Guidelines for the Use of Acid Sulfate Soil Risk Maps

Acid Sulfate Soils Management
Advisory Committee

LAND & WATER
CONSERVATION

Second Edition
March 1998

Department of Land and Water Conservation

Map Updates

The Acid Sulfate Soil Risk Maps may be periodically updated based on any new or additional information that will enhance the understanding of issues related to acid sulfate soils. Any person or organisation wishing to comment on the maps should address correspondence in writing to the Manager, Soils Information and Planning, Department of Land and Water Conservation, PO Box 3720, Parramatta NSW 2124.

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Naylor, S.D. 1995, *Acid Sulfate Soil Risk of the Clybucca Map Sheet*, Department of Land and Water Conservation, Sydney.

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Cover photos (L to R; clockwise): Low risk acid sulfate soils site, photo courtesy Department of Land and Water Conservation (DLWC); Acid discharge from drained acid sulfate soils (centre), DLWC photo; Undisturbed marine sediments with high acid sulfate soil risk, DLWC photo; A degraded dam site caused by excavation of acid sulfate soils, photo courtesy H. Milford; Acid sulfate scald, photo courtesy M. Eddie.

CONTENTS

SUMMARY

Disturbance of acid sulfate soils in NSW coastal areas has resulted in degradation of lowland environments and estuarine water quality. As a first step towards identification and future management of acid sulfate soils in these areas, a series of Acid Sulfate Soil Risk Maps was prepared by a team of soil surveyors.

The Acid Sulfate Soil Risk Maps predict the distribution of acid sulfate soils based on an assessment of the geomorphic environment. This assessment has involved aerial photo interpretation, extensive field work and laboratory analyses of soil samples.

The maps have three primary map classes:

- High Probability of Occurrence of Acid Sulfate Soils
- Low Probability of Occurrence of Acid Sulfate Soils
- No Known Occurrence of Acid Sulfate Soils.

Where there is a probability of occurrence of acid sulfate soils (ASS), the depth to the ASS layer is provided. A guide is also given to land use activities which may create an environmental risk if carried out without acid sulfate soils investigation.

The mapping has been designed to provide information on acid sulfate soil distribution and indicate land uses which are likely to create an environmental risk by disturbing ASS. The maps will assist with land management and the environmental planning of landscapes in coastal NSW.

Alluvial backswamp. Acid sulfate soils are a natural part of coastal lowlands and do not cause any problems if left undisturbed. Photo: M. Eddie.

INTRODUCTION

Many areas of coastal NSW are undergoing rapid expansion and development of rural and urban land uses. Accompanying such development are many soil-related problems, including acid sulfate soils (ASS). The growth and development of our coastal resources must incorporate a full understanding of the problems associated with ASS and their distribution.

The presence of acid sulfate soils and their associated problems have largely gone unrecognised in the past, despite the fact that Australian soil scientists identified them as early as 1963 (Walker 1963). The presence of ASS along the NSW coastline is now recognised as an extremely important coastal management issue.

Acid sulfate soils are widespread in estuarine floodplains of coastal NSW. They are found in coastal lowlands such as mangrove tidal flats, salt marshes or tea-tree swamps. Typical land uses associated with environments containing acid sulfate soils include grazing, dairying, sugar cane production, urban development and sandmining. Various aquaculture industries are also associated with these environments.

A series of Acid Sulfate Soil Risk Maps covering the entire NSW coastline has been prepared by the Department of Land and Water Conservation. The mapping has been designed to provide information on acid sulfate soil distribution and indicate land uses that are likely to create an environmental risk by exposing ASS to air. The maps have been prepared for a wide range of users to assist with land management and the environmental planning of coastal landscapes in NSW.

Acid Sulfate Soil Risk Maps can fulfil a primary role in the management of acid sulfate soils by providing an understanding of the distribution and extent of these problematic soils.

The objectives of the Acid Sulfate Soil Risk Mapping Program, which have been met with the publication of these guidelines and associated maps, were to:

- map the environments containing ASS along the NSW coastline
- provide relevant soils information in an easily accessible form
- produce guidelines for the use of the Acid Sulfate Soil Risk Maps.

This document has been prepared primarily to assist in the understanding and use of the Acid Sulfate Soil Risk Maps, and is presented in three parts. The first part outlines the process for interpreting a map, indicates how these guidelines should and should not be used, and defines the appropriate information which can be derived from an Acid Sulfate Soil Risk Map. The second part provides information on the characteristics and management principles of acid sulfate soils, and the final part describes the methods used to prepare the Acid Sulfate Soil Risk Maps.

WHAT ARE ACID SULFATE SOILS?

Acid sulfate soils are extremely acidic soil horizons or layers resulting from the aeration of soil materials that are rich in iron sulphides, primarily pyrite (FeS_2) (van Breeman 1982). When drainage or excavation brings oxygen into these previously waterlogged soils, the pyrite is oxidised to sulphuric acid. Should the production of acid exceed the neutralising capacity of the soil, so that the pH falls to below 4, these soils are known as **actual acid sulfate soils (AASS)**.

Potential acid sulfate soils (PASS) are waterlogged soils rich in pyrite that have not been oxidised. Any disturbance that admits oxygen will lead to the development of actual acid sulfate soil layers. Potential acid sulfate soils are completely innocuous to the environment if kept under water. Actual acid sulfate soils overlay PASS in Australian coastal environments.

Actual acid sulfate soils were not mapped separately from potential acid sulfate soils. Unless specified as Actual or Potential, the use of the term “acid sulfate soils” or ASS in this document or on the Acid Sulfate Soil Risk Maps is a generic term used to imply both actual and potential acid sulfate soils.

A technical definition of both actual and potential acid sulfate soils is provided in the Glossary of Terms.

THE NEED FOR A SECOND EDITION

Acid Sulfate Soil Risk Maps have been used extensively by developers, Local and State Government researchers and consultants as well as the general community for over two and a half years since they were released. Further reliance on these risk maps is anticipated since they may now form the basis for a series of Acid Sulfate Soil Planning maps. It is intended that Local Government will use the planning maps to indicate areas where conditions will apply to new developments in order to avoid further acid sulfate soil damage.

To ensure the greatest possible accuracy of the planning maps, the first edition risk maps were revised and a second edition produced. This was done by examining more recent acid sulfate studies (completed in NSW since the original risk mapping work was done); canvassing the views of acid sulfate soil scientists and major known users, including Local Government authorities; re-evaluation of air photos; and field inspections.

The main change to second edition Acid Sulfate Risk Maps is that *Low Risk* areas have been reduced. Initially, acid sulfate soils were mapped somewhat conservatively. Because of the amount of damage that could be done by disturbance of even small amounts of acid sulfate soil, it was decided to map environments as being low probability of risk in all areas where coastal acid sulfate soils could conceivably be found within the depths indicated. It has since been realised, in some cases, that low risk areas of acid sulfate soils do not extend as far inland as was originally expected, especially where streams and creeks enter the coastal floodplain. The limit of low probability acid sulfate soils has often been set at the tidal limit.

Further, the first edition risk maps relied on relative elevations provided as spot heights on 1:25 000 topographic maps. In some instances, the spot heights were questioned. For the second edition risk maps, air photos were examined again to re-assess elevations and the likelihood of environments with acid sulfate soils.

Many second edition risk maps remain the same as their first edition. The following is a list of risk maps where there are differences between the first and second editions:

1	Bilambil
2	Tweed Heads
3	Murwillumbah
4	Cudgen
5	Burringbar/Pottsville
6	Huonbrook/Brunswick Heads
9	Lismore/Ballina
10	Tatham
11	Wardell
12	Empire Vale
13	Ellangowan
14	Woodburn
16	Tabbimoble
17	Banyabba
18	Woombah
19	Maclean/Coaldale
20	Yamba
22	Tyndale
23	Brooms Head
26	Sandon
27	Pillar Valley
28	Bare Point
29	Red Rock/North Solitary Is.
30	Woolgoolga
31	Moonee Beach
32	Coffs Harbour
33	Bellingen/Raleigh
34	Missabotti/Wenonah Head
35	Macksville
36	Eungai
37	Clybucca
38	South West Rocks
50	Nabiac/Hallidays Point
51	Coolongolook
52	Forster
53	Marwell
54	Wootton
55	Pacific Palms
56	Bulahdelah
57	Myall Lake
58	Seal Rocks
59	Paterson
60	Clarence Town
61	The Branch
64	Maitland
65	Karuah
66	Port Stephens
67	Cessnock
68	Beresfield
69	Williamtown
71	Wallsend
73	Morisset
74	Swansea
75	Borralong
76	Catherine Hill Bay
77	St Albans
78	Mangrove
79	Wyong
81	Lower Portland
82	Gunderman
83	Gosford
84	Kurrajong
85	Wilberforce
87	Broken Bay
88	Springwood/Riverstone
89	Hornsby/Mona Vale
90	Parramatta/Prospect
91	Sydney Heads
92	Liverpool
93	Botany Bay
94	Bondi
101	Burrier/Berry
103	Yalwal/Nowra
104	Crookhaven
105	Huskisson
108	Sussex Inlet
109	Milton/Cunjurong Point
111	Currowan
113	Nelligen
115	Mogo
116	Moruya
117	Bodalla/Nerrigundah
118	Narooma
119	Wandella/Central Tilba
120	Bermagui
121	Brogo/Murrah
122	Bega
123	Wolumla
124	Pambula
125	Eden
126	Kiah
127	Narrabarba

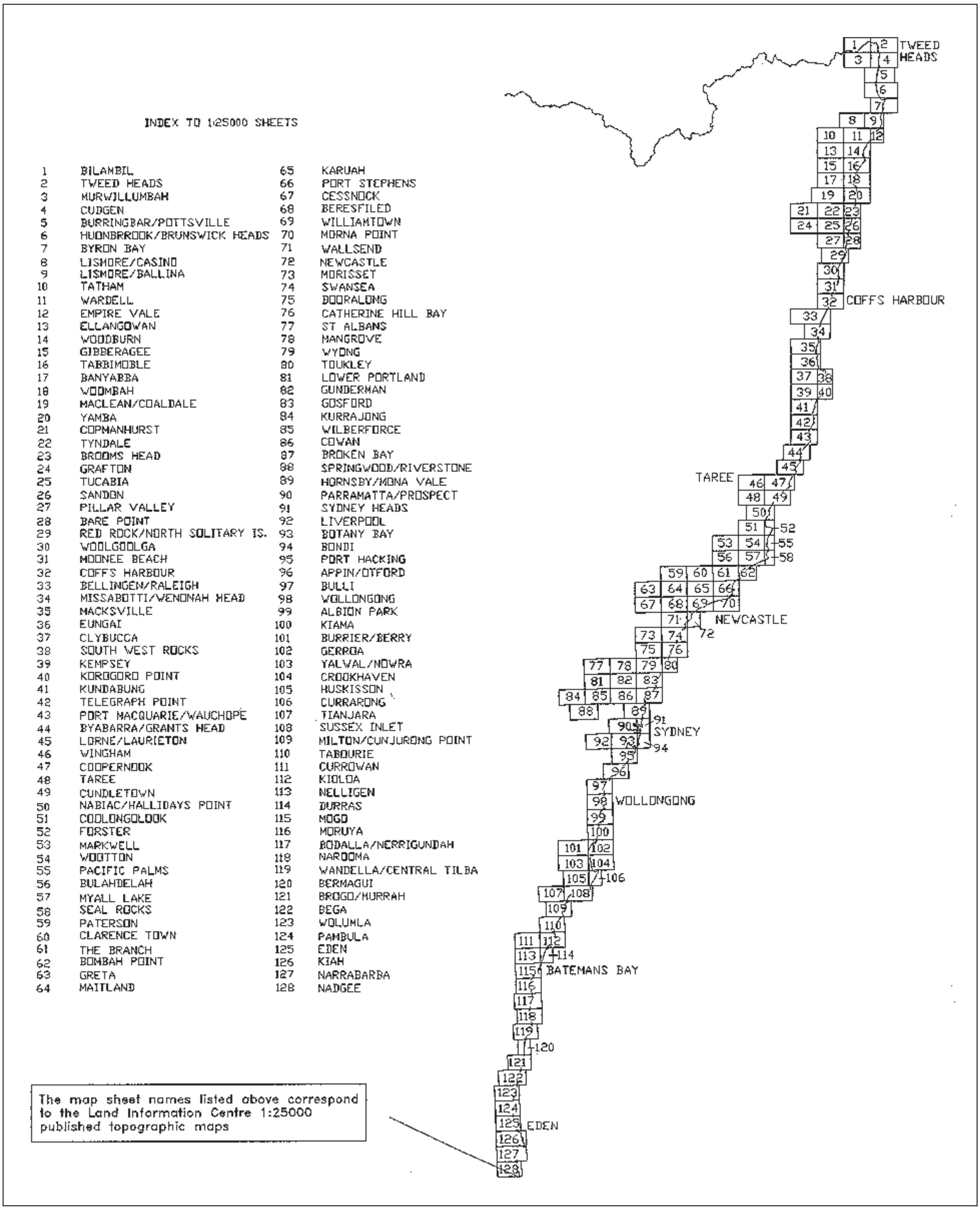

Figure 1 *- Index to Acid Sulfate Soil Risk Maps.*

1. INTERPRETING THE ACID SULFATE SOIL RISK MAPS

1.1 Intended Use of the Acid Sulfate Soil Risk Maps

The Acid Sulfate Soil Risk Maps predict the distribution of ASS based on an assessment of the geomorphic environment. This assessment has involved mapping the environments in which they are likely to be found, those being coastal lowlands up to about 10 m Australian Height Datum (AHD), and carrying out field work to establish field relationships between landform, elevation and occurrence of ASS. Soil samples were collected in the field and analysed in the laboratory, the data being used in this assessment.

Landform elements were used as the basic mapping unit. These provide a basis for land use planning and allow the application of elevation classes so that the depth of occurrence of ASS within a landform element can be estimated. It also allows the prediction of soil management problems in other areas with similar landform and soil characteristics.

The Acid Sulfate Soil Risk Maps are not intended to provide site specific ASS information. The information derived from the maps cannot be used in the assessment of the potential to effectively manage ASS in a particular development.

When using the Acid Sulfate Soil Risk Maps, the following must always be kept in mind:

- Extreme variations in the nature and distribution of ASS can be expected.
- Depth to the ASS layer can be highly variable. The depths given in the key on the maps should be used as a guide only and not used for a specific assessment of development potential.

It is recommended that all land use activities likely to disturb ASS require appropriate soil investigations and a management plan to avoid environmental degradation.

1.2 Locating Yourself on an Acid Sulfate Soil Risk Map

Each Acid Sulfate Soil Risk Map was prepared using a NSW Land Information Centre 1:25 000 topographic map as a base. The name of each Risk Map corresponds to the same name of the topographic map. For example, the Clybucca 1:25 000 topographic map corresponds to the Clybucca Acid Sulfate Soil Risk Map. A diagram and list of the names of the Acid Sulfate Soil Risk Maps that have been prepared along the coast are shown on Figure 1.

Limited features such as main roads and towns have been put on the maps to assist locating a particular area. Also provided is the Australian Map Grid; however, the easiest way to locate yourself on a Risk Map is to overlay the corresponding 1:25 000 topographic map and identify recognisable features.

1.3 Use of Map Key

The map key defines the probability of occurrence of acid sulfate soils (MAP CLASS DESCRIPTION), the DEPTH TO ACID SULFATE SOIL MATERIALS, the ENVIRONMENTAL RISK associated with disturbing the soil materials, and gives examples of TYPICAL LANDFORM TYPES.

Once you have identified the area on the map you are interested in and its associated colour, refer to the key. On the left-hand side of the colour bar, you can identify the probability of occurrence of ASS. Immediately to the right of the colour bar, you can identify the depth at which the ASS layer is likely to be found. If you then continue to move to the right, the environmental risk can be identified.

1.3.1 Map Class Description

High Probability of Occurrence

Landform elements in which the geomorphic processes have been suitable for the formation of ASS have been classed as having a High Probability of Occurrence. ASS in these environments are widespread or sporadic. They may also be very close to the surface or buried by many metres of alluvium or windblown sand. Bottom sediments of estuaries, rivers, creeks and lakes are also considered areas of High Probability of Occurrence. Environments associated with this map class are all closely related to Holocene deposits.

Low Probability of Occurrence

Where environments have not generally been suitable for ASS formation, or ASS are highly localised or sporadic, they have been classed as having a Low Probability of Occurrence. ASS may be close to the surface or buried by many metres of alluvium or windblown sand. The majority of these landforms are not expected to contain ASS. Soil materials are often Pleistocene in age.

No Known Occurrence

Acid sulfate soils are not known or expected to occur in these environments. In general, landforms above 10 m AHD were classed as having No Known Occurrence of ASS. Below this level other landforms were also placed into this map class based on an assessment of the geomorphic processes occurring there. Some of these environments include elevated Pleistocene and Holocene dunes, low hills with *in situ* bedrock soils, drainage plains or fluvial dominated plains and levees. These environments are not expected to contain ASS.

Disturbed Terrain

Disturbed terrain indicates areas which have been mined or filled or have been subjected to other significant soil disturbance activities.

1.3.2 Depth to Acid Sulfate Soil Materials

The Key indicates at what depth ASS materials may start to be encountered within that area; however, the depth of occurrence will depend on the exact elevation of the site.

1.3.3 Environmental Risk

Whether or not a particular land use activity will contribute to any acidification hazard in an area by exposing ASS will depend on the depth of soil disturbance, and the depth of occurrence of ASS materials. Therefore, the environmental risk associated with disturbing ASS will depend on the type of land use activity and where in the landscape it is carried out.

Where ASS are identified as bottom sediments, at or near the ground surface, or within 1 m of the ground surface, there is considered to be a severe environmental risk because the likelihood of disturbance of ASS materials by various land uses is greatest in these areas. This does not imply that any particular land use should be excluded from these areas. Rather, appropriate soils investigation will be essential to develop an ASS management plan for the particular land use.

Where ASS are identified at greater than 1 m in depth, the environmental risk is associated with deep excavation or disturbance for such activities as major drains, pipes, dams and foundations. Problems associated with ASS are not expected in these areas if the use of the land requires no or only shallow disturbance (less than 1 m).

The activities which may disturb ASS noted on the map Key are not exhaustive. Each proposed activity and land use must be assessed on its merits relating to the level and depth of disturbance.

Figure 2 shows a schematic cross-section of a levee to backswamp landform within an area of high probability of occurrence of ASS. Typical landform codes, the depths to ASS and the land use activities with an environmental risk are shown on the figure.

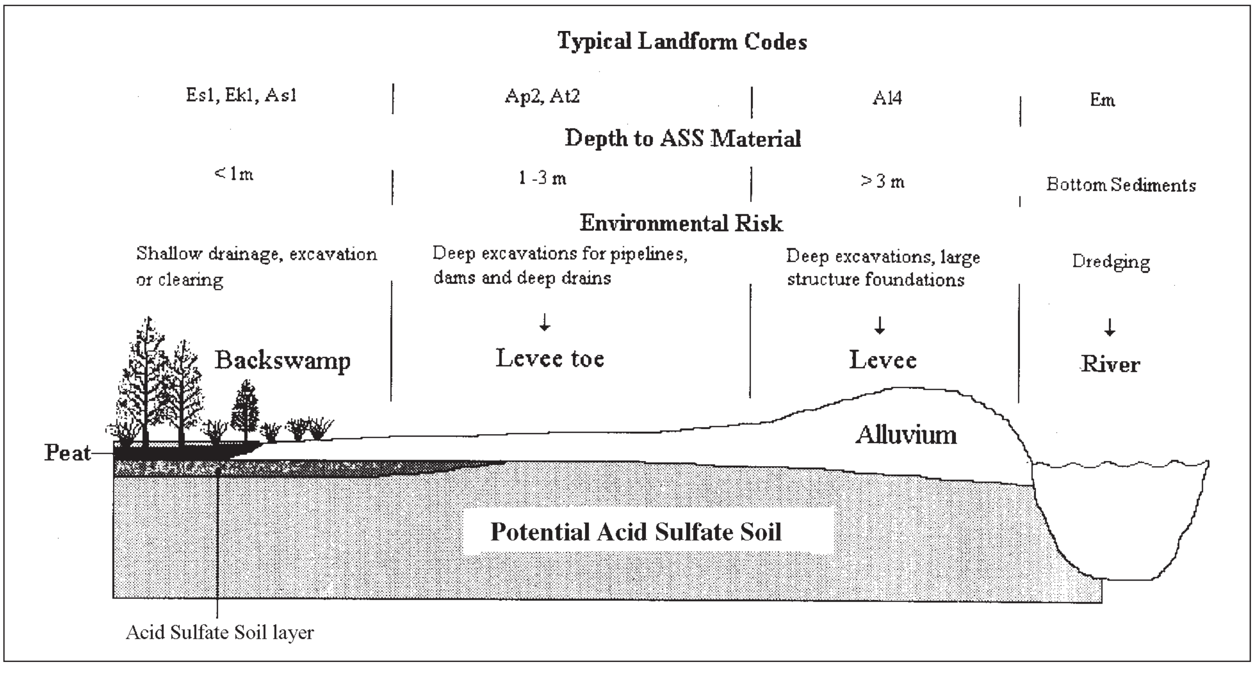

Figure 2 *- Schematic cross-section of a levee to backswamp landform indicating typical landform codes, depth to ASS materials and land use activities with an environmental risk.*

Within the Low Probability of Occurrence Map Class, there is a wider range of variability of environmental risk associated with land use activities. Because ASS are not expected to occur widely in these landforms, land management is generally not affected by these soil materials; however, the environmental risk associated with disturbing ASS is no less severe as a result of the soil's localised occurrences. If ASS are located in these areas, then the level and depth of disturbance will need to be considered for proposed land use activities. An example of a landform with a low probability of ASS is shown in Figure 6.

Assessment of environmental risk in areas of disturbed terrain will require soil investigation based on the nature of the existing land disturbance and elevation of the site.

1.4 Interpretation of Landform Codes

An alphanumeric landform code is shown on the maps. The first symbol of the code characterises the dominant process under which the geomorphic environment developed. The second symbol (landform element) describes land surface features providing a recognisable link between the processes and conditions of soil information and the occurrence of ASS. The third symbol is the approximate elevation (AHD) of the landform element.

An additional descriptive code in brackets delineates Pleistocene sediments (P) or acidic scalds (s). The acidic scald code was applied where ASS had contributed to scalding of the ground surface due to acidification resulting in loss of vegetation.

A detailed discussion of the landform codes is provided in a later section of this report - *How the Acid Sulfate Soils Risk Maps Were Prepared*. Definitions of each of the landform terms are provided in the Glossary of Terms.

1.5 Soil Profile Description Sites

Soil profile description sites are identified on the Risk Maps by blue coloured numbers. The majority of soil profiles were inspected specifically for the Acid Sulfate Soil Risk Mapping Program; however, in some areas, results of previous soil surveys were used to identify ASS, in particular, soil surveys undertaken as part of the Soil Conservation Service's Soil Landscape Mapping Program.

Laboratory soil test results were used to confirm field observations or expected areas of ASS. Acid sulfate soils vary both vertically and laterally, and a single test or profile should not be relied upon for determining land use or management that involves soil disturbance. Further soil sampling and testing will be required to investigate the potential environmental risk of the proposed land use.

Soil profile data, site data and laboratory data can be accessed through the Department of Land and Water Conservation's Soil Data System on application to the Soil Data System Coordinator, Department of Land and Water Conservation, PO Box 3720, Parramatta NSW 2124. Inquiries must quote the site number and the map sheet name.

1.6 Map Reliability

Landform element boundaries were delineated and published at 1:25 000 scale. Boundaries between landform elements that could be delineated reliably are drawn as solid lines. Where boundaries are diffuse or difficult to identify, they are drawn as broken lines. Elevation provided on each landform element is only approximate. The minimum area mapped is 1.7 ha. Areas smaller than this were generally not mapped separately.

Disturbed terrain was identified by aerial photograph interpretation or from other sources such as maps supplied by local Councils; however, there are some areas of disturbed terrain that are not shown on the maps. These are typically associated with urban areas where the development prevented the identification and delineation of the disturbance.

During the field work phase, field meetings were held with the ASS surveyors to ensure consistency in site selection strategies, soil profile description methods, and soil sampling techniques. Quality control and consistency in the mapping and coding of landform elements were also maintained by:

- field checking by other ASS surveyors in the team
- regular meetings of the surveyors to discuss and review the process
- checking of codes and boundaries after the maps were entered into the Geographic Information System prior to publication.

The Acid Sulfate Soil Risk Maps should be used at the scale at which they are published. Enlarging the maps will produce distortions whereby map boundaries will no longer represent the map units on the ground.

2. ACID SULFATE SOILS - CHARACTERISTICS AND MANAGEMENT PRINCIPLES

2.1 Formation of Potential Acid Sulfate Soils

Pyrite forms in waterlogged, saline sediments that contain iron and where there is a supply of easily decomposed organic matter (Dent 1986). Bacteria break down the organic matter under waterlogged anaerobic conditions and reduce sulfate from seawater to sulfide (Pons *et al*. 1982). Pyrite is the end product of these processes, resulting in what is known as a potential acid sulfate soil (PASS) .

The formation of pyrite in coastal sediments occurs in two main environments. The first and most dominant is saline and brackish lowlands including tidal flats, salt marshes and mangrove swamps (Figure 3) (Pons & van Breeman 1982). The second is the bottom sediments of saline and brackish estuaries, rivers, lakes and creeks. Depending on a number of factors including rates of sedimentation and degree of tidal flushing, intricate patterns of PASS can develop woven in amongst non-acid sulfate soils (Dent 1986). These soil patterns do not usually exhibit ground surface features.

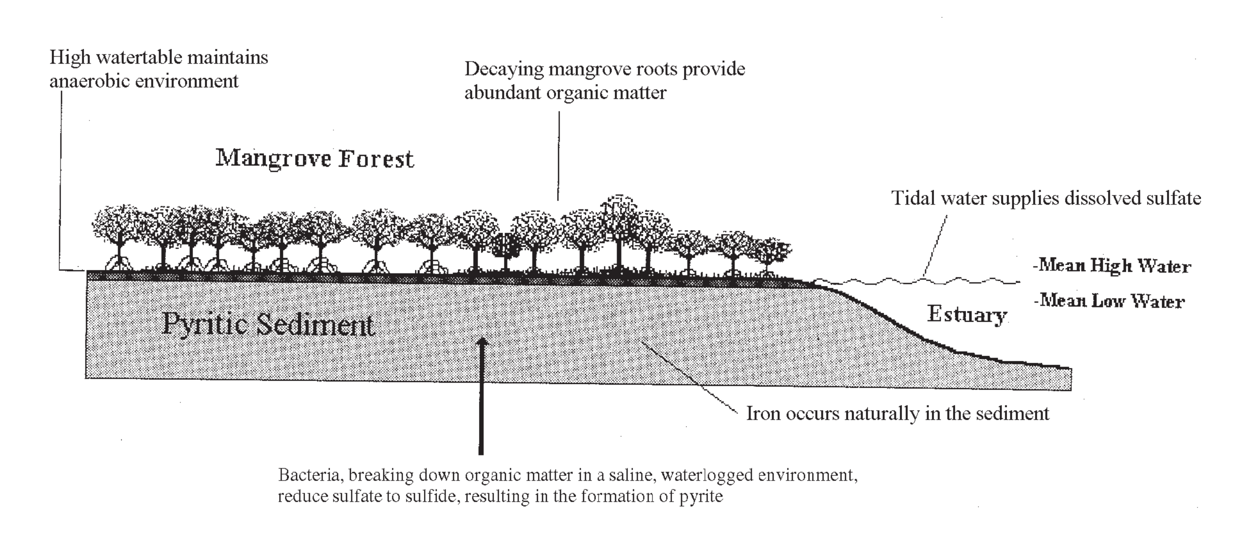

Figure 3 *- Schematic cross-section of a mangrove tidal swamp showing the necessary conditions for pyrite formation.*

Pyritic material of concern in NSW coastal lowlands has been forming in the Holocene period between about 10 000 years ago and the present day (Pons *et al*. 1982). Since the last ice age, sea levels rose about 100 m and coastal valleys slowly infilled with sea water and fine sediments creating vast tidal swamps such as mangrove flats (Chappell 1990). The maximum degree of pyrite accumulation appears to have been following the last sea level rise, about 7 000 years ago (Melville *et al*. 1993). Pyrite is still being formed in present-day mangrove and salt marshes.

Pyrite can also exist naturally in various rocks. Activities such as mining and road construction can expose deposits of rock containing pyrite causing oxidation and creating acid sulfate conditions. These sources of acidification were not considered in this mapping program.

2.2 Development of Actual Acid Sulfate Soil Layers

If a PASS is drained or excavated, it will become extremely acid due to the exposure of pyrite to air. A number of oxidation products are formed, but the principal end-product is sulfuric acid. The resulting acid soil layers are called actual acid sulfate soils (AASS).

The oxidation of pyrite not only acidifies the soil and groundwater, but also mobilises aluminium, iron and manganese from the soils (Sammut *et al*. 1994). Following heavy rains, these oxidation products may then enter drains and other waterways forming a toxic effluent that may affect aquatic fauna at some distance from the soil disturbance.

2.3 Characteristics of Potential and Actual Acid Sulfate Soils

Typically PASS have a pH of 6 - 7 and are commonly dark grey or dark greenish grey in colour. They may contain shell and other carbonates and have pyrite concentrations which, when oxidised, exceed the soil's neutralising capacity. Potential acidity as a result of pyrite formation may be found in sands, peats and clays, but is most extensive in clays or what are known as estuarine gels due to their buttery consistency. The identification of PASS requires specific chemical tests in the field (White & Melville 1993).

The primary criterion for identification of an actual acid sulfate soil is pH, which by definition is less than 4. In the field, jarosite mottles (yellow streaks and mottles around old root channels) are a positive indicator of AASS. Jarosite can form as an intermediate mineral during the chemical reaction, which results in sulfuric acid. It forms when the soil is both acid and is in contact with oxygen (van Breeman 1982). Not all AASS form jarosite, however, especially organic soils.

2.4 Significance of Acid Sulfate Soils

The effects of poorly managed ASS are felt by many people in the community including farmers, fishermen, planners, engineers and people involved in land resource management in local Councils and government agencies. Acid sulfate soils are unique in that the impacts of drainage can be so severe that they can affect engineering works, agricultural productivity and water quality of estuarine systems (Dent 1986).

Landholders face the difficulties of ASS at the source of the problem. The sulfuric acid produced upon oxidation of pyrite lowers the pH in the soil to extreme levels, at times to less than 3. Highly acidic conditions in the soil result in toxicities including increased solubility of aluminium, iron and sometimes manganese, and nutrient deficiencies can be severe (Rorison 1973).

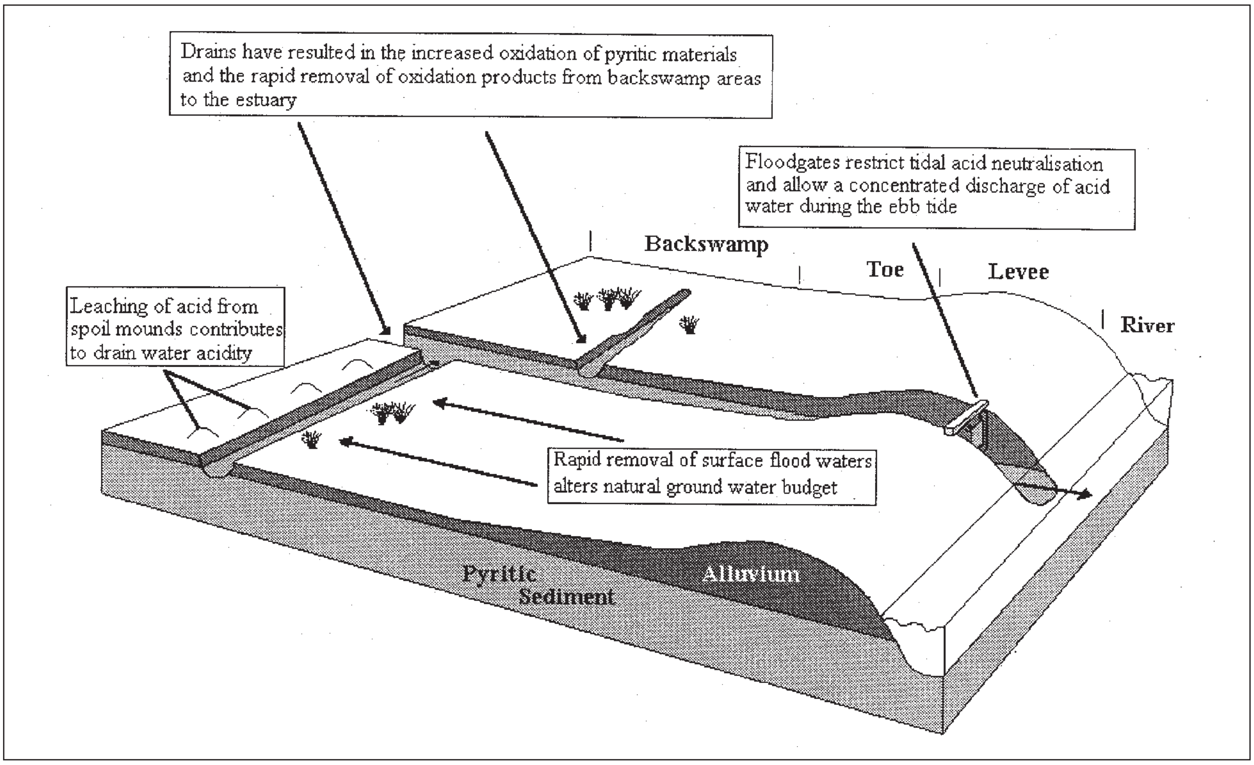

Figure 4 *- Schematic cross-section of a backswamp to levee landform showing a simplification of the processes leading to estuarine acidification.*

Oxidation of pyrite can also contribute acid salts to the soil causing a high degree of salinity (Fanning 1993). These problems create challenges for farmers wanting to improve the agricultural productivity of an area.

Fishermen experience the off-site effects of ASS. Following dry periods, heavy rains in areas of ASS cause flushing of extremely acid and aluminium-rich toxic water (Callinan *et al*. 1993). Acid water contamination may have profound effects on the aquatic populations of estuarine systems including massive fish kills and estuarine habitat degradation (Phuc Tuong 1993).

Callinan *et al.* (1993) reports that a fish disease known as Epizootic Ulcerative Syndrome (EUS) has shown a pattern of seasonal recurrence associated with drainage waters from areas of acid sulfate soils on the east coast of Australia. This has cost commercial estuarine fisheries about $1 million annually in discarded fish.

Engineers must cope with extremely aggressive soil conditions for construction when using concrete and steel in ASS. Corrosion by acidity and salts can cause serious problems for pipelines, pylons, piles and other structures. Significant costs can be incurred to the community through maintenance of public structures such as bridges, pipelines and floodgates.

Planners and developers must be aware of the presence of ASS when preparing land development proposals. The engineering hazards and environmental consequences associated with ASS must be taken into account during initial design of the development. Large costs have been and will continue to be incurred through ignorance of the problem.

2.5 Understanding Acid Sulfate Soils

Oxidation of potential acid sulfate soils can occur under natural conditions due to evapotranspiration processes drying soils (White & Melville 1993) and during extreme and prolonged dry periods. However, over the last few years research has indicated that excavation and drainage works can accelerate the oxidation process and increase the amount of acid entering drains and ultimately estuarine systems (White 1994). Artificial drainage and flood mitigation works have altered long-term watertable levels causing oxidation of pyrite (Sammut & Melville 1995). Figure 4 shows a schematic representation of how drains can contribute to estuarine acidification.

Since the formation of PASS, many of the environments have been buried by freshwater alluvium or windblown sands. These soil materials effectively cap the ASS and inhibit the penetration of oxygen into the pyritic layer (Lin & Melville 1993). These layers may also hide a complex pattern of PASS amongst other non-acid sulfate soils. The thickness of alluvium over the PASS layer has been found to be up to 5 m, for example, in the Grafton area of northern NSW. Only when deep excavations expose the underlying PASS is there acidification risk in these areas.

Alteration of floodplain hydrology results in severe ASS conditions developing closest to the ground surface in the backswamps, where the PASS layer is covered only by a thin veneer of alluvium or peat (Figure 5). In these areas, little alteration to the drainage conditions is required to result in oxidation and acidification of the soils.

Pleistocene soil materials generally do not inherently contain ASS conditions. However, during sea level rise and the formation of PASS, many irregular features in Pleistocene landforms of low elevation were later infilled with pyritic sediments or other Holocene soil materials, so in some landscapes, ASS are highly sporadic and form intricate patterns amongst Pleistocene non-acid sulfate soils (Figure 6). Without intensive soil survey, many of these types of ASS deposits can go unrecognised in the landscape.

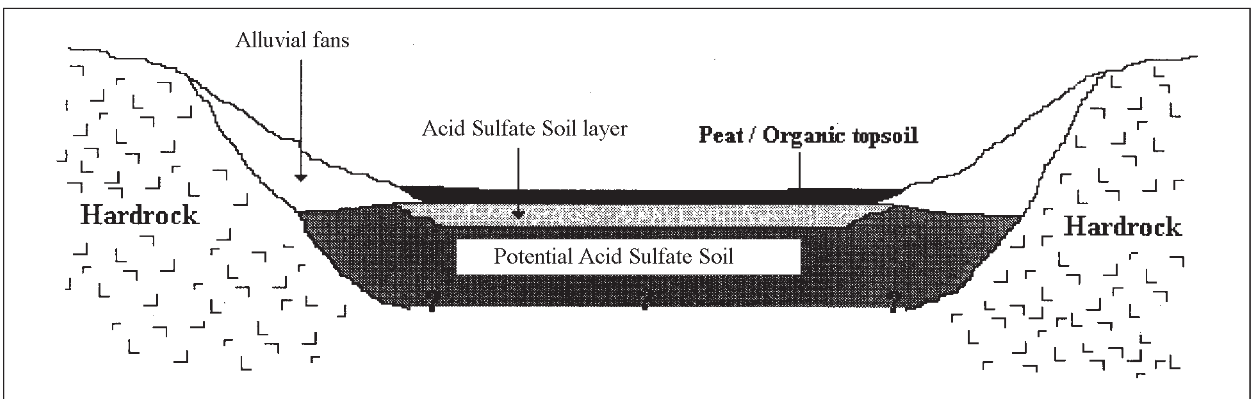

Figure 5 *- Schematic cross-section of a landform in which the potential acid sulfate soil layer is covered by a thin layer of peat.*

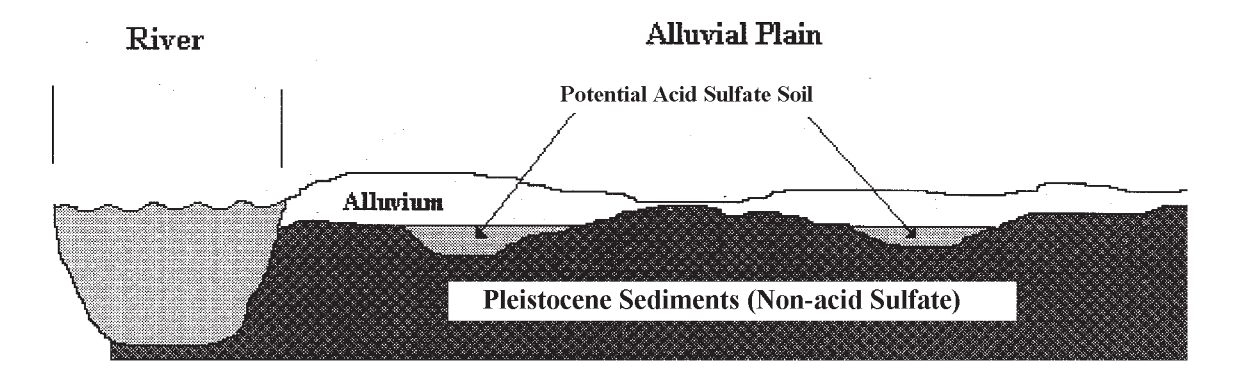

Figure 6 *- Schematic cross-section of a landform containing Pleistocene sediments indicating the sporadic occurrence of potential acid sulfate soils.*

2.6 Acid Sulfate Soils Management Principles

Management of ASS first requires their recognition. The Acid Sulfate Soil Risk Maps are available along the entire NSW coast to provide an initial assessment of the likelihood of ASS. Where land use activities are likely to disturb ASS, appropriate site assessment is essential, taking into account all the factors that may result in adverse effects on the environment.

In general, there are five main principles for the management of ASS (Table 1). These can be used individually or in combination. In addition, there are other innovative and effective ways in which ASS can be managed on a case by case basis.

Table 1. Acid Sulfate Soils Management Principles

Management Principles	**Options**	**Comments**
Avoid land management activities that disturb ASS.	1. Choose an alternative site. 2. Adopt land uses which do not disturb PASS. 3. Place fill over PASS.	Do not disturb PASS. This strategy will be required where proposed development is unsuitable and carries many environmental risks.
Prevent oxidation of PASS.	1. Replace any excavated PASS back below the watertable. 2. Do not allow new drains to lower the watertable below the PASS. 3. Reconstruct drains to raise the watertable. 4. Place fill over PASS.	Watertable management is the key to efficient ASS management. Drains are the most common impact on the watertable. Capping of PASS is highly effective and commonly used in urban development.
Neutralise ASS, or acid produced in PASS.	Add neutralising agents such as lime or dolomite.	Effective when lime or other agents can be incorporated thoroughly into the soil. Likely to be too expensive for broadacre applications.
Oxidise and leach PASS.	Expose ASS to oxygen and flush acidity quickly out of the soil. Contain and treat the acid leachate.	Can be used to treat stockpiles. Environmental consequences are difficult to control. Probably limited to small, capital intensive projects.
Remove pyritic material.	In principle, pyrite can be removed by hydraulic separation and disposed of in an anaerobic environment.	Appears feasible in dredging operations. Limited to capital intensive projects. Success of this technique limited.

Acid sulfate soil management does not imply only the treatment and handling of the acid soils themselves or the oxidation products, but must also take into account the social, environmental, hydrologic and ecologic setting of the environment in which they are contained. So management strategies for ASS will be determined by a range of environmental and economic factors, in cooperation with the people who depend on the land. In any case, the best option will be achieved with the priority being a sound regard for the environment and carried out in an economic manner.

Given the threat of long-term environmental pollution, the degradation of coastal lowland environments and the high cost of treatment, the sensible option in most cases is to leave ASS alone. The most compatible land uses will not involve drainage and excavation of the ASS. Unless projects are on a small scale (which can be well-monitored and managed) development disturbing ASS could prove a costly mistake both environmentally and financially.

Where development must proceed into areas of ASS, the local environment must be well understood. Acid sulfate soils are not all the same and respond differently to different management options; therefore, should ASS need to be disturbed, detailed soil investigation will be required. The investigation design will need to incorporate the variable soil characteristics, sensitivity of the local environment and the nature of the proposed development. Only then can feasible management strategies be formulated. In many instances, the threat of environmental degradation could be so great as to prohibit development. There must be no doubt of the management strategy fulfilling its requirements.

The management of existing areas of disturbed ASS is a complex problem as a result of the irreversible alteration of many environments and will need to be approached with a view towards improving the productivity of those areas and the environmental quality. In the drained backswamps of floodplains, it may be a case of relatively low cost alteration to the drainage management to enhance pasture production for grazing, and, over time, improve the long-term water quality of discharges from those areas. In an urban situation, where, for instance, ASS have been used as fill, treatment may require high cost neutralisation techniques. Each problem will need to be dealt with on a case-by-case basis.

Tidal Creeks are typical landforms with high ecological value and should remain undisturbed. Photo: H. Milford.

3. HOW THE ACID SULFATE SOIL RISK MAPS WERE PREPARED

3.1 Initial Map Preparation

Initial maps were prepared by stereoscopic interpretation of 1:25 000 colour aerial photographs to identify landform elements in coastal environments with an elevation up to about 10 m AHD. Boundaries of landform elements were transferred onto 1:25 000 topographic maps using the 10 m contour line to focus the mapping below this level. Mapping of some landforms including dune systems and alluvial plains in the upper reaches of catchments went beyond 10 m AHD.

Sets of aerial photographs taken in different years were used at various locations to take into account seasonal effects, such as the boundaries of swamps. The date of photography varied between 1986 and 1993, according to availability throughout the State.

Where available, existing soils information such as Soil Landscape Maps was used to assist in the mapping process. Satellite imagery was also used to identify and help understand dominant landform patterns in each catchment.

Landform elements were chosen as a basis for the Acid Sulfate Soil Risk Mapping Program for several main reasons:

- landform elements are easily mappable using aerial photo interpretation techniques
- landform elements are surface features of landform which provide a recognisable link between known processes and conditions of soil formation and the occurrence of ASS
- extrapolation of point observations can be made between similar landform elements
- prediction of soil management problems can be made between similar landform elements
- Landform elements, because of the above points, have useful applications for land use planning.

Each landform element was allocated a code (Table 2). Subsequently, a code was added to describe the geomorphic environment of formation (Landform Process Class) and the elevation (AHD) of the landform element. Hence, a three-character alphanumeric landform code is shown on the Risk Maps providing a recognisable link between the processes and conditions of soil formation, and the occurrence and depth of ASS.

Landform Code Example

A map unit having the landform code Ek1 indicates that the area formed under estuarine (E) conditions, is the identifiable land surface feature of a backswamp (k) and the backswamp has an elevation (1) of 1 to 2 m AHD.

Elevation data were applied to landform elements from 1:4000 scale orthophotomaps where they were available and by relating to known elevation points. Elevation given on the Risk Maps is approximate only, due to the extrapolation of elevation data between known elevation points.

Areas which had been mined, filled or subjected to major soil disturbance were delineated and labelled Disturbed Terrain. The elevation code was used to indicate the elevation of the present-day ground surface. Disturbed terrain was identified by aerial photograph interpretation or from other sources such as maps supplied by local Councils; however, there are some areas of disturbed terrain that could not be delineated. These are typically associated with urban areas where the development prevented the identification and delineation of the disturbance.

Landform Code Example

A map unit having the landform code X2 indicates that the area is disturbed terrain (X) with an elevation (2) of 2 to 4 m AHD. A landform element code is not shown because the disturbance prevented the identification of the landform feature.

Water bodies such as rivers, lakes, creeks and estuaries were also mapped, due to the likelihood of PASS conditions within bottom sediments. No elevation code was allocated to these areas.

Landform Code Example

A map unit having the landform code Em indicates that the area is below water level, being Estuarine (E) bottom sediments (m).

Soil investigations were necessary to determine the landform process class of many landform elements. The Estuarine (E) code was applied only to landform elements where estuarine soil materials occurred within 50 cm of the ground surface. The Estuarine landform process class was also applied to elements comprising of, for example, estuaries and lakes, where the bottom sediments have been influenced by estuarine water.

Table 2. Landform Codes used on the Acid Sulfate Soil Risk Maps (Landform elements are consistent with McDonald *et al*. 1990)

Landform Codes			
Landform Process Class	**Code**	**Landform Element**	**Code**
Aeolian	W	Backplain	b
Alluvial	A	Backswamp	k
Beach	B	Bottom Sediments	m
Estuarine	E	Channel	n
Lacustrine	L	Dune	d
Swamp	S	Interbarrier Swamp	r
Disturbed Terrain	X	Intertidal Flat	i
		Lagoon	g
		Levee	l
		Levee Toe	t
		Ox-bow	o
		Plain	p
		Sandplain	a
		Swamp	s
		Splay	y
		Supratidal Flat	u
		Swale	w
		Tidal Creek	c
Elevation (AHD)	**Code**	**Additional Descriptive Codes**	**Code**
0 - 1 m	0	Pleistocene	(p)
1 - 2 m	1	Acidic Scald	(s)
2 - 4 m	2		
>4 m	4		

3.2 Soil Data Collection and Analysis

Soils were examined and described in detail at over 840 sites and inspected at thousands more along the NSW coast by the team of soil surveyors. Field work began in March 1994 and was completed by April 1995. In some areas, soil inspection and testing had been recorded in previous soil surveys, such as those associated with the Soil Landscape Mapping Program. Where this data was available, it was used to assist in the Acid Sulfate Soil Risk Mapping.

Initially, representative soil profile sites were chosen during the aerial photograph interpretation phase to establish field relationships between landform, elevation and depth of ASS. Following this, site selection was primarily aimed at obtaining the most useful information on ASS in each landform and to test or confirm the occurrence of ASS.

At each soil profile site, soil morphological data, pH and site information were recorded on Soil Data cards. Positive identification was often made of ASS in the field by recognition of soil characteristics, such as jarosite, or surface observations of ASS.

Soil sampling equipment included stainless steel extendable hand augers from which 10 cm cores could be extracted using a Jarret detachable auger head. Detachable stainless steel gouges were used for soft, waterlogged soil materials. In some areas, a trailer-mounted backhoe was used for limited excavation of soil pits for soil profile description.

The maximum depth to which the soils are described is 3 m. This was defined by the limit of the hand augers and the authorised safe operation of the backhoe. The depth of sampling varied between sites depending on inspection requirements at each site. Depth data was recorded with other soil information. All soil holes and pits were refilled after inspection.

Between soil profile description sites, the extent of ASS was interpolated from other soils data obtained in the field and laboratory, and an understanding of the relationship between the geomorphic environment and the occurrence of ASS. In some environments, such as bottom sediments of estuaries, lakes and rivers, no soil profile descriptions or sample analyses were obtained. The occurrence or otherwise of ASS was based on an assessment of the geomorphic environment.

Analysis of the relationship between elevation levels (AHD) and soil data established the critical level at which the upper limit of ASS occurs. This is at or less than about 1 m AHD. This allowed an estimation of the depth of occurrence of ASS based on elevation of the ground surface.

Soil profile inspections were not made on landforms higher than 4 m AHD as soil auger equipment did not allow inspections to penetrate to the anticipated level of ASS. These areas were assessed based on information obtained from other sources or assessment of ASS distribution based on geomorphology, using soil profile information from surrounding landforms.

In the field, site inspection was often difficult due to poor accessibility of some areas by vehicle. Dense vegetation, flooding, waterlogged soils and restricted access onto private property also inhibited soil profile description at some preferred sites.

Soil profile descriptions were supplemented by many thousands of observations of ASS indicators, including;

- ferric iron staining on drain sides
- jarosite in spoil from excavations and drain construction
- unusually clear water and iron flocs in drain waters
- low pH in surface water and drain water.

In some areas, observations of indicators of ASS enabled an accurate assessment of ASS distribution and allowed the surveyor to concentrate efforts in more marginal areas.

At selected sites, soil samples were collected for laboratory analysis from soil horizons suspected or considered to be acid sulfate or potentially acid sulfate. Between 1 and 4 samples were taken depending on the number of horizons and the soil morphology. Over 1600 samples were collected for laboratory analysis. Each sample was approximately 300 to 500 g in weight. The soil horizon depth and sample site grid location were recorded. All samples were sealed and tagged within 2 plastic bags to minimise contact with oxygen during time of transport, and thus minimise oxidation of any pyrite material.

In the field, it was often not necessary to sample some layers because soil characteristics allowed the positive identification of acid sulfate conditions. For example, jarosite was a clear indicator of actual acid sulfate soils.

Within 24 hours of collection, samples were either frozen for dispatch at a later date or chilled and transported in "eskies" to the Department of Land and Water Conservation's Wellington Laboratory for immediate oven drying. These procedures were necessary to minimise oxidation of the soil materials.

The laboratory tests listed in Table 3 were undertaken on all soil samples, viz:

- Electrical Conductivity (1:5 soil:water) indicates the amount of soluble ions (salt) in the soil. It is determined on a 1:5 soil:water suspension and is prepared from the fine earth fraction of the sample.
- pH (1:5 soil:water) is a standard test for soil acidity.
- pH 1:20 in H_20_2 (hydrogen peroxide treatment) is a simple and rapid technique to assess the potential of a soil material to acidify. In this technique, 30% hydrogen peroxide is added to a soil sample in a plastic bottle. The reaction can be violent and the test should proceed slowly with only a few drops at a time being added. Peroxide is added until reaction has ceased. The more violent the reaction, the higher the pyrite concentration. The sample volume is then made up to a 1:20 extract, and the pH measured. Values of pH less than 3 and certainly less than 2.5 strongly indicate the presence of potential acid sulfate soil materials.
- Total Actual Acidity (TAA) is a simple measure of acidity within the soil including free acid and acidity absorbed on the clay and organic matter, and in acid salts.

- Total Potential Acidity (TPA) is a modified version of the procedure described by Konsten *et al.* (1990). The amount of acid in a 1:5 soil extract is measured before and after oxidation with peroxide. This technique does not quantify the pyritic materials in the soil, but rather measures the acidity produced before and after oxidation. A disadvantage of this test is that organic materials when oxidised with peroxide may produce acid but may not do so under natural conditions. Careful consideration was given to organic matter levels observed during field collection when interpreting results of this test.

The difference between TPA and TAA gives an indication of the soil’s potential to produce further acidity.

Table 3. Acid Sulfate Soil Laboratory Tests

Laboratory Test	**Sym bol**	**Units**	**Lab. Code***
Electrical Conductivity (1:5 soil:water)	(EC)	dS/m	C1A/3
pH (1:5 soil:water)	(pH)	-	C2A/2
pH (1:20) in H_20_2	-	-	C2C/1
Total Actual Acidity	(TAA)	mol/kg	C16A/1
Total Potential Acidity	(TPA)	mol/kg	C17A/1

* Full descriptions of these tests can be obtained from the Department of Land and Water Conservation’s Wellington Laboratory by quoting the laboratory code.

3.3 Final Map Preparation

Final map preparation involved the determination of the occurrence of ASS material (map class) and the depth of that material.

A map class was allocated to each landform element based on an assessment of the suitability of the geomorphic environment for PASS formation. This assessment utilised the field and laboratory data to facilitate an understanding of the complex interactions and relationships characterising ASS environments.

Determining the depth to the ASS layer utilised the relationship between the ground surface elevation and the critical elevation for the upper level of ASS occurrence, being 1 m AHD. Thus, if the surface elevation was 2 m AHD, then the depth from the ground surface to the ASS layer is about 1 m.

GLOSSARY OF TERMS

Actual Acid Sulfate Soil (AASS)

Acidic soil material resulting from the oxidation of iron sulphides. The soil material has a pH <4 (1:5 soil:water) when measured in dry season conditions and may be identified by one of the following:

- yellow mottles and coatings of jarosite (straw yellow with a hue of 2.5Y or more yellow and chroma of 6 or more)
- underlying potential acid sulfate soils
- 0.05% or more water-soluble sulfate.

May also be referred to as sulphuric materials. *See also* **potential acid sulfate soil**.

Aeolian

Deposits of soil material transported and/or arranged by wind.

Alluvial

Describes material deposited by, or in transit in, flowing water.

Anaerobic

Describes soil conditions in which free oxygen is deficient and chemically reducing processes prevail. Such conditions are usually found in waterlogged or poorly drained soils in which water has replaced soil air.

Backplain

Large flat resulting from aggradation by overbank stream flow at some distance from the stream channel and, in some cases, having peat accumulations; often characterised by a high watertable.

Backswamp

Almost level, closed or almost closed depression bounded in part by either hillslopes or dunes. Has a seasonal or permanent watertable at or above the surface.

Channel

Linear, generally sinuous open depression, in parts eroded, excavated, built up and aggraded by channelled stream flow.

Dune

Moderately inclined to very steep ridge or hillock built up by wind action.

Estuarine

Of, pertaining to, or formed in an estuary (brackish water). Relates to those soil materials that have been under the influence of brackish water during their deposition.

Geomorphology

Relating to the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of landforms.

Holocene

Refers to a geologic period of time occurring from the end of the last glacial event, about 10-12 000 years ago, to the present.

Intertidal flat

Large flat subject to frequent inundation by water that is usually salty or brackish, aggraded by tides.

Jarosite

Under strongly oxidising, severely acid conditions in acid sulfate soils, pale yellow deposits precipitate around old root channels and on ped faces. These deposits are known as jarosite. Jarosite is one of the most commonly used morphologic features to identify acid sulfate soils, although not always present.

Lacustrine

Unconsolidated surface material deposited mainly in standing water, e.g., lakes.

Lagoon

A natural closed depression filled with water that is typically salty or brackish, bounded at least in part by forms aggraded or built up by waves or reef-building organisms.

Landform Element

Part of the landform characterised by a distinctive slope, shape, size, form and the type of geomorphological processes (e.g., aeolian, alluvial) active on it.

Levee

Very long, low ridge that is immediately adjacent to a stream or river channel, built up by overbank flow.

Ox-bow

Long, curved, commonly water-filled closed depression, eroded by channelled stream flow, but closed as a result of aggradation by channelled or overbank stream flow during the formation of a meander plain.

Oxidation

To combine with oxygen resulting in the removal of one or more electrons from an atom or ion, or groups of atoms. Oxidation is important in the formation of acid sulfate soils by converting pyrite to jarosite and sulphuric acid.

pH

A measure of the acidity or alkalinity of the soil. A pH of 7.0 denotes neutrality, higher values indicate increasing alkalinity, and lower values indicate increasing acidity.

Plain

A general term encompassing large, very gently inclined or level landforms of unspecified geomorphological origin.

Pleistocene

Refers to a geologic period of time between about 2 million years ago to the start of the Holocene, 10-12 000 years ago.

Potential Acid Sulfate Soil (PASS)

Soil material which is waterlogged and contains oxidisable sulphur compounds, usually ferrous iron disulphide (pyrite, FeS_2) that has a field pH of 4 or more (1:5 soil:water) but will become severely acid when oxidised. May also be referred to as sulfidic materials. *See also* **actual acid sulfate soil**.

Pyrite

Pyrite is the cubic crystalline form of ferrous disulphide (FeS_2).

Sandplain

Level to gently undulating plain of extremely low relief and without channels; formed possibly by sheet flow or stream flow, but now relict and modified by wind action.

Splay

A fan-shaped deposit or other outspread deposit formed where an overloaded stream breaks through a levee (natural or artificial) and deposits its material (often coarse-grained) on the floodplain.

Supratidal flat

Large flat subject to infrequent inundation by water that is usually salty or brackish, aggraded by tides.

Swale

Linear, level-floored open depression excavated by wind, or a relict feature between ridges built up by wind or waves, or built up to a lesser height than them; or a long curved relict open or closed depression between scrolls built up by channelled stream flow.

Swamp

Almost level, closed or almost closed depression with a seasonal or permanent watertable at or above the surface.

Tidal creek

Intermittently water-filled open depression in parts eroded, excavated and aggraded by channelled tide-water flow; type of stream channel characterised by a rapid increase in width downstream.

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