indicative distribution of coastal and estuarine ASS in Queensland.

Source: Queensland Department of Natural Resources.