Acid Sulfate Soils

Assessment Guidelines

NSW
Acid Sulfate Soils Management Advisory Committee
August 1998

ACID SOIL ACTION
An Initiative of the NSW Government

The Acid Sulfate Soils Assessment Guidelines is a component of the ASS Manual which forms part of an 'all of government's approach to the management of acid sulfate soils in New South Wales.

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Disclaimer

About the guidelines

The *Acid Sulfate Soils Assessment Guidelines* outline best practice in assessing the impacts of proposed works in areas likely to contain acid sulfate soils. The guidelines should be read in conjunction with the *Management Guidelines* and the *Laboratory Methods Guidelines*. These three guidelines update and expand on the *Environmental Guidelines: Assessing and Managing Acid Sulfate Soils* published by the Environment Protection Authority (EPA) in 1995. Numerous technical innovations in the sampling, assessment and management of acid sulfate soils have occurred since the publication of the EPA guidelines, in particular, standardised acid sulfate soils analytical testing protocols developed by the Acid Sulfate Soils Management Advisory Committee (Technical Committee). The ASSMAC guidelines will facilitate uniform assessment and reporting of actual and potential acid sulfate soils.

As local councils introduce planning and development controls to manage acid sulfate soils, there is an increasing need for standardised efficient procedures and methodology to ensure that the appropriate level of assessment is undertaken and that effective controls are put in place to prevent degradation of the water quality of coastal estuaries. These guidelines aim to provide information for proponents, councils, government agencies and the community to encourage sustainable development in the coastal area.

Acknowledgment

The *Acid Sulfate Soils Management Guidelines* (1998) were prepared by Col Ahern (Queensland Department of Natural Resources), Yolande Stone (Department of Urban Affairs and Planning) and Bruce Blunden (Environment Protection Authority), with technical assistance from the Acid Sulfate Soils Management Advisory Committee (Technical Committee):

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NATURAL
RESOURCES

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1. Introduction

1.1 Purpose of the Guidelines

The Assessment Guidelines have been developed primarily for proponents of activities that are likely to disturb acid sulfate soils, and for councils and government authorities responsible for assessing these proposals. The guidelines outline a stepwise process for site assessment and management of proposals in areas containing acid sulfate soils.

The guidelines recommend the adoption of best management practice in the planning, design and undertaking of activities that disturb acid sulfate soils. When intending to undertake any activities in areas where acid sulfate soils may occur, the local council and government agencies should be contacted at the outset. In most cases, gaining early assistance from soil scientists or other relevant technical experts with experience in assessing and managing acid sulfate soils can save time and money in the long term.

The guidelines set out:

- how to decide if acid sulfate soils are present on the site, if the works are likely to disturb the soils and if an acid sulfate soil management plan should be prepared because of the level of risk to the environment (Section 2)
- how to develop mitigation strategies for a particular proposal (Section 3,4, 5 and 6 in conjunction with the Management Guidelines in the ASS Manual)
- steps in the assessment and approval process and matters that should be included in an application for approval of works disturbing acid sulfate soils (Figure 1.2 and Section 7)
- matters that approval authorities should consider in making a decision in relation to works disturbing acid sulfate soils (Section 8).

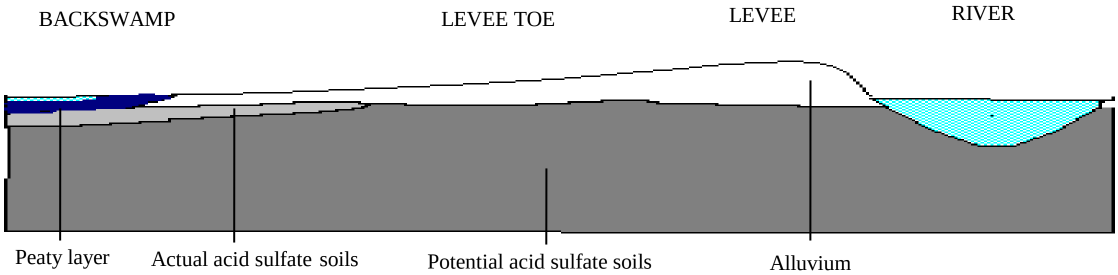
Not all the recommendations in the guidelines are relevant to all proposals. The level of assessment undertaken, or the complexity of an acid sulfate soils management plan, should match the level of risks to the environment from the proposed activity. The proponent must ensure that those matters that are relevant are considered when formulating the proposal, and are addressed in any application for an approval in relation to the proposal.

1.2 What are Acid Sulfate Soils?

Acid sulfate soils are the common name given to sediments and soils containing iron sulfides which, when exposed to oxygen generate sulfuric acid. The majority of acid sulfate sediments were formed by natural processes when certain conditions existed in the Holocene geological period (the last 10,000 years). Formation conditions require the presence of iron-rich sediments, sulfate (usually from seawater), removal of reaction products such as bicarbonate, the presence of sulfate reducing bacteria and a plentiful supply of organic matter). It should be noted that these conditions exist in mangroves, salt marsh vegetation or tidal areas , and at the bottom of coastal rivers and lakes.

The relatively specific conditions under which acid sulfate soils are formed usually limit their occurrence to low lying parts of coastal floodplains, rivers and creeks. This includes areas with saline or brackish water such as deltas, coastal flats, backswamps and seasonal or permanent freshwater swamps that were formerly brackish. Due to flooding and stormwater erosion, these sulfidic sediments may continue to be re-distributed through the sands and sediments of the estuarine floodplain region. Sulfidic sediment may be found at any depth in suitable coastal sediments – usually beneath the watertable.

Figure 1.1 Schematic cross section of a typical coastal estuary



Any lowering in the watertable that covers and protects potential acid sulfate soils will result in their aeration and the exposure of iron sulfide sediments to oxygen. The lowering in the watertable can occur naturally due to seasonal fluctuations and drought or by human intervention, in particular agricultural drainage and excavation for development. Potential acid sulfate soils can also be exposed to air during physical disturbance with the material at the disturbance face, as well as the extracted material, both potentially being oxidised. The oxidation of iron sulfide sediments in potential acid sulfate soils results in actual acid sulfate soils.

The Definition of Acid Sulfate Soils

Acid sulfate soils are the common name given to naturally occurring sediments and soils containing iron sulfides (principally iron sulfide or iron disulfide or their precursors). The exposure of the sulfide in these soils to oxygen by drainage or excavation leads to the generation of sulfuric acid.

"acid sulfate soils" include *actual acid sulfate soils* or *potential acid sulfate soils.* Actual and potential acid sulfate soils are often found in the same soil profile, with actual acid sulfate soils generally overlying potential acid sulfate soil horizons.

"*actual acid sulfate soils*" are soils containing highly acidic soil horizons or layers resulting from the aeration of soil materials that are rich in iron sulfides, primarily sulfide. This oxidation produces hydrogen ions in excess of the sediment's capacity to neutralise the acidity resulting in soils of pH of 4 or less when measured in dry season conditions. These soils can usually be identified by the presence of pale yellow mottles and coatings of jarosite.

"*potential acid sulfate soils*" are soils which contain iron sulfides or sulfidic material which have not been exposed to air and oxidised. The field pH of these soils in their undisturbed state is pH 4 or more and may be neutral or slightly alkaline. However, they pose a considerable environmental risk when disturbed, as they will become severely acid when exposed to air and oxidised.

Not all acid soils in coastal areas are acid sulfate soils. It is important to note that acidic soil and water conditions can occur with other soils that do not contain iron sulfide sediments. Organic acids (for example humic acid) are common in coastal ecosystems and can produce acid water and sediments. The pH of these sediments are usually around 4.5-5.5. As they do not have the ability to generate additional acid when exposed to air, they do not exhibit the same kinds of environmental risks that are associated with acid sulfate sediments. These guidelines only deal with acid sulfate materials.

1.3 Why are acid sulfate soils an issue?

There are increasing, often competing, demands on coastal land resources from urban development, agriculture, forestry, aquaculture, fisheries, mining and conservation. Acid sulfate soils can be a major constraint on planning at the regional and local level and on land use and development options.

Acid sulfate soils can have considerable effects on:

- engineering and landscaping works (including affecting the type of concrete or steel required, the design of roads, buildings, embankment and drainage system, extractive materials specifications, maintenance programs for drains, water and sewage pipelines and other structures)
- agricultural and tea tree management practices (including the choice of crops, liming practices, fertiliser requirements, drainage practices, laser levelling)
- aquaculture management practices (including choice of site, pond design and management practices, liming practices)
- the management of contaminated soil (particularly in relation to mobility of metals)
- the conservation of biodiversity and protection of wetlands and shallow freshwater aquifer systems (in relation to the degradation of habitat or water quality, killing or disease of fish and other aquatic organisms).

Successful management of areas with acid sulfate soils is possible but must take into account the specific nature of the site and the environmental consequences of development. While it is preferable that sites exhibiting acid sulfate characteristics not be disturbed, management techniques have been devised to minimise and manage impacts in certain circumstances. It is necessary to design cost-effective management strategies prior to undertaking the works, and to implement these at appropriate stages so that on-site and off-site impacts are managed. Consideration of alternatives should always include the “no action” or “status quo” option. In some high-risk instances, the only cost effective strategy may be to avoid disturbing acid sulfate soils.

1.4 When do the Guidelines apply?

The following activities undertaken in areas likely to affect or use coastal sediments, warrant an assessment of the risk of exposing acid sulfate soil:

- **excavation or disturbance of acid sulfate soil**
  For example: construction of roads, foundations, drainage works, laser levelling, land forming works, flood mitigation works, dams and aquaculture ponds, sand or gravel extraction, dredging. When acid sulfate materials are being excavated, attention must be given to the excavation site as well as the location where the excavated material is placed or used.
- **lowering the watertable**
  For example: new drainage works or deepening of existing drains, use of groundwater, de-watering of dams, wetlands or quarries, dredging works lowering the bed of a river
- **use of acid sulfate soil**
  For example: aquaculture pond walls, dams, flood mitigation works, imported fill material, reclamation or foreshore works
- **physical habitat modification for mosquito control**
  For example: runnelling, drainage and selective ditching to remove water or allow predatory fish access to tidal pools.

Appropriate management procedures require an understanding of acid sulfate soils, their distribution and severity as well as the nature of the proposed activity. The procedures identified in the guidelines for the assessment and management of acid sulfate soils will be regarded as a minimum requirement for environment protection and provide a basis for the formulation of approval and licence conditions.

1.5 Statutory Considerations

a. Planning controls

It is recommended that all coastal councils develop acid sulfate soil planning controls in their Local Environmental Plans (LEP) consistent with the Acid Sulfate Soils Model LEP and based on Acid Sulfate Soil Planning Maps. The Acid Sulfate Soil Planning Maps were developed by Department of Land and Water Conservation (DLWC) based on the Acid Sulfate Soils Risk Maps and identify the types of works which are likely to disturb acid sulfate soils in particular zones. The ASS Model LEP and Planning Maps recognise five classes of works based on the level of risk associated with the particular works and the probable distribution of acid sulfate soils. When proposing to undertake works likely to disturb acid sulfate soils or the associated watertable, a preliminary assessment should be undertaken and advice sought from the local council as to whether a development consent is required. Even if development consent is not required, an environmental assessment under Part 5 of the Environmental Planning and Assessment (EP&A) Act 1979 may be required.

In circumstances where no approval or consent is required, as good practice and part of a general civic responsibility for the environment, individuals or organisations undertaking works likely to disturb acid sulfate soils should follow the assessment and management procedures in these guidelines. Figure 1.1 provides a flow chart of the steps in assessing proposals.

b. If development consent is required from Council

If development consent is required, a development application must be lodged with council accompanied by either a Statement of Environmental Effects (SEE) (if not designated) or an Environmental Impact Statement (EIS) (if designated). Under the provisions of the EP&A Act, the environmental impacts of a proposal must be considered prior to development consent being granted. To determine if an EIS is required, Schedule 3 of the EP&A Regulation (1994) must be consulted. This schedule lists a number of types of developments that, if undertaken in acid sulfate soil areas, will require an EIS. In addition, if the proposal involves disturbance of an area mapped under State Environmental Planning Policy (SEPP) - No 14 Coastal Wetlands, development consent under the provisions of this policy may be required and an EIS will be triggered. If an EIS is required, advice should be sought from the Department of Urban Affairs and Planning on matters to be addressed in the EIS.

Irrespective of whether a SEE or EIS is prepared, the level of assessment of impacts from the disturbance of acid sulfate soils should match the level of risk to the environment. In both cases, the type of activity and the acid sulfate soil characteristics will affect the level of assessment, management and monitoring required.

c. If development consent is not required

If development consent is not required but an approval is required:

- for any licence, lease or any other approval under any other government legislation (such as those listed in Table 1.1); or
- for funding or financial accommodation from a public authority (this includes budgets for agency, councils, county councils and drainage unions for their own projects or maintenance programs or for projects undertaken by others funded by the public authority)

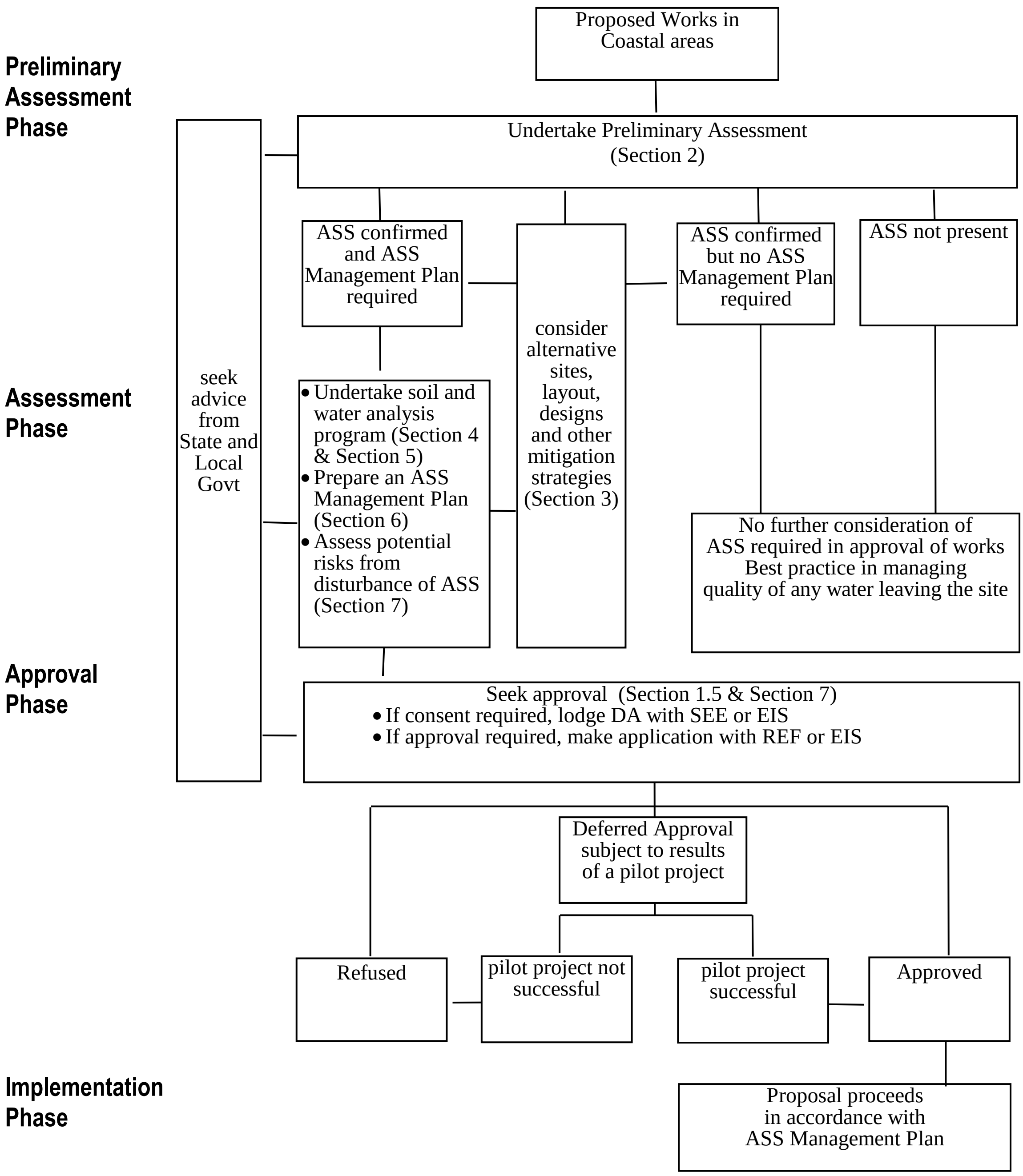
then the potential environmental impacts of granting the approval for the activity must be assessed by the responsible authority under Part 5 of the EP&A Act. Advice should be sought from the responsible authority regarding the need for an approval and the appropriate level of environmental assessment.

Usually a Review of Environmental Factors (REF) is prepared by the proponent, so that the responsible authority can decide if an EIS is required based on the factors in Department of Urban Affairs and Planning (DUAP) Guideline "*Is an EIS Required?*" (1995). If the activity is likely to significantly affect the environment, under Part 5 of the EP&A Act, an Environmental Impact Statement (EIS) must be prepared and assessed prior to the approval being granted. If an EIS is not required, the responsible authority should make a decision based on the issues assessed in the REF.

Table 1.1 Approvals that trigger the provisions of Part 5 of the EP&A Act

Legislation	*Type of activity requiring approval*	*Responsible authority*
Local Government Act 1993	• carrying out of water supply, stormwater drainage or sewerage works • connecting a private drain or sewer to a public drain or sewer controlled by council • works on public land vested in a council	Council
Rivers & Foreshores Improvement Act 1948	• works within 40 metres of the high bank of a natural waterbody	DLWC
Water Act 1912	• the extraction of water from a natural waterbody • installation of wells or bores or extraction of groundwater	DLWC
Crowns Land Act 1989	• works on public land (eg road reserves, the bed of most rivers or estuaries or other Crown land)	DLWC
Protection of the Environment Operations Act 1997 and related pollution control legislation	• works that are likely to discharge pollutants into natural waterbodies. A pollution control approval or licence provides for licensing of activities that are likely to pollute the waters	EPA
Fisheries Management Act 1995	• works involving dredging • works likely to affect fish habitat • install or maintain floodgates	NSW Fisheries
Any Act	• approval of funding or financial accommodation by a public authority for any "activities" undertaken by the authority or by others (such as capital works, maintenance programs, grants etc by government agencies, councils, county councils or drainage unions)	Relevant authority eg Council, Drainage Union, County Council, DLWC

Figure 1.2 Flowchart for assessment of proposals affecting Acid Sulfate Soils



2. The Preliminary Assessment

When works involving the disturbance of soil or the change of groundwater levels are proposed in coastal areas, a preliminary assessment should be undertaken to determine whether acid sulfate soils are present and if the proposed works are likely to disturb these soils. The purpose of the preliminary assessment is:

1. to establish the characteristics of the proposed works
2. to establish whether acid sulfate soils are present on the site and if they are in such concentrations so as to warrant the preparation of an acid sulfate soils management plan (and trigger the need for development approval if an ASS LEP applies)
3. to provide information to assist in designing a soil and water assessment program
4. to provide information to assist in decision making

The steps in a preliminary assessment are set out in Figure 2.1.

2.1 Establish the general parameters of the proposed works

At this preliminary stage, the general parameters of the proposed works should be described so as to ascertain whether the works are likely to affect acid sulfate soils if they are present.

i) Earthwork issues

If earthworks are to be undertaken, then the depth and nature of the disturbance should be identified. At this stage the principle issue with regard to triggering the need for a management plan and development consent is "*what is the depth of disturbance of the soil*". Other factors described below should also be considered at this early stage in relation to developing mitigation strategies:

- What is the volume of the soil to be disturbed?
- What is the depth of disturbance of any construction or operational works
- Is the disturbance likely to be short term or permanent? Can the disturbance be staged so as to minimise exposure of disturbed soil to the air?
- How are the disturbed area and any excavated soils to be managed in the short or long term? Do the landscape or soil characteristics make mitigation easy or difficult? Is there sufficient area available to undertake any mitigation treatment? Can any leachate be easily contained and neutralised?
- Is there an existing acid sulfate soil problem in the area? Will the proposed works improve or exacerbate the problem in the short or long term? Is there information available on oxidisable sulfur values from other adjoining or local areas? Will they exceed the Action Criteria (Table 4.4)?

ii) Groundwater issues

At this stage of the preliminary assessment, the other principle issue with regard to triggering the need for an management plan and development consent is "*is the groundwater level likely to be lowered and by how much".* In coastal areas where there are acid sulfate soils and shallow groundwater, altering the watertable (as a direct or indirect outcome of the proposed activity) can result in oxidation of the sulfidic material and acidification of both surface and groundwater.

Depending on the works, a temporary or permanent lowering of the watertable may result. It can be assumed that any of the following types of works undertaken in areas mapped as Class 1-3 on the Acid Sulfate Soils Planning Maps will have an effect on acid sulfate soils and should be considered in the assessment of impacts:

- the use of groundwater from shallow aquifers or changes to groundwater recharge areas
- the construction or modification of drains, floodgates, levees and barrages

- dredging or other changes to rivers flow patterns
- dewatering of quarries or major construction sites

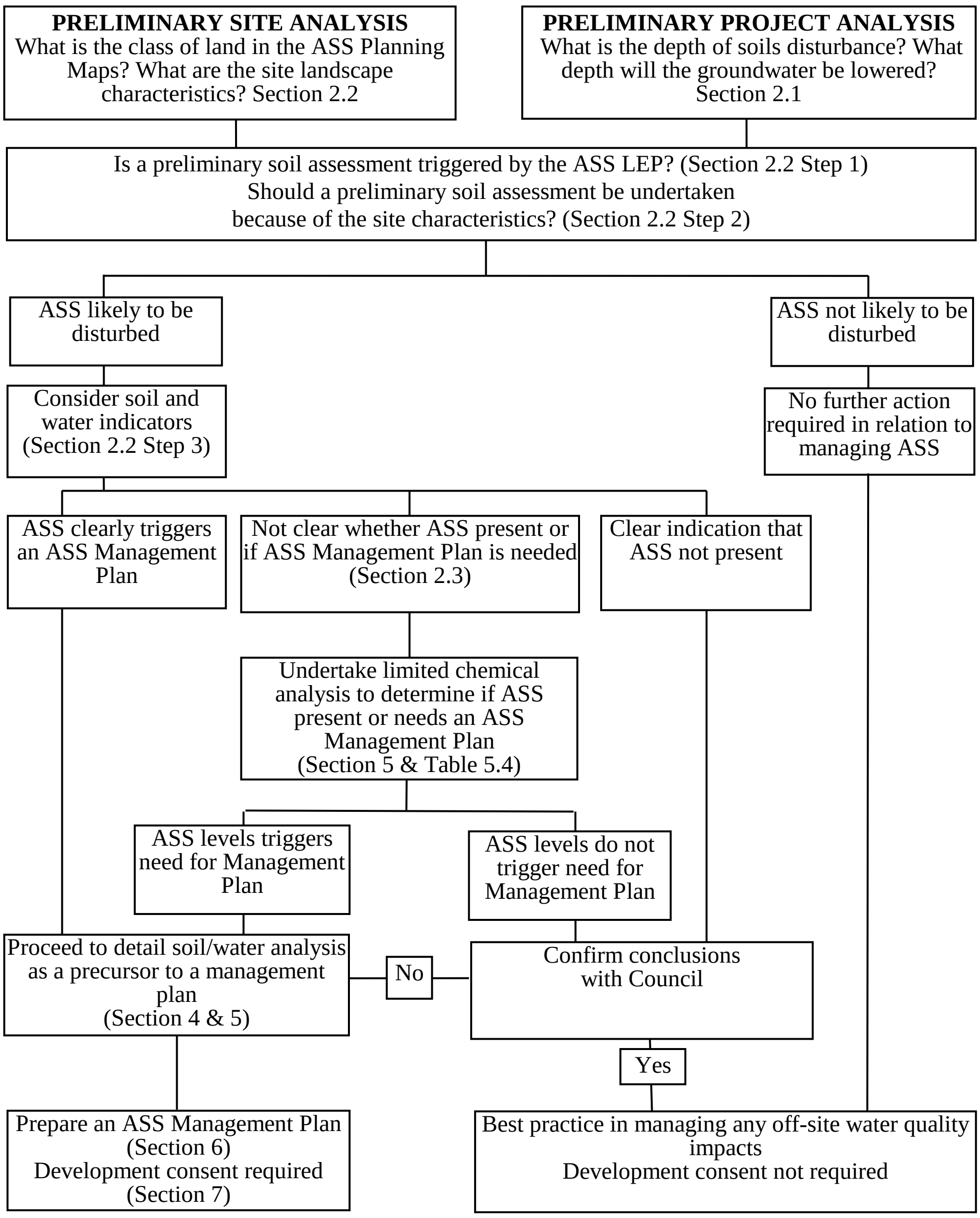
For works in areas mapped as Class 4 or as Class 5 (within 500 metres of Class 1-4 areas), a preliminary hydrology study should be undertaken to determine if the activity is likely to affect the groundwater levels.

A Preliminary hydrology study should consider:

- current groundwater depth and flow direction in relation to any acid sulfate soils in the vicinity
- the likely draw-down rate as a result of the activity
- the resulting permanent or temporary change in the watertable depth.

Works within 500 metres of adjacent Class 1,2, 3 or 4 land which are likely to lower the watertable to below 1 metre AHD in adjacent Class 1,2, 3 or 4 land, will normally require a management plan and development consent from council.

Figure 2.1 Preliminary Assessment Phase



2.2 Establish whether acid sulfate soils are present on the site

Reference to acid sulfate soils planning maps should be the first step in any investigation. This information should be supported by field tests, soil and water sampling and laboratory analysis to validate the likely environmental risks of undertaking the proposal. A desktop study should always be undertaken prior to proceeding to field assessments or soil and water analysis. This study can assist in designing an efficient investigation so there will be a high level of confidence with the results.

Step 1: Check the acid sulfate soils maps

As a first step, Acid Sulfate Soils Planning Maps should be consulted to determine if the works will be undertaken in an area where there are known acid sulfate soils risks. In 1995, the Department of Land and Water Conservation (DLWC) published Acid Sulfate Soils Risk Maps for NSW coastal areas that identified where acid sulfate soils may be found with a high, low or zero probability. In 1998, these risk maps were updated by DLWC and adapted for planning purposes.

The Acid Sulfate Soils Planning Maps establish five classes of land (see Table 2.1) based on the probability of the acid sulfate soils being present. The Acid Sulfate Soils Planning Maps are available from the regional offices of DLWC in digital and paper form. Local councils should have copies of both types of maps for their area.

Table 2.1 Classification scheme in the Acid Sulfate Soils Planning Maps

Class of land as shown on Acid Sulfate Soils Planning Maps	***Works***
1	Any works
2	Works below natural ground surface Works by which the watertable is likely to be lowered
3	Works beyond 1 metre below natural ground surface Works by which the watertable is likely to be lowered beyond 1 metre below natural ground surface
4	Works beyond 2 metres below natural ground surface Works by which the watertable is likely to be lowered beyond 2 metres below natural ground surface
5	Works within 500 metres of adjacent Class 1, 2, 3, or 4 land which are likely to lower the watertable below 1 metre AHD on adjacent Class 1, 2, 3 or 4 land.

The maps do not describe the actual severity of acid sulfate soils in a particular area but provide a first indication that acid sulfate soils could be present on the site. For each class of land, the maps identify the type of works likely to present an environmental risk if undertaken in the particular class of land. If these types of works are proposed, further investigation is required to determine if acid sulfate soils are actually present and whether they are present in such concentrations as to pose a risk to the environment. If the concentration meets or exceeds the "*action criteria*" in Table 4.4, an acid sulfate soils management plan must be prepared and development consent must be obtained from council.

Action following Step 1:

- If the works are in an area identified in the ASS Planning Maps as presenting a risk to the environment, and the works are likely to disturb these soils proceed to Step 3. Step 2 can help confirm if ASS are in the mapped area and identify areas of highest risk.
- If the works are near to any area mapped as having a risk of acid sulfate soils being present, proceed to Step 2 to confirm that acid sulfate soils are not likely to be present based on geomorphic or site criteria.
- If the works are not in or near a mapped area, proceed without further consideration of acid sulfate soils.

Step 2: Check to see if the area meets the geomorphic or site criteria

Due to the scale of the acid sulfate soils maps and the local variability (associated with the processes under which acid sulfate soils was formed or deposited), some Class 3, 4 and 5 areas in the Acid Sulfate Soils Planning Maps which have been mapped as having lower risks of acid sulfate soils being present, may have deposits or lenses of highly sulfidic material. If a proposal is to be undertaken in these areas, a desktop assessment should be undertaken to check if the location meets the geomorphic or site description criteria outlined below. This step provides a quick backup procedure to the maps to ensure that areas where acid sulfate soils may occur (but were missed in the mapping process because of local variability) are not inadvertently disturbed without appropriate management measures.

As a precursor to considering these criteria, a site description should be compiled from topographic maps and/or aerial photographs. As a minimum, a site description should include a delineation of the area to be disturbed on an appropriately scaled map. Further information from maps describing the soil landscapes/attributes, geology, hydrogeology/groundwater, tidal limits, vegetation communities and topography could also be used to provide a preliminary evaluation of the site. A recent colour or high quality black and white aerial photo will assist in identifying vegetation communities and other site characteristics.

The following geomorphic or site criteria should be used to determine if acid sulfate soils are likely to be present:

- sediments of recent geological age (Holocene)
- soil horizons less than 5 m AHD
- marine or estuarine sediments and tidal lakes
- in coastal wetlands or back swamp areas; waterlogged or scalded areas; interdune swales or coastal sand dunes (if deep excavation or drainage proposed)
- in area where the dominant vegetation is mangroves, reeds, rushes and other swamp-tolerant or marine vegetation such as swamp mahogany (*Eucalyptus robusta*), paperbark (*Melaleuca quinquenervia*) and swamp oak (*Casuarina glauca*)
- in areas identified in geological descriptions or in maps as bearing sulfide minerals, coal deposits or former marine shales/sediments (geological maps and accompanying descriptions may need to be checked)
- deep older estuarine sediments >10 metres below ground surface, Holocene or Pleistocene age (only an issue if deep excavation or drainage is proposed).

Action following Step 2:

- If the proposal is likely to disturb areas which meet any of the criteria (or are mapped as having a probability of acid sulfate soils being present), soil and water indicators (step 3) should be checked to determine if acid sulfate soils are likely to be present.
- If activities are proposed in locations which do not meet these geomorphic or site criteria and are not in areas mapped as class 1-4 on the planning maps, proponents can be confident that acid sulfate soils will not be present in the landscape. Soils of older geological age or those not derived from sedimentary deposition can be excluded from further investigation (unless very deep disturbance is proposed).

Table 2.2 provides a summary of the preliminary "desktop" assessment to this point. If the proposed works are in an area mapped as possibly having acid sulfate soils, the proponent can agree that there are acid sulfate soils present which meet the "action criteria" and proceed to preparing a management plan and obtaining development consent. Or the proponent can undertake soil and water analysis to determine whether acid sulfate soils are present and if they occur in such concentrations as to warrant the preparation of a management plan and hence trigger the need for development consent.

Table 2.2 Summary of typical desktop assessment options and outcomes

Location of works likely to disturb ASS with reference to ASS Planning Maps	*Assessment options and outcomes*
In a mapped area Class 1-4 and high probability of acid sulfate soils being present based on geomorphology	accept that there will be disturbance of acid sulfate soils, and proceed to assess the potential impacts of disturbing acid sulfate soils prior to developing a management strategy (and obtaining development consent)
In a mapped area Class 1-4 but a lower probability of acid sulfate soils being present based on geomorphology	undertake Step 3 and 4 to verify whether acid sulfate soils are present on the land in question and whether a management plan is required or not. • If not, proceed with the proposal. • If an acid sulfate soils management plan is required, proceed to assess the potential impacts of the activity prior to developing a management strategy (and obtaining development consent)
In an area mapped Class 5 and within 500 metres of an adjacent Class 1-4 land and involving an activity likely to affect groundwater of adjacent Class 1-4	undertake Step 3 and Step 4 to verify whether acid sulfate soils are present or not on the land in question or the adjacent Class 1-4 land. • If not present, proceed with the proposal • If acid sulfate soils are present, proceed to assess the potential impacts of the activity prior to developing a management plan (and obtaining development consent)
Not in any of the above mapped areas but a probability of acid sulfate soils being present based on landscape characteristics	undertake a Step 3 and Step 4 to verify whether acid sulfate soils are present or not. • If acid sulfate soils are present and a management plan is justified, proceed to assess the potential impacts of the activity prior to developing a management plan

Step 3: Analyse soil and water indicators

The investigation should include a field inspection to consider soil and surface and sub-surface water characteristics and if necessary, limited groundwater analysis (Melville et al 1996). The landscape analysis undertaken at Step 2 should be used to ensure that a thorough examination is undertaken of the areas most likely to have acid sulfate soils.

Table 2.3 Deciding if acid sulfate soils are present based on soil or water field indicators

Soil type	*Indicators*
acid sulfate soils	*Landscape characteristics* • dominance of mangroves, reeds, rushes and other marine/estuarine or swamp-tolerant vegetation • low lying areas, back swamps or scalded/bare areas in coastal estuaries and floodplains • sulfurous smell after rain following a dry spell or when the soils are disturbed
actual acid sulfate soil	*Soil characteristics* • field pH ≤4 in soils (see Appendix 1) • presence of shell • any jarositic horizons or substantial iron oxide mottling in auger holes, in surface encrustations or in any material dredged or excavated and left exposed. Jarosite is a characteristic pale yellow mineral deposits which can be precipitate as pore fillings and coatings on fissures. In the situation of a fluctuating watertable, jarosite may be found along cracks and root channels in the soil. However, jarosite is not always found in actual acid sulfate soils. *Water characteristics* • water of pH < 5.5 in adjacent streams, drains, groundwater or ponding on the surface • unusually clear or milky blue-green drain water flowing from or within the area (aluminium released by the acid sulfate soils acts as a flocculating agent.) • extensive iron stains on any drain or pond surfaces, or iron-stained water and ochre deposits *Landscape and other characteristics* • scalded or bare low lying areas • corrosion of concrete and/or steel structures.
potential acid sulfate soils	*Soil characteristics* • waterlogged soils - unripe muds (soft, buttery, blue grey or dark greenish grey) or estuarine silty sands or sands (mid to dark grey) or bottom sediments of estuaries or tidal lakes (dark grey to black) • presence of shell • soil pH usually neutral but may be acid - positive Peroxide Test (see Appendix 1) *Water characteristics* • water pH usually neutral but may be acid

i) Field soil and water characteristics as indicators of acid sulfate soils

As many of the indicators for actual and potential actual acid sulfate soils are quite different, the field inspection should investigate for the presence of both soils. Commonly actual acid sulfate soils are found overlaying potential acid sulfate soils and both are usually covered by non-acid sulfate alluvial topsoil.

If soils or associated waterbodies demonstrate one or more of the following indicators in Table 2.3, it can be assumed acid sulfate soils are present and a full assessment should be undertaken. Soil field pH provides a useful quick indication of the likely presence and severity of “actual” acid sulfate soils. In undertaking field pH testing at this preliminary assessment phase, as a minimum, the sampling frequency should be similar to that outlined in Section 4.1 with a concentration of testing in areas where the site characteristics indicate that acid sulfate soils may be present.

Field pH readings should be taken at regular intervals down the soil profile.

- pH readings of pH ≤4, indicates that actual acid sulfate soil are present with the sulfides having been oxidised in the past, resulting in acid soils (and soil pore water).
- pH readings of pH >4 may indicate the absence of "actual" acid sulfate soils but does not give any indication as to the presence of "potential" acid sulfate soils.

In order to test for "potential" acid sulfate soils which contain unoxidised sulfides, 30% hydrogen peroxide is used to rapidly oxidise the sulfide, resulting in the production of acid with a corresponding drop in pH. Appendix 1 provides more details on the Peroxide Test and the use of field pH results as an indicator of the presence of acid sulfate soils.

A positive peroxide test may include one but preferably more of the following:

- change in colour of the soil from grey tones to brown tones
- effervescence
- the release of sulfur smelling gases such as sulfur dioxide or hydrogen sulfide
- a lowering of the soil pH by at least one unit
- a final pH < 3.5 and preferably pH <3.

ii) Groundwater analysis as indicators of acid sulfate soils

The analysis of groundwater or drain water for the soluble chloride: soluble sulfate (Cl^-:SO_4^{2-}) ratio can indicate that sulfidic material in the vicinity of the site is being, or has been, oxidised. In order to undertake this test, water samples should be submitted for laboratory analysis. The location of each borehole or sampling site should be clearly marked on a map with grid references for each sample site and elevation (m AHD).

As seawater has a SO_4^{2-} concentration of approximately 2,700 mg/L and Cl^- concentration of approximately 19,400 mg/L, the ratio of $Cl^{1-}SO_4^{2-}$ on a mass basis is 7.2. As the ratios of the dominant ions in saline water remains approximately the same when diluted with rainwater, estuaries, coastal saline creeks and associated groundwater can be expected to have similar ratios to the dominant ions in seawater (Mulvey, 1993). Where the analysis indicates that there is an elevated level of sulfate ions relative to the chloride ions, these results provide a good indication of the presence of acid sulfate soils in the landscape. A Cl^-:SO_4^{2-} ratio of less than four, and certainly a ratio less than two, is a strong indication of an extra source of sulfate from previous sulfide oxidation (Mulvey, 1993).

Caution must be exercised in interpreting Cl^-:SO_4^{2-} ratio results. The Cl^-:SO_4^{2-} ratio becomes less predictive in freshwater or as brackish water approaches that of freshwater. Care must also be taken with the interpretation of data in tropical areas during the wet season or where large freshwater inputs occur. With groundwater, as the layer supplying most of the water within a hole will influence the final analysis outcomes, properly installed 'nested' piezometers, accessing particular strata or horizon/depth intervals, will assist in overcoming sampling limitations and improve the reliability of results (Mulvey 1997). The Groundwater Guidelines in the ASS Manual should be consulted for the correct installation, sampling and monitoring of groundwater.

iv) Microscopic soil analysis

Soil suspensions/slurries can be examined under a microscope for sulfide framboids and individual crystals. As a further confirmation, the reaction of the sulfide to peroxide can be observed on the slide. If effervescence is observed, this provides a positive test to confirm the presence of sulfide. However, failure to see crystals or framboids is not evidence that sulfide is absent as sulfidic crystals may have been lost in the sampling or slide preparation. Caution is required with the use of this technique as it requires acquired skills. False positives are common when high levels of organic material or manganese are present.

v) Consideration of preliminary soil, water and groundwater indicators

In making a preliminary determination as to whether acid sulfate soils are present or not, all field soil and water indicators, the peroxide test results and any groundwater Cl^-: SO_4^{2-} ratio results must be considered in combination to arrive at an interpretation. Table 2.4 contains a summary of the likely outcomes and the possible interpretation of the results and suggests when further investigations may be required to clarify the presence or absence of acid sulfate soils. There are circumstances where these general indicators do not apply because of the soil, geology or water characteristics.

Table 2.4 Deciding if acid sulfate soils may be present based on soil and water indicators

Field pH of water	*Water analysis Cl^{1-}:SO_4^{2-} (by mass)*	*Field soils or water indicators*	*Typical soil reaction to 30% H_2O_2*	*Preliminary Assessment*
6-8	approx 7 but may be between 5-9	nil	nil reaction and no drop in pH	no sulfidic material present
		ASS indicators	mild to strong effervescence and drop in pH	sulfide present but probably has not been oxidised at any time
<5	approx 7 but may be between 5-9	nil	nil reaction and no drop in pH	no sulfidic material present and low pH can be attributed to other causes
		ASS indicators	mild effervescence and drop in pH	sulfide has probably not been oxidised at any time and low pH can be attributed to other causes
6-8	2 - 5	unclear indicators	mild effervescence and drop in pH	presence of sulfidic material is uncertain; must be verified by chemical analysis or visual observation of crystals
	<2	indicators of actual or potential ASS	mild to strong effervescence and drop in pH	presence of sulfidic material plus the presence of a buffering agent
< 5	2 - 5	unclear indicators	mild effervescence and drop in pH	presence of sulfidic material is uncertain; must be verified by chemical analysis or visual observation of crystals
< 5	<2	indicators of actual or potential ASS	mild to strong effervescence and drop in pH	presence of sulfidic material with little buffering agent

Action following Step 3:

- If based on the indicators in Table 2.3 and 2.4, it is clear that acid sulfate soils
  - are present, proceed to chemical analysis to determine the likely level of risk or assume the risks are high and proceed with preparing a management plan (section 4, 5 and 6). Table 4.4 will assist with determining if *action criteria* are exceeded and Table 4.5 will assist with determining the treatment category.
  - are not present, proponents can proceed with the works without further consideration of acid sulfate soil management considerations. If the works are of the type that are identified in the ASS Planning Maps as requiring preliminary investigation, a copy of the preliminary assessment and a letter from Council agreeing with the conclusion must be obtained prior to undertaking the works.
- If based on the indicators in Table 2.3 and 2.4 it is not clear one way or the other that acid sulfate soils are present, proceed with limited chemical analysis to determine the likely presence of sulfidic material.

Step 4 Chemical analysis to confirm acid sulfate soils and "action levels"

Section 5 of the Guidelines provides the details for soil sampling, analysis and interpretation of the results. At this stage a full sampling and analysis program may not be warranted. However representative sampling should be taken in all areas identified in Step 2 or Step 3 as having the highest probability of acid sulfate soils being present. Judgement will need to be exercised in deciding how many samples will be needed to provide proof that a management plan is required or not. In making a decision, the risks associated with the type of disturbance proposed should also be taken into consideration.

Samples for analysis should be selected from the profiles that have:

- the lowest pH
- highest drop in pH after oxidation
- soil containing jarosite or iron mottling
- dark grey/green muds or dark grey sands from below the water table

Chemical analysis of these samples should be undertaken to ascertain if sulfidic material is present and the oxidisable sulfur concentrations. Ascertaining which soil layers are clear of acid sulfate soils is just as important as finding those with a problem. Table 4.4 sets out the "*Action Criteria*" which triggers the need for a management plan to be prepared.

2.3 Reporting on the Preliminary Assessment

In justifying the conclusion that acid sulfate soils are present or absent from the site and if present, whether they occur at such concentrations to justify the preparation of a management plan, the preliminary assessment should document the field investigations and any analysis undertaken. The preliminary assessment should report on the following:

- the characteristics of the proposed works and the likelihood of them disturbing acid sulfate soils or lowering the groundwater
- the physical characteristics as well as the pH for soil and groundwater tabulated by depth. The location of each borehole or sampling site should be clearly marked on a map with grid references and height (m AHD)
- the reaction to peroxide and pH after peroxide oxidation
- if water analysis is required as an indication of the presence or absence of acid sulfate soils, the pH and ratio Cl^{1-}:SO_4^{2-} concentrations for each borehole site
- if groundwater hydrological studies are required as an indication of the likely impacts of lowering of the watertable on acid sulfate soils, the piezometer locations and depths and any flow analysis are required.

Table 2.5 provides a summary of matters that should be considered to draw conclusions with regard to acid sulfate soils. Not all matters will need to be investigated for sites.

If works are identified in an ASS Planning Map as requiring a preliminary assessment, and the investigation concludes that acid sulfate soils will not be disturbed, then a management plan and development consent is not required. After the proponent has completed the preliminary assessment and ascertained that an acid sulfate soils management plan is not required, they must present their preliminary assessment to their local council seeking agreement with their decision. If council agrees in writing that an acid sulfate soils management plan is not required, then a development application is not required. If not, then the proponent must submit an acid sulfate soils management plan and obtain development consent prior to undertaking the works.

Table 2.5 Report on the Results of Preliminary Assessment

Characteristics	***Sample no***	***Sample no***	***Sample no***	***Sample no***	***Sample no***	***Sample no***
Location or bore site						
Map class						
Landscape characteristics						
Depth						
Field indicators						
pH - field						
peroxide reaction						
pH after peroxide						
$Cl^-:SO_4^{2-}$ ratio (if necessary)						
Pyrite crystals (if necessary)						
Soil analysis S% (confirmation)						
Initial Assessment Of Soils						

Based on the preliminary assessment, a decision can be made as to whether acid sulfate soils are likely to be disturbed and the risks to the environment from that disturbance.

- If there is sufficient certainty that acid sulfate soils will not be disturbed, no further assessment will be required. It should be noted that in most circumstances, some laboratory analysis will be required to confirm the absence of acid sulfate soil in an area which has been mapped as having a risk of acid sulfate soils being present.
- In areas where an ASS LEP applies, the person must submit to Council prior to undertaking the works, a copy of the preliminary assessment justifying the conclusion that "no acid sulfate soils management plan is required". No work should proceed until a letter has been received from council agreeing with the conclusion. It should be noted that Council is likely to respond more quickly if the preliminary assessment is undertaken in a systematic manner as set out in this guideline and some laboratory analysis is undertaken to confirm the "action levels" are not triggered.
- If there is still a level of uncertainty or if it is clear that an acid sulfate soils management plan is required, more detailed investigations will be required.
- Before proceeding to the expense of more detailed investigations, mitigation strategies should be considered which may result in disturbance being avoided or reduced.

3.

Applying the mitigation principles to manage potential impacts

3.1 Early consideration of alternatives

All alternative approaches that present the lowest risk to the environment should be considered at the preliminary investigation phase prior to finalising the design of the proposal. Where possible the project should be designed or redesigned to minimise the disturbance of acid sulfate soils. If an evaluation of the soil attributes indicates areas of high sulfide concentration (hot spots) where the impacts may be difficult to manage, consideration should be given to reconfiguring the proposal to avoid these areas as much as possible.

In the early stages of the project design and environmental assessment, it will be cost effective to consider:

- *alternative sites.* For example, if an aquaculture project is proposed at a site with high acid sulfate soils potential, consideration should be given to alternative sites where the ongoing acid sulfate soils management costs would be less of an issue.
- *alternative uses of the land*. For example, if an urban subdivision is proposed on land that contains acid sulfate soils, consider reserving the highest risk areas for environmental protection and not disturbing them.
- *alternative site layouts.* For example, when identifying routes for pipelines or roads, avoid hot spot areas especially if close to wetlands or areas where the management of any acid generated, as a result of construction works, could be difficult.
- *alternative management strategies.* For example, with farm management, consider laser levelling with alternative drainage designs, liming rates, vegetation types or cropping rates.
- *alternative drainage and flood design or management strategies*. For example, consider wider shallower drains, alternative design of levees or floodgates or alternative operation regimes for the floodgates during variable flow conditions.
- *alternative groundwater use or management strategies*. For example, consider using alternative sources of water rather than groundwater, or alternative operation of floodgates or levee levels to maintain existing groundwater levels.
- *alternative sources of extractive material.* For example, consider the use of clean imported fill rather than acid sulfate soils sourced on site.

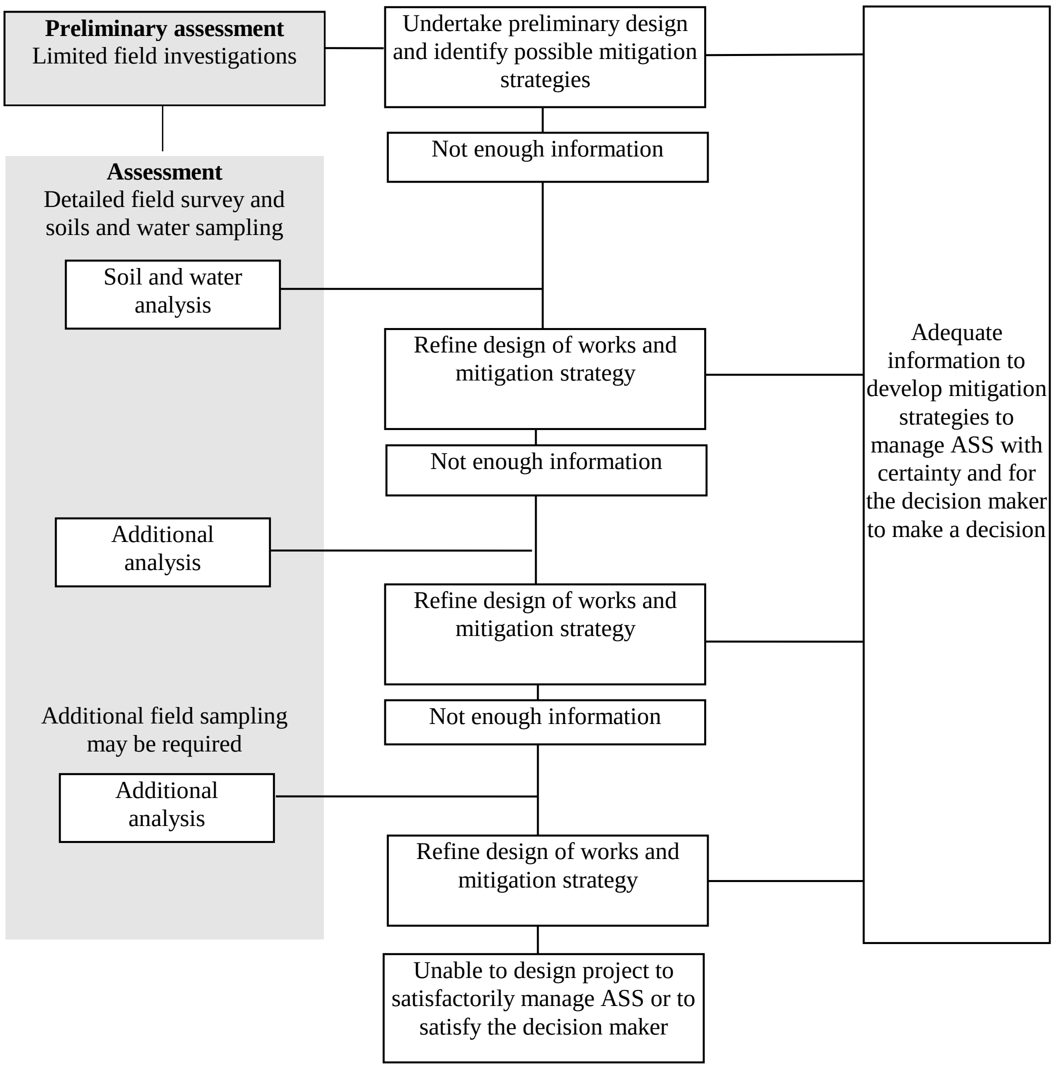
While all the mitigation strategies in Management Guidelines in the *ASS Manual* and others are theoretically possible, some are largely unproven and often have practical difficulties when implemented on a large scale or with marine mud/clay soils. It should be noted that if a proposed mitigation strategy is largely unproven or potentially higher risk, site specific experiments or pilot projects will be required prior to proceeding with the mitigation strategy. The pilot study (and full project if approved) will have an ongoing requirement for close site supervision, extensive bunding on the site and a long term monitoring program.

When making decisions regarding assessment of and selection of project options, consideration should be given to the principles of Ecologically Sustainable Development (ESD) and best practice environmental management. In particular, with regard to the precautionary principle, where there are risks to the environment, careful evaluation should be given to avoiding wherever practicable, serious or irreversible damage to the environment. In these circumstances, a full assessment of the risk-weighted consequences of various options should be undertaken prior to proceeding with design and implementation of the proposed works.

3.2 Staging the assessment while developing mitigation strategies

Following the preliminary assessment, a more detailed soil and water analysis program is required to understand the nature of the acid soil properties and to appreciate the extent of risk from undertaking the proposed works. This will facilitate the development of feasible mitigation strategies. Alternative mitigation strategies should be evaluated as early as possible, so an appropriate soil sampling and assessment program can be developed. Development of these alternative mitigation strategies should be an adaptive process in response to soil and water analysis information and any trials undertaken (Figure 3.1). For larger projects especially in high risk areas or those involving new or untested mitigation options, it may be appropriate to stage the assessment program so that an appropriate level of information is available for the level of detail required for the feasibility study and design development.

Figure 3.1 Staging the assessment to provide information for the design of the project



3.3 Identifying the level of potential risk

Table 3.1 has been developed to assist in identifying the likely level of risk associated with a proposal. The higher the level of risk, the more detailed the soil and water field survey and the more intense the analysis program. The table provides an indication only of the types of factors that should be considered. No attempt should be made to tally-up scores but a professional opinion can be made on the basis of these factors about the potential significance of the likely impacts.

To fully understand the risks for disturbing a site, a soil survey should be undertaken with soil and water analysis as described in section 4 and 5. Once these assessments have been completed, costs and benefits of management options can be fully evaluated.

Table 3.1 Early indication of the likely environmental risks from proposed works

	LEVEL OF ENVIRONMENTAL RISK			
FACTORS IN DECIDING THE LEVEL RISK	*nil or positive*	*low risk*	*increasing risks*	*high risks*
❑ volume of material to be disturbed	< 1 tonne	1- 10 tonne	11- 50	> 50 tonne
Project ranking				
❑ Distance between acid sulfate soils and depth of disturbance	>2 metres	>1 metres	0.5 - 1 metres	0 metres
Project ranking				
❑ change of surface drainage	nil or reduction in depth of existing drains	shallow drainage well above the level of acid sulfate soils	mid level drains within 0.5 metres of acid sulfate soils	deep drains
Project ranking				
❑ duration of disturbance	nil	< 1 day	1-7 days	>7 days
Project ranking				
❑ level of certainty with mitigation strategy	no mitigation as no disturbance	high certainty with method	certainty with method but in clay soils	method untested
Project ranking				
❑ likely severity of acid sulfate soils based on peroxide reaction and final pH	nil pH>4.5	mild after 5 minutes pH <4.5	medium pH <3.5	vigorous pH<3
Project ranking				
❑ connection to natural waterbodies or wetlands	nil	Areas totally bunded to prevent untreated discharge	Levees or flood gates provide some control	Connected directly to creek, drain, wetlands or near wetlands
Project ranking				

4. Designing a soil assessment program

4.1 Designing a soil sampling or monitoring program to understand and manage the risks

If the preliminary assessment confirms the presence of acid sulfate soils on the site, a sampling program should be designed to understand the extent and characteristics of the soils. If the soils sampling program establishes that a management plan is required, additional soil surveying and sampling may be required to provide information to develop a management strategy. The level of investigation will depend on the characteristics of the site particularly site variability, the type of disturbance proposed and the sensitivity of the surrounding environment. The resulting soil sampling and laboratory analysis will also provide baseline data for any monitoring program.

The onus is on the proponent to justify that sufficient sampling has been undertaken to understand and manage the site without causing environmental harm. Many proposals have site specific issues that are not possible to cover in generic guidelines. Early consultation with relevant technical experts and government authorities helps to reduce later delays because of inadequate or technically unsound assessment or management strategies.

It can often be cost efficient to stage the soil investigation for large or complex projects. When the results of the initial sampling and analysis are known, the sampling program can be refined so the most efficient and cost effective sampling regime can be developed to complete the acid sulfate soil assessment. Consultation with key government authorities at this stage can assist in focusing the investigations.

a. Number of soil sampling sites

The location of each borehole or sampling site must be clearly marked on a map or overlaid on an aerial photograph. Grid references for each sample site and elevation (m AHD) must be documented.

The frequency of sampling and inspection locations should conform to the Australian Soil and Land Survey Handbook (McDonald et al., 1990). The number of sampling points will depend on the area of land and variability of soil characteristics, but should give a comprehensive coverage of the area. It is important to structure the sampling regime to take into consideration the intended future landuse. Professional judgement will be necessary to ensure the sampling programs identify any actual or potential acid sulfate soil "hot spots" on the site.

Table 4.1 Minimum number of sampling holes

Area of site	*Number of holes*
Up to 1 ha	4 holes
1-2 ha	6 holes
2-3 ha	8 holes
3-4 ha	10 holes
> 4 ha	2 holes/ha

The following general principles for soil sampling relating to extensive, linear and dredging projects are set out below.

i) Extensive projects

For projects proposing to disturb a large area of acid sulfate soils (eg. subdivisions, agriculture, golf courses, highway construction) sampling should cover the whole area with intensive sampling in areas of significant soil disturbance, high environmental sensitivity and areas of likely high sulfide concentrations. As a guide for extensive developments, the minimum number of sampling holes/profiles sufficient to characterise the acid sulfate soils constraint is described in Table 4.1. However, additional samples may need to be taken in areas of more intensive disturbance or in potential hot spots. In these areas, sampling may be required on a 50-75 metre grid. This sampling intensity is not expected on areas of the site where the likelihood of acid sulfate soils occurring is low eg located above 5 m AHD or soils on hard rock. However, justification for reduced sampling intensity and some confirmatory sampling and laboratory analysis will still be required for these areas.

ii) Linear projects

Where disturbance of the acid sulfate soil will be confined to a linear path (eg. services trench, narrow road, drain), soil profiles should be sampled along the line of the disturbance where the proposal will affect acid sulfate soils, in for example, every 50 to 100 metre intervals, depending on the soils characteristics and type of disturbance. Sampling should also target likely "hot spots" or sensitive areas. In addition, some linear developments (eg, major roads or drains) can severely affect groundwater regimes requiring soil sampling well beyond the area impacted by soil disturbance. In these cases, sampling as for extensive projects may be more appropriate.

iii) Dredging projects

Sampling of material to be dredged from coastal rivers, lakes, dams and wetlands should be undertaken according to the transect spacing described above. Samples should be collected to at least one (1) metre below the maximum depth of expected material extraction, ensuring that samples from all sedimentary layers are included. Careful attention must be paid in collecting underwater sediment samples to ensure that all sediment particle sizes are collected. The fine silt and clay fraction of the dredged material may contain high concentrations of sulfide but this material can easily drain from the sample during collection. In some wet dredging operations, acid sulfate material (usually silt and clay) can separate from the bulk material (sand) during stockpiling. Assessment of such dredged material may require that the constituent fractions of the resource be separated and tested accordingly. Interpretation of soil analysis on the dredge material may be complicated due to the neutralising influences of shell or seawater in the sample.

b. Sampling depth

The depth of investigation should usually be at least one (1) metre beyond the depth of the proposed excavation or the estimated drop in watertable height, or to a minimum two (2) metres below the land surface, whichever is the greatest.

Professional judgement will be necessary to ensure the sampling program provides representative and adequate samples to understand the risks and to develop a management strategy.

Soil samples should be collected for every soil layer or every half (0.5) metre. The depth of the sample within the layer must be recorded, along with the upper and lower horizon depths. Where distinct soil layers or horizons occur in the soil profile, sampling intervals should be adjusted to take account of these horizons. Sampling intervals must not be taken across two (2) or more different horizons and should not be combined. If sampling is being staged then a number of complete soil profiles should be analysed for all depths irrespective of the field tests showing negative results for some depths.

c. Sample size

Ideally, samples of soil should constitute at least 0.5 kg each to allow sufficient sample for chemical and physical analyses. Soil samples should not be bulked.

d. Soil sampling equipment

Various manual and mechanical sampling equipment may need to be employed. Choice of equipment will depend on site access and environmental sensitivities, soil texture, wetness and depth of layers in the profile. Details of the drilling/sampling equipment used, together with the drilling operator's name and contact phone numbers should be provided in the assessment report. Commonly used equipment is listed in Table 4.2 with comments on the suitability for sampling of acid sulfate material. As a general rule, augers should have a diameter greater that fifty (50) millimetres to ensure representative soil sampling.

Care should be taken to ensure that sampling equipment is washed down and cleaned between samples. A high pressure washing system is essential for mechanical drilling equipment. Trace amounts of sulfidic material from previous sampling may contaminate a sample that has no sulfides present, resulting in a false positive test. This can lead to unnecessary and costly earthworks and liming application to soils with no acid producing potential. An acid sulfate soil consultant or a trained soils technician must be present to supervise all drilling and sampling.

Extreme care must be taken with sampling coarse material such as sand and gravels, as low detection limits are required. Sample collection of these types of materials from below the watertable is difficult, particularly for gravel layers. The further the sampling is below the watertable, the more difficult and hazardous it is likely to be. In addition, gravel and sand fractions immersed in a 'sulfidic soup' have been found to contain sulfide framboids in their fine pores and fractures or as mud coatings (White and Melville, 1993). These materials are difficult to sample representatively and require modified sample preparation before laboratory testing. At present sampling using an excavator is recommended for gravels.

If sampling from a pit, relevant workplace health and safety practices need to be followed for pit height and size. A minimum of two people is required for pit sampling because of the possibilities of poisonous or suffocating gases as well as wall collapse. The person in the pit should have a harness attached to a rope leading to the other person who should remain outside the pit at all times and be ready to haul up should difficulties arise.

Soils with high levels of organic matter are also challenging to sample. Particular care is required in the sampling of these materials to ensure that representative samples are taken.

Care should also be taken when drilling below the watertable in coffee rock as it may cause significant damage to aquifers. Prior to drilling through coffee rock, it is recommended that advice be obtained from the Department of Land and Water Conservation concerning local aquifer characteristics.

Table 4.2 Soil sampling equipment and their suitability for sampling acid sulfate soils

Manual sampling equipment	
Jarret auger	▪ use only to sample the upper profile of dry and moist soil ▪ not generally suitable for sands
Tapered gouge auger	▪ suitable for soft muds, but not sands
Push tube with tapered tip	▪ limited use due to sample loss as suction is created on extraction (adding a sealable cap before extraction improves retention) ▪ limited use with sticky soils as it is hard to remove sample from the tube ▪ generally not suited for saturated sands
Piston sampler	▪ acceptable for many wet soils ▪ good for saturated sands but limited by the length of the piston as walls collapse as it is withdrawn. Using a suitable size poly pipe for casing can increase the depth of excavation on saturated sands but care is needed to limit contamination or sample mixing. ▪ allows only one extraction per hole
Mechanical sampling equipment	
Hydraulic push tube	▪ limited use due to sample loss as suction is created on extraction (adding a sealable cap before extraction improves retention) ▪ limited use on sticky soils because hard to remove sample from tube ▪ limited use on wet sands because of sample loss
Spiral auger	▪ generally unsatisfactory as it mixes the sample
Hollow flight screw auger incorporating an internal 'split tube' sampler. In addition a Standard Penetration Test (SPT) sampler or thin walled 50 mm diameter tube designated U50 (undisturbed, 50mm diameter) can sample within the hollow auger.	▪ acceptable for most soils ▪ some difficulties may be experienced with compression of muds ▪ some difficulties may be experienced with saturated sands with loss of sample on sands below the watertable. A catcher may improve sand retention.
Wash bore drilling combined with a driven Standard Penetration Test (SPT) split tube sampling	▪ may have a limited use for deep drilling particularly on saturated sands ▪ with a bentonite and polymer solution continually pumped under pressure, the borehole walls may remain sufficiently intact for reasonable sampling. ▪ contamination of samples can be a problem even when the upper part of the core is rejected
Core sampling employing a suction and vibrating technique	▪ recommended and ideal on wet sands, muds and soft soils, giving accurate depths and intact cores. Compressed air is used to remove the sample from the tube into a 'clean plastic sausage'. ▪ If the upper profile is hard and dry, a hydraulic push tube or auguring device may be required until soft moist material lower in the profile is encountered.

e. Soil sample handling, transport and storage

Large shells, stones and fragments of wood, charcoal or other matter should be noted and then removed from the samples in the field. Small roots may contain sulfides and should not be removed from the soil sample. The use of composite samples is not acceptable.

Upon collection in the field, soil samples should be immediately placed in leakproof containers that minimise the sample's contact with air and avoid moisture loss from the sample. The samples should be kept cold (ideally less than 4ºC) in the field to reduce the possibility of oxidation of sulfidic compounds. A portable freezer or dry ice are the most efficient coolers but where not available 'frozen bricks' or ordinary ice should be employed for cooling. It is most important that sample labelling and documentation remain with the samples at all times. Labels should be water- and ovenproof (85ºC). Waterproof paper has been found effective.

It is preferable that samples be sent to the engaged laboratory within 24 hours of collection. For transport and short-term storage during transit, samples should be chilled and stored in an insulated container so that they reach the laboratory at less than 4ºC. If samples cannot be received at the laboratory within 24 hours then the samples must be managed to minimise the oxidation of sulfides before laboratory analysis.

Methods of minimising sulfide oxidation in soil include:

- quick oven drying the sample at 80-85ºC in a forced convection, large capacity oven (care must be taken not to overload the oven's moisture removal capacity). The dried samples must then be stored in a low humidity environment.
- freezing the sample in a sealed, plastic microwaveable container.

Samples containing high concentrations of iron monosulfides, (usually black in colour and associated with bottom sediments and/or decaying vegetation), may generate acidity on oven-drying. Special sampling, storage and freeze drying techniques may be used to overcome this problem.

To avoid delays in sample processing and the potential for the oxidisation of sulfides in soil samples, it is important to contact the laboratory to let the laboratory manager know that samples will soon be delivered for analysis. It is important that the laboratory confirm the receipt of the samples. If samples are not stored appropriately during transport or at the laboratory, analysis results may be affected because of the change in oxidation state between collection and laboratory analysis. This is of particular concern when samples are delayed during transport.

There is no legal requirement to submit a Chain of Custody declaration to the relevant State or Local Government authorities. However, auditable sample records should be maintained at all times.

f. Preparing samples for audit purposes

Representative portions of all dried soil samples collected for acid sulfate soils investigations should be well marked and retained for possible future audit purposes. Special arrangement may need to be made with the laboratory to retain at least 50g of sample, as most commercial laboratories would discard samples about a month after results are reported. Storage in an oven-dried state is the safest and preferred approach. A less desirable method of storage is freezing. These samples should be retained until the end of the project unless they become an unreasonable impost. The appropriateness of discarding of any samples should be discussed with the regulatory authority. Stored samples can be important in defence of legal actions.

g. Selection of consultants to undertake acid sulfate soil investigations

A suitably qualified and experienced consultant should be engaged to develop and undertake acid sulfate soil investigation program. Preferably, consultants should have qualifications in agricultural or environmental soil science with specialisation in soil chemistry and hydrology, be experienced in acid sulfate soils management and be accredited by a professional organisation such as the Australian Society of Soil Science.

When calling tenders for acid sulfate soil investigations, proponents should request quotations based on the number of sites/cores drilled, a sample every 0.5m interval down a soil profile and detailed laboratory analyses. Without a sample-based approach, the cheapest quote often involves insufficient sites, samples or analysis, resulting in costly delays and the need for further supplementary investigations and costs.

For large projects, staging the soil analysis program is recommended as the sampling design can be adjusted and refined as a result of earlier site information. Savings can be considerable, particularly where stage 1 shows acid sulfate soils are minor or insignificant or if as a result of stage 1 analysis, mitigation strategies can be adopted so as to avoid disturbance of acid sulfate soils. In addition the level of analysis required at later stages will be dependent on the particular mitigation strategy selected, which may not be known until stage 1 analysis has been completed. It is therefore preferable that a staged approach be taken with the tendering and appointment of consultants to undertake acid sulfate soil investigations .

4.2 Analysing the soil samples

Standard methods have been developed for routine laboratory analysis of soil samples and are in Laboratory Methods Guidelines in the ASS Manual. The principle analytical methods are:

- TOS - Total Oxidisable Sulfur (Method 20)
- POCAS - Peroxide Oxidation Combined Acidity & Sulfate (Method 21)

The Laboratory Methods Guidelines outline other methods that can be used to complement the POCAS and TOS methods. Electron Microscopy can be used to visually confirm the presence of sulfidic framboids.

The TOS - Total Oxidisable Sulfur (Method 20) procedure is a useful, low cost screening tool for sulfide levels but does not take into account actual acidity. The TOS method is generally not suitable for accurate analysis of soils with low levels of sulfidic material such as sands and gravels. Field pH, conducted at the time of sampling, can assist identifying soil acidity but not the quantification of actual soil acidity.

For assessment purposes and for the development of effective management strategies, TOS results will need to be complemented with the POCAS method for a fuller understanding of the oxidisable sulfur content of the soil (particularly where the pH of the soil is less than 5.5 and particularly less than 4.5). For this reason, a percentage of samples should be analysed by POCAS (method 21) to understand the “sulfur trail” and the “acid trail”, assisting in interpretations. Each case needs careful consideration.

Where clear relationships between the ‘acid trail’ and the ‘sulfur trail’ have been established during the initial analytical testing for a particular project, it may be appropriate to use only the ‘acid trail’ of the POCAS method for the management and monitoring of impacts during the earth works/construction stage. This will allow for a quicker turn around of analytical results, allowing earlier liming calculations and management of exposed potential acid sulfate material.

Table 4.3 Example of the types of analysis for Acid Sulfate Soils

Samples supplied by: .... Date: .... Lab Job No:......................

Sample Size Site No.	Depth interval (m)	Soil Description texture	pH_F	pH_{FOX}	Conductivity	Lab Bulk Density	Total Sulfur %S	S_T	S_{HCl}	S_{TOS}	S_P	S_{KCl}	S_{POS}	TPA	TAA	TSA	S_{TSA}	Potential Neutralising requirement

This approach should be discussed with relevant authorities, so the appropriate sampling regime including what percentage of samples must be submitted for full laboratory assessment to monitor the calibration, can be established.

If physical separation is proposed as a management method, analysis of the particle size of the material, in particular the fines associated with the sulfidic material, will also need to be undertaken.

The typical information required following soil analysis is presented in Table 4.3. When presenting laboratory results, the method names and codes as described in the laboratory Methods Guidelines should be recorded. If variations in the approved methods are used, the methodology must be clearly documented in the assessment report along with the justification for the variation. The provision of additional data and the use of other methods or techniques, may be necessary in some situations.

4.3 Interpretation of the results - Action criteria triggering the need for a management plan

The *Action Criteria* in Table 4.4 trigger the need to prepare a management plan and are based on the percentage of oxidisable sulfur (or equivalent TPA, TAA) for broad categories of soil types. Works in soils that exceed these action criteria must prepare a management plan and obtain development consent. For projects that disturb >1000 tonnes of ASS soils with ≥ 0.03 % oxidisable sulfur or equivalent existing acidity, a detailed management plan and development consent will be required.

Table 4.4. Action criteria based on ASS soil analysis for three broad texture categories

Type of Material		*Action Criteria 1-1000 tonnes disturbed*		*Action Criteria if more than 1000 tonnes disturbed*	
Texture range.McDonald et al. (1990)	***Approx. clay content*** *(%<0.002 mm)*	***Sulfur trail*** *% S oxidisable (oven-dry basis) eg S_{TOS} or S_{POS}*	***Acid trail*** *mol H^+/ tonne (oven-dry basis) eg, TPA or TSA*	***Sulfur trail*** *% S oxidisable (oven-dry basis) eg S_{TOS} or S_{POS}*	***Acid trail*** *mol H^+/ tonne (oven-dry basis) eg, TPA or TSA*
Coarse Texture Sands to loamy sands	≤5	0.03	18	0.03	18
Medium Texture Sandy loams to light clays	5 - 40	0.06	36	0.03	18
Fine Texture Medium to heavy clays and silty clays	≥40	0.1	62	0.03	18

Table 4.5 provides an indication of the treatment or risk category a disturbance of acid sulfate soils would entail. This table allows estimation of the quantity of lime involved if the total volume/mass of acid sulfate soils to be disturbed is known and soil analysis has been performed. The table was developed based on the quantity of lime required to neutralise the acid that could potentially be produced and includes the minimum industry safety factor of 1.5.

TABLE 4.5 Treatment categories and lime required to treat a weight of disturbed acid sulfate soils – based on soil analysis

The tonnes (t) of pure fine lime required to fully treat the total weight/volume of ASS can be read from the table at the intersection of the weight of disturbed soil (row) with the soil sulfur analysis (column). Where the exact weight or soil analysis figure does not appear in the heading of the row or column, use the next highest value (or calculate values exactly using factors from Table 4.6).

Disturbed soil	**Soil Analysis - Oxidisable Sulfur (S %)** or equivalent TPA/TAA													
(tonnes)	***0.03***	***0.06***	***0.1***	***0.2***	***0.4***	***0.6***	***0.8***	***1***	***1.5***	***2***	***2.5***	***3***	***4***	***5***
1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.2	0.2
5	0.05	0.05	0.05	0.05	0.1	0.1	0.2	0.2	0.4	0.5	0.6	0.7	0.9	1.2
10	0.05	0.05	0.05	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.2	1.4	1.9	2.3
15	0.05	0.05	0.1	0.1	0.3	0.4	0.6	0.7	1.1	1.4	1.8	2.1	2.8	3.5
20	0.05	0.1	0.1	0.2	0.4	0.6	0.7	0.9	1.4	1.9	2.3	2.8	3.7	4.7
25	0.05	0.1	0.1	0.2	0.5	0.7	0.9	1.2	1.8	2.3	2.9	3.5	4.7	5.9
35	0.05	0.1	0.2	0.3	0.7	1.0	1.3	1.6	2.5	3.3	4.1	4.9	6.6	8.2
50	0.1	0.1	0.2	0.5	0.9	1.4	1.9	2.3	3.5	4.7	5.9	7.0	9.4	11.7
75	0.1	0.2	0.4	0.7	1.4	2.1	2.8	3.5	5.3	7.0	8.8	10.5	14.0	17.6
100	0.1	0.3	0.5	0.9	1.9	2.8	3.7	4.7	7.0	9.4	11.7	14.0	18.7	23.4
200	0.3	0.6	0.9	1.9	3.7	5.6	7.5	9.4	14.0	18.7	23.4	28.1	37.5	46.8
500	0.7	1.4	2.3	4.7	9.4	14.0	18.7	23.4	35.1	46.8	58.5	70.2	93.6	117.1
750	1.1	2.1	3.5	7.0	14.0	21.1	28.1	35.1	52.7	70.2	87.8	105.3	140.5	175.6
1,000	1.4	2.8	4.7	9.4	18.7	28.1	37.5	46.8	70.2	93.6	117.1	140.5	187.3	234.1
2,000	2.8	5.6	9.4	18.7	37.5	56.2	74.9	93.6	140.5	187.3	234.1	280.9	374.6	468.2
5,000	7.0	14.0	23.4	46.8	93.6	140.5	187.3	234.1	351.2	468.2	585.3	702.3	936.4	1170.5
10,000	14.0	28.1	46.8	93.6	187.3	280.9	374.6	468.2	702.3	936.4	1170.5	1404.6	1872.8	2341.0

L	**Low treatment**: (<0.1 t lime). Apply 0.05 t (1 bag) or 0.1 t (2 bags) of lime to prevent some soil acidity from the ASS disturbance.
M	**Medium treatment:** (>0.1 to 1 t lime).
H	**High treatment**:(>1 to 5 t lime).
VH	**Very High treatment:** (>5 tonne lime).

A detailed management plan is required if disturbing > 1,000 tonnes of ASS (oxidisable S ≥ 0.03 %S or equivalent TPA or TAA.)

Lime rates are for pure fine $CaCO_3$ using a safety factor of 1.5. A factor that accounts for Effective Neutralising Value is needed for commercial grade lime (see Management Guidelines).

An approximate volume (cubic m) can be obtained by dividing weight (tonne) by bulk density (t/m^3).

For example, 100 tonnes of clay material with 1.0 % oxidisable sulfur is to be disturbed, the landowner should observe best practice, bund any extracted material, fully mix at least 4.7 tonnes of lime and return it into anaerobic conditions as soon as possible. This example would fall into the 'High Treatment category' on Table 4.5. A management plan and development consent would be required.

If 1,000 tonnes of the same material is to be disturbed, a more detailed management plan will be required, along with development consent before the works can be undertaken. In these circumstances approximately 46.8 tonnes of lime will be required to treat the material. This latter example would be in the 'Very High treatment category' of Table 4.5.

Notes on assessment of risks based on the level of oxidisable sulfur

Levels of oxidisable sulfur within a soil or sediment can indicate the level of risk to the environment if the soil is disturbed. For all soils with oxidisable sulfur values greater than the "*Action Criteria*" in Table 4.4, a management plan must be developed to manage the potential harm to the environment. As a general rule, the highest result (by either the "sulfur "or the "acid" trail) should be used as the action criteria. Existing acidity (TAA) needs to be included in the assessment. If it is proposed to use the lower result of the 'acid' or 'sulfur' trail, this will need to be justified in advanced, eg the acid trail may be higher than the sulfur trail for organic rich surface material.

Notes on assessment of risks based on the type of material to be disturbed

The potential impacts from disturbance of acid sulfate soils can vary considerably depending upon its texture and mineralogy eg. The fineness of the soil particles and reactivity of naturally occurring neutralising material such as shell. In addition, because of the natural buffering capacity of clay soils, the level of clay in the soil can also influence the net level of sulfuric acid likely to be produced when the soil is disturbed.

As a result, the potential impacts from the disturbance of soil with a particular level of oxidisable sulfur can be moderated by this buffering process. Therefore, the levels of oxidisable sulfur that warrants management action will vary with the clay content. For assessment purposes, the criteria (based on oxidisable sulfur) which should trigger management action are grouped into three broad texture categories in Table 4.4. Lower criteria may be necessary if large quantities are to be disturbed as in Table 4.5. Soil samples that meet or exceed these criteria present a risk if disturbed and require management action if disturbance is to be undertaken.

Extreme care must be taken with interpretation of results from the analysis of 'coarse material', particularly low sulfur sands as lower detection limits are required. Sands have a lower action level because they can oxidise rapidly and usually have little or no pH buffering capacity. Preferably, more than one analytical method may be needed when analysing sands with the 'POCAS' method the recommended approach.

The interpretation of results of samples from peaty soils, high organic material, coffee rock and indurated sands can also be difficult. Sulfides commonly occur inside old root channels and its formation is usually closely associated with organic matter, which if abundant, may form sulfidic peats. However, it may be possible to get a positive laboratory result on peats, by both the sulfur and acid trail testing methods where there is no identifiable mineral sulfide under the electron microscope. The positive oxidisable sulfur result in these cases *may be* attributed to a high organic sulfur content in the organic matter. Such organic sulfur compounds are less of an environmental risk.

Coffee rock is expected to be fully oxidised due to its pedological and geomorphological history and in many circumstances do not pose environmental risks. However, this is not the case for all coffee rock. The chromium reducible sulfur method (Method 22 B) Chapter 9 of *the ASS Laboratory Methods Guidelines* may be useful in assisting to improve information on the contribution of organic sulfur to these complex situations.

Notes on the assessment of risks based on the maximum level of acid which could be produced

The analysis of the oxidisable sulfur in the soil samples can be used to calculate the theoretical maximum amount acid that can be generated as result of the complete oxidation of sulfides. The assumption is that all the oxidisable sulfur in the sample is pyrite (FeS_2) and it produces 2 mol of sulfuric acid per mol of pyrite and no soil buffering is available. A number of methods of determining oxidisable sulfur are available (eg S_{TOS} and S_{POS}) and their result is normally expressed as % S or kg H_2SO_4 / t (Table 4.6). Methods for titrating acidity (TAA TPA) are usually expressed in mole of acidity / t and approximate conversions between the various units are shown in Table 4.6. This analysis can provide an indication of the quantity of lime that could be required to neutralise all the acid and the data in Table 4.6 includes a 1.5 safety factor.

Table 4.6 Acid sulfate soil conversions

(based on 1 mol sulfide producing 2 mol sulfuric acid and corresponding liming rates)

Oxid. sulfur S (%)	*moles H^+ / kg (S % x0.6237)*	*moles H^+ / t or moles H^+ /m^3 (S % x 623.7)*	*kg H_2SO_4/tonne or kg H_2SO_4 /m^3 (S % x 30.59)*	*kg lime/tonne soil or kg lime/ m^3 Safety factor =1.5*	*Approx. lime cost/tonne soil or Cost/ m3 of soil $*	*Cost/ha/m depth of soil @ $50/t of lime $*
0.01	0.0062	6.237	0.306	0.47	0.02	234
0.02	0.0125	12.47	0.61	0.94	0.05	468
0.05	0.0312	31.19	1.53	2.3	0.12	1,170
0.1	0.0624	62.37	3.06	4.7	0.23	2,340
0.2	0.1247	124.7	6.12	9.4	0.47	4,680
0.3	0.1871	187.1	9.18	14.0	0.70	7,020
1.0	0.6237	623.7	30.6	46.8	2.34	23,410
5.0	3.119	3119	153.0	234.0	11.70	117,000

Note 1: Assumes a bulk density of 1.0 g /cm^3 or 1 tonne/m^3 (range can be 0.7-2.0 and as low as 0.2 for peats). Where bulk density is > 1 g /cm^3 or 1 tonne/m^3 then the safety factor will increase for lime rates/m^3 soil (eg. if BD=1.6, then 1 m^3 of soil with 1.0 % S_{POS} will require 75 kg lime/m^3 instead of 47 kg).

It is essential to provide adequate neutralising material to neutralise all acid that may be produced and to bring the pH of the soil to above 5.5. In most cases, there is only limited for raising the soil pH to neutrality (pH 7) as a pH above 5.5 is enough to avoid most acid sulfate problems (Dent, 1992). However the pH of leachate should be above pH of 5.5 at all times and should ideally be in the range 6.5-8.5 to remove toxic forms of aluminium and other heavy metals.

Table 4.6 provides an indication of the quantities of lime required and the likely financial implications and practicability of managing the disturbance of the soil. Even when an "oxidation" mitigation strategy is not proposed, the quantity of lime required provides a signal as to the likely environmental hazards from undertaking the proposed works. Using a cost of $50 per tonne for lime, (the actual cost of lime could vary from $40 to $150 per tonne depending on the location and quality), a rough understanding of the likely economic costs from disturbance of the soils (earthworks not included) can be gained.

Notes on the assessment of risks based on the quantity of material to be disturbed

The amount of lime required to neutralise a certain quantity of acid sulfate soil can be used as a crude calculator to determine the degree of risk associated with disturbing acid sulfate soil. Where the volume of acid sulfate soil is small and the concentration of oxidisable sulfur is low, the risks are considered to be relatively low. Conversely, where large volumes of acid sulfate soils are to be disturbed then the potential cumulative risks are high. A treatment rating has been developed in Table 4.5 based on the calculated quantities of lime required per tonne of soil. This table provides a rough guide. It is a useful tool for those proposing the project and an aid to the regulators in deciding the acceptability of the project.

Considerable care should be taken when using Table 4.5 to justify activities that disturb acid sulfate soil. Table 4.5 is intended to provide as a rough indicator between projects with differing levels of soil disturbance and different concentrations of oxidisable sulfur. Individual works have their own environmental characteristics and should always be assessed on all the information available for that site and proposed works.

Impacts associated with the physical characteristics of acid sulfate soils

For projects (such as extensive landfilling, heavy structures such as roads, bridges, dams or major buildings) the physical characteristics of the subsoils and the potential for compaction and subsidence of unripe acid sulfate clays should be considered. As some potential acid sulfate soil clays have the consistency of a gel with up to 80% water content and hence low bearing capacity considerable lateral movement or subsidence can be expected under load.

For these types of projects, geotechnical data should be analysed to consider the extent of possible movement of the sulfidic material under load and appropriate management strategies developed. Preloading of the site may need to be considered. If preloading or loading of the site is to be undertaken, hydrological analysis should also be undertaken to consider the effects of compaction on groundwater levels and clay gel material flows and the potential for discharge of acid. The material used for preload should be non ASS and if to be removed in the future, it should be separated by some geotech fabric to allow final removal without ASS contamination.

4.5 Consider the precautionary principle

When designing a soil sampling program or undertaking soil analysis, the precautionary principle should be considered. Where there are doubts, be conservative. Always follow best practice. If there are uncertainties, analyse extra samples. In interpreting the results, err on the side of caution. There is a responsibility on those proposing to undertake the works, the consultants advising them and any approval authority in making a decision, to ensure that if there are uncertainties, both the short and long term implications of the worst case scenarios are considered.

Designing a water assessment program

5.1 Surface water issues

Changes in drainage have implications for the likely generation of acid. When acid sulfate soils are drained, the sulfide can become exposed to oxygen producing sulfuric acid. The sulfuric acid can dissolve clay and release toxic concentrations of aluminium and iron into estuarine and groundwater systems leading to poor water quality and the death or disease of vegetation and aquatic organisms. Changes in hydrology can also result in the drying out of unripened potential acid sulfate soils causing shrinkage, surface subsidence and sulfide oxidation. Impacts can result if the proposal involves the modification of the drainage pattern and surface runoff yield and hydrologic flow regimes.

Table 5.1 Works that are likely to change hydrological characteristics

Type of works	*Potential impacts*
▪ vegetation clearance ▪ soil compaction or the sealing of land surfaces with buildings or pavement ▪ laser levelling ▪ construction and operation of culverts, drains, floodgates or other works	potential to increase surface runoff yields and flow regimes with likely increases in flooding, water logging and soil erosion with the potential to directly affect acid sulfate soils or indirectly through groundwater changes
▪ watercourse abstraction ▪ construction of on-stream storages, weirs, barrages, floodgates or other instream temporary or permanent obstructions to flow ▪ construction of ditches, drains or runnels for mosquito control near urban areas	potential to decrease surface runoff yields and flow regimes with accelerated sediment deposition in the stream or drains, water quality deterioration, degradation of the aquatic/riparian environment, inhibit breeding cycles and the movement of aquatic fauna and lowering of groundwater levels with the potential to affect acid sulfate soils

Wetland hydrological regimes can be affected by changes in the watertable, the surface runoff yield, hydrologic flow regimes or drainage pattern. If natural wetlands are used for water or flood storage, both the average water level and the pattern of seasonal fluctuations is likely to change. This will directly affect the ecology of the wetland, the generation and export of acid from acid sulfate soils and the drainage pattern of any out-flowing streams. It may also have indirect hydrological effects through groundwater connections. The magnitude of the impact is dependent on such factors as the duration and frequency that the wetland is used for storage and the quality of the water to be stored, the drainage or levee systems affecting the flow through or away from the wetlands and the tidal exchange. It should be noted that the use of a natural wetland for water storage is deleterious to wetland functions and is inconsistent with the principles of the NSW Wetlands Management Policy.

Assessment of impacts on acid sulfate soils

Consideration of potential changes to the hydrologic regime may be necessary to predict the magnitude of the impacts on acid sulfate soils, and in the design/redesign of drainage or flood management systems.

Factors to be considered include:

- the likely volume of the river or drain flows (sub-catchment or whole of catchment flows), the existing channel capacity and run-off routes, the likely flow conditions in the receiving waters; the timing of the flood or storm event (ie. whether flows changes are likely to occur during known fish movement periods), the likely duration and frequency of the event, and the likely extent of flooding under relevant flood regimes;

- the likely changes to the channel capacity and run-off routes as a result of the works, and the likely change in the extent and behaviour of flood or storm water under relevant regimes; the likely waterlogging or drying out of areas as a result of changes in run-off patterns and levels; and
- the assessment of potential changes to the hydrological regime in the context of any relevant flood, estuary or drainage management plans for the catchment or sub-catchment.

Reliable data are required to assess the drainage capacity requirements and any likely hydrologic changes as a result of the works. In some circumstances when significant changes are expected, eg if there is to be a major change in flood mitigation works or a drainage network, flow history analysis should be performed on historical data and hydrological processes simulated. A range of methods is used for the characterisation of impacts associated with changes in the flow regime and with the shape of the hydrograph (Pilgrim 1993). The assessment of hydrological changes may involve flow duration curve analysis, flow-exceedence frequency duration analysis and analysis of the flood frequency and rates of rise and fall. Application of commercially available surface and groundwater hydrology models may be appropriate for the assessment of new or modified works.

5.3 Water quality issues

a. Designing a water quality sampling or monitoring program

A systematic sampling strategy should be developed to understand the river or drainage system and its vulnerability to impacts. The appropriate number of sampling locations and frequency will be defined by the scale of the works, the characteristics of the waterbody and the nature of the potential impacts. The sampling locations may be needed both upstream and downstream of the site as well as adjacent to any site where discharge or seepage is likely to occur.

Where there are potential impacts as a result of wet weather run-off, seepage or discharge, a wet weather sampling should be included in the program with sampling frequencies influenced by rainfall pattern and drain or creek flow characteristics. If suitable field equipment is available, pH and EC should be measured in the field as soon as the sample is collected. Automatic event-controlled sampler or submersible dataloggers are more appropriate for monitoring of water quality during wet weather, whereas grab samples may be adequate for monitoring of water quality during dry weather.

The water samples should be representative of the water column of the water body being investigated and may require sampling from different depths within the water column (Sammut et al 1994). Where stratification is likely, samples should not be bulked. Water samples should be at least 0.5 litre each to allow a full range of analyses. With water samples, containers should be filled to the top to exclude air and chilled immediately to minimise chemical activity. If iron analysis is required, a separate sample should be collected and acidified with nitric acid to prevent iron precipitation that can occur due to oxidation of a disturbed sample.

Water quality measurements should routinely include the following indicators:

- pH
- total dissolved solids or electrical conductivity
- soluble Cl^- and SO_4^{2-} concentration for groundwater or drain water
- calculation of $Cl:SO_4$ ratio.

Only in certain circumstances will samples need to be submitted for analysis of Fe, Al, CO_3^{2-} and HCO_3^- and dissolved oxygen. Soluble aluminium and iron in acid sulfate soils leachate can contribute to poor water quality and have significant detrimental impacts on the ecosystem. However analysis for soluble aluminium and iron is expensive and the results are difficult to interpret.

These tests should not be routinely required.

- Iron and aluminium analysis should be only required in circumstances where there is a level of uncertainty with mitigation strategies, if major volumes of material containing high concentrations of sulfide are to be disturbed or if drainage from the site is like to directly affect commercial aquaculture, fish breeding grounds or highly valued ecosystems.
- Carbonate, bicarbonate and dissolved oxygen analysis should be undertaken if mitigation strategies are likely to result in the significant changes in carbonate levels or if drainage from the site is likely to directly affect commercial aquaculture or natural wetlands.

b. Interpretation of the results

The baseline data should provide an indication of:

- the general health of the system and the extent to which the system is already impacted by acid sulfate soils; and
- the likely short and long term effects on the system from the proposed works
- the likely impacts on the health of the ecosystem, people or animals from poor water quality.

See next page for information on water quality performance criteria.

Minimising the risks from poor water quality

For acid sulfate soils, the principle water quality issues of concern are acidity, soluble iron, aluminium and other heavy metal levels, and changes in bicarbonate, carbonate and dissolved oxygen levels. All potentially "polluted" water should be:

- contained and managed within the site boundary; or
- treated to acceptable levels prior to discharge to a natural /external water body.

Controlling the pH of all 'site water' is the least expensive and easiest control. As a standard procedure, site management plans should include the bunding or containment of the area to be disturbed using non-acid sulfate soil material in the bunds or levees. All water should be treated to an acceptable level prior to release. The discharge of any acid leachate with dissolved toxic forms of aluminium is not acceptable.

When water discharge is proposed, the discharge must only occur when pH is in the approved range (usually 6.5-8.5). Raising the pH well above pH 5.2 (eg. pH>6.5) ensures a substantial reduction in the total soluble aluminium concentration and a reduction in the potentially toxic ionic species. Preferably an automatic recording system should monitor any discharge point for pH and EC.

WATER QUALITY PERFORMANCE CRITERIA

Specific performance criteria

Where Interim or Final Environmental Water Quality Objectives for a particular river system have been established as a result of the Water Reform Agenda, these criteria should be used as a basis for assessing the current health of the system and for estimating the potential effects of the proposal.

Aquatic ecology criteria

Where these objectives have not been established, the water quality criteria for protection of aquatic ecosystems in the *ANZECC Australian Water Quality Guidelines for Fresh and Marine Waters* (1992) should be paramount. The *Guidelines* recommend that the water quality criteria for the indicators in Table 5.2 be met for the discharge of water into the environment.

Table 5.2 ANZECC Water Quality Criteria for protection of aquatic ecosystems

Indicator	*Fresh Water*	*Marine Water*
pH	6.5-9.0	< 0.2 unit change
Fe (total)	500 µg/L	NA
TDS	0-1500 mg/L	> 1500 mg/L
Al (total)	5 µg/L for pH < 6.5 100 µg/L for pH > 6.5	NA

Most natural fresh water has a pH between 6 and 7 and marine water close to pH 8.2. The ANZECC Guidelines recommend that changes of more than 0.5 pH units from the natural seasonal maximum or minimum should be investigated, and that in marine waters, the pH should not be permitted to vary by more than 0.2 units from the normal values. As marine waters are strongly buffered, even small changes in the pH levels indicates a major change to the system. Total alkalinity of seawater is 115-120 mg/L (as $CaCO_3$).

Research has demonstrated that the chemistry of aluminium in natural waters is complex and the solubility of aluminium species is pH dependent. If the pH is at or below 5.2, the total soluble aluminium concentration increases with an increase in the range of dissolved ionic species present. Aluminium species are toxic to fish over a pH range of 4.4-5.4 and are most toxic when the pH of water is 5.0 - 5.2 (Sammut *et al*. 1996, ANZECC Guidelines). Under very acid conditions, the toxic effects of the high H^+ concentrations appear to be more important than the effects of aluminium.

Where iron is precipitating from the acidic water, very low dissolved oxygen levels may result. The ANZECC Guidelines recommend that dissolved oxygen should not normally be permitted to fall below 6 mg/l or 80-90% saturation, having been determined over at least one diurnal cycle. Where ever possible, dissolved oxygen should be measured over the full diurnal cycle for a period of a few days to establish the diurnal range in concentration.

Drinking water criteria

In circumstances when drinking water is likely to be affected (eg groundwater aquifers used for drinking water) references should also be made to the *National Water Quality Management Strategy: Australian Drinking Water Guidelines* (1996). The water quality criteria for the indicators in Table 5.3 should be met.

Table 5.3 Australian Drinking Water Guidelines Water Quality Criteria

Indicator	*Health*	*Aesthetic*
pH	*	6.5-8.5
Fe (total)	*	0.3 mg/L
TDS	**	500 mg/L
Arsenic	0.007 mg/L	
sulfate	500	250
H_2S	*	0.05
Al (acid soluble)	*	0.2 mg/L

* insufficient data for health guidance ** no health based guideline required

Groundwater issues

Changes in groundwater levels can have major impacts on the generation and export of sulfuric acid.

Table 5.4 Works that are likely to change watertable levels

Types of works	*Potential impact*
• irrigation and effluent disposal schemes • clearing of trees • raising of water levels in drains • filling in drains • maintenance of natural wetlands	raise groundwater levels
• extraction of groundwater • excavations to or below the watertable • dewatering of dams, quarries, construction sites or landfills • construction of deep drains • dredging and the lowering of the bed of river • growing of trees on previously cleared land	lower groundwater levels

Raising the groundwater level can result in waterlogging and changes in the hydrology and ecology of an area. Works which lower the watertable result in the oxidation of acid sulfate soils leading to the degradation of groundwater quality with reduced pH and increased levels of soluble metals. Exposure or near exposure of the groundwater from excavation increases the potential threat of contamination from the oxidation of sulfide. Reducing the unsaturated zone thickness as well as increasing evaporation losses places a limit on the potential storage of groundwater for an unconfined aquifer and may impact on the existing groundwater flow system.

Impacts on groundwater will vary according to the material properties of the aquifer, the characteristics of the proposed works and its interaction with the surrounding environment.

Information on the existing groundwater characteristics can be obtained from the DLWC groundwater data system, bore records groundwater data system and relevant Groundwater Vulnerability Maps. DLWC should also be consulted regarding the existence of any existing licensed groundwater users and their licence conditions. Australian Standards 2368 - 1990 *Test pumping of water wells; Archiving of groundwater dependent environments in the area; slug testing* should be consulted regarding test wells.

a. Hydrological issues

The level of investigation to determine the likely generation and export of acid from any changes to the groundwater will depend on the duration and extent of the impacts on groundwater levels. If groundwater impacts are likely to be significant, the following site specific investigations may be required:

- determine the depth to the watertable with an indication of the seasonal variation. The greater the groundwater depth the less likely is the potential for impacts to the groundwater or for watertable levels to change as a result of the proposal;
- identify adjoining groundwater related environments eg wetlands, springs, rivers and creeks and any likely recharge areas eg areas of waterlogging. Sites that contain surface water linkages to the groundwater increase the likelihood of groundwater being affected;
- identify the hydraulic characteristics of the aquifer - hydraulic conductivity (aquifer thickness, type, porosity, transmissibility), groundwater gradient and flow direction, soil permeability and attenuation/sorption characteristics (soils with high permeability increase the potential for infiltration to the groundwater), pumping test; and
- identify any existing groundwater users, density of bores, uses of groundwater extraction - the impact on existing users is likely to be low if the existing groundwater use is low, however the aquatic

environment needs to be considered in this assessment. If groundwater is not linked to the surface water environment, the impact of groundwater extraction on the aquatic environment is likely to be minimal

Modelling of the changes to the groundwater system and possible groundwater interaction scenarios may be required if adverse impacts on acid sulfate soils are indicated.

b. Water quality issues

A systematic sampling strategy should be developed to understand the groundwater system and its vulnerability to impacts. The appropriate number of sampling locations and frequency will be defined by the scale of the works, nature of the potential impacts and the vulnerability of the groundwater resource.

For groundwater, if a major disturbance of acid sulfate soils is likely, piezometers should be established to monitor both the groundwater movements and water chemistry. Where large scale disturbance over the long term is proposed, semi-continuous water level recorders should be installed. Prior to installing piezometers, DLWC should be consulted about the most appropriate type of piezometers, monitoring regimes and whether an approval is required. The guideline *A practical guide for groundwater sampling* (1992) should also be consulted.

Water samples will be required from different depths within the water column and should be representative of the strata in the water column being investigated. Samples should not be bulked. Water samples should contain at least 0.5 litre each. With water samples, containers should be filled to the top to exclude air and chilled immediately to minimise chemical activity. If iron analysis is required, a separate sample should be collected and acidified with nitric acid to prevent iron precipitation that can occur due to oxidation of a disturbed sample.

The water analysis and criteria for surface water also apply for groundwater.

Consider the precautionary principle

When designing a water sampling program or undertaking water analysis, the precautionary principle should be considered. Where there are doubts, be conservative. Always follow best practice. If there are uncertainties, analyse extra samples. In interpreting the results, err on the side of caution. There is a responsibility on those proposing to undertake the works, the consultants advising them and any approval authorities in making a decision, to ensure that if there are uncertainties, both the short and long term implications of worst case scenarios are considered.

Managing Acid Sulfate Soils

6.1 The need for an Acid Sulfate Soil Management Plan

An Acid Sulfate Soil Management Plan must be prepared in all circumstances when the *Action Criteria* in Table 4.4 are met or exceeded.

The Plan should be based on the acid sulfate soil mitigation principles set out in the Management Guidelines of the ASS Manual. The plan should provide a framework for the on-going management and monitoring of the impacts throughout the construction and operation phases of any project. An acid sulfate soil management plan is a fundamental component of any proposal application. The approval authority should assess the adequacy of the management plan before approving a development application, a licence or a lease, and should require the implementation of the plan as a condition of approval.

The acid sulfate soil management plan should consider both the on-site and off-site impacts of the disturbance of the soil, with any acid leachate being managed in a coordinated and pro-active manner. The acid sulfate soil management strategy should be integrated into the design, layout and engineering of each component of the proposal and the procedures and schedules of the construction or operational phases of the proposed works. Where practicable, the proposal should be staged so that the area disturbed at any one time is restricted, so that any potential impact can be limited and easily managed. This is particularly important when disturbing acid sulfate soils near water bodies or wetlands. The plan should also provide a description of the contingency procedures to be implemented at the site if the management procedures prove to be unsuccessful and acid leachate problems occur. The plan should demonstrate how these contingency strategies could be integrated into the procedures and schedules of the construction or operational phases of the proposed works.

The acid sulfate soil management plan should be developed in consultation with relevant Councils and government agencies. To develop appropriate management strategies, it may be necessary to consider other environmental issues such as hydrology, aquatic and terrestrial ecology, social issues and economic factors. It is important to collaborate with consultants preparing the assessment of these other issues so that their assessment considers the impact from the disturbance of acid sulfate soils and the management strategy for acid sulfate soils considers other relevant environmental factors.

The level of detail in the management plan will depend on:

- the size and complexity of the project and the level of risk associated with the proposed works;
- the level of certainty associated with the proposed mitigation strategy; and
- the sensitivity of the environment likely to be affected.

There is no set “formula” for managing acid sulfate soils and each case must depend on the particular circumstances. In addition, there is no set prescription as to what should be in a management plan as the level of detail should reflect the level of risk from the potential disturbance of acid sulfate soils.

Prior to preparing an acid sulfate soil management plan, the acid-producing potential of the soil needs to be quantified and evaluated in the context of the local environment. In most cases, a detailed soil survey needs to have been undertaken with analysis of the sulfide content across the soil profiles. Additionally, there should be an understanding of the sensitivity of the local environment including an understanding of the hydrology of the surface and groundwater including their key chemical, physical and biological characteristics.

6.2 The Acid Sulfate Soil Management Plan

The plan should pull together all the mitigation measures to protect the soils, surface and groundwater, ecology and the community. It should outline the staging of works so that the impacts can be minimised and managed. As a minimum it should contain the following:

1. an overview of environmental attributes of the site and surrounds (see Section 5 and 6)
2. an overview of the proposed works
3. a description of the acid sulfate soils mitigation strategies (see Section 3 and 4) incorporating a schedule of construction and operational phases to minimise impacts from :
   a) the disturbance (including excavation or changes in surface or subsurface water systems)
   b) any excavated soils (including storage, treatment or use)
   c) any acid leachate produced (including storage, treatment, discharge or use)
4. a monitoring program for soils and the surface and subsurface water quality (see Section 7.4) outlining:
   a) what parameters will be monitored
   b) monitoring locations
   c) monitoring frequency
   d) analyses to be conducted
   e) laboratory conducting analyses
   f) procedures to be undertaken if monitoring indicates that thresholds are being exceeded
   g) reporting procedures to relevant authorities and the community (if appropriate).
5. a description of the pilot project or field trial (if new mitigation strategies are being used or a pilot is required by the determining authority) (see Section 7.3) to:
   a) prove the effectiveness and feasibility of new technology, or selected management procedures to deal with the acid sulfate soils and other environmental impacts
   b) demonstrate that the proponent has the capability to implement those management procedures effectively
   c) demonstrate the ability to comply with agreed standards and performance targets
6. a description of the contingency procedures to be implemented at the site to deal with unexpected events or in the event of failure of management procedures (see Section 7.5) including a Remedial Action and Restoration Action Plan related to:
   a) any failure to implement any proposed acid sulfate soil management strategies
   b) any mitigation strategies being ineffective so that the project fails to meets agreed standards or performance levels.

6.3 Pilot Project or Field Trial

When the outcomes from a proposed management strategy are unclear or not generally accepted the successful completion of a trial to test these strategies on a small scale should be undertaken before the proposal commences. The trials could test options for mitigating impacts, for example:

- alternative neutralising agents especially if the use of commercial waste material is proposed;
- methods for separating and managing fines containing sulfide; and
- methods to fully oxidise certain types of soils.

A well-designed trial can assist in identification of the most efficient and economical management approach for the proposal. A trial may not provide information on the potential long-term impacts of a management strategy or treatment option. For projects that present significant environmental risks, monitoring of the long-term effects will usually also be required.

The pilot project usually consists of two phases - a laboratory 'bench top' phase followed by a small-scale field trial. Before any field trials, all relevant State and Local government authorities should be consulted and in some cases, planning or other approvals may be required.

The pilot project proposal must describe:

1. the mitigation options being tested;
2. the monitoring program and performance standards to be achieved;
3. the precise description of the location and scale;
4. the proposed timeframe for the trial with the commencement and completion date; and
5. a full outline of restoration works to be undertaken if the pilot demonstrates that the project should not proceed as proposed

On completion of the pilot project , the outcomes should be assessed by the relevant government authorities and the proponent, to determine:

- whether to proceed with the project as proposed, or
- to review alternatives, or
- to abandon the proposal with restoration of the trial area.

If the trial demonstrated that the impacts could be managed with a degree of certainty, the monitoring data and a review of the operational efficiency of the works should be used to refine the proposed management plan.

6.4 Monitoring Programs

The monitoring program should be designed to provide feedback on the effectiveness of the management strategy and to provide an early warning of the development of any environmental degradation or impact. The monitoring program must be tailored to the specific proposal and should reflect the level of disturbance, and the chemical and physical properties of acid sulfate soil and surrounding surface and groundwater. It is important that the monitoring programs are carried out objectively in a way that is clearly auditable.

Depending on the type or scale of the proposal and the sensitivity of the location, the following should be monitored:

- surface, ground and leachate water associated with any disturbance of acid sulfate soils for parameters including pH, EC or total dissolved solids; pH monitoring of treatment ponds should be a high priority. As a precaution against major accidents, pH controls should be undertaken in small treatment ponds before discharge back to the main pond(s);
- hydrological factors including freshwater inflows (including peak flows), tidal water levels and watertable fluctuations to ensure development is not affecting maintenance of an adequate water cover over acid sulfate soil horizons; and
- any soils stockpiled on site should be the subject of an ongoing assessment of the status of any oxidation occurring within the soils. Regular testing of soil and water by approved laboratory methods.

During and immediately after the disturbance of acid sulfate soil, parameters may need to be monitored daily or more frequently. Automatic data logging of pH and EC may be required to establish background data prior to the construction phase, during construction and post-construction. Automatic data logging systems should be capable of initiating an alarm or management procedure should pH fall below an agreed value. Sites involving substantial disturbance such as dredging, levee construction, sand extraction, etc. may require more than one automated recording device, with pH monitoring of treatment ponds being a high priority. Significant projects should consider automated monitoring of any run-on water source (or upstream) in addition to their discharge points.

As the impact of the proposal becomes more predictable, the frequency of monitoring may be able to be reduced. A greater frequency of monitoring may be required to assess the impact of events such as heavy rains, droughts and tides, so that management strategies can be adjusted. However acid sulfate leachate may take years to develop. It is important to maintain an on-going monitoring program for an agreed period. Depending on the level of acid sulfate soils disturbance, this post-monitoring period may range from two to greater than five years.

All monitoring data should be compiled and reviewed regularly against baseline data, appropriate standards and agreed performance targets. Monitoring should ensure that all water discharged from a site complies with the requirements of the relevant water quality legislation, the ANZECC Australian Water Quality Guidelines (1992) and any specific water quality objectives set for receiving waters (for example any Interim (or Final) Objectives for the river system developed under the Water Reform Agenda). Performance outside these standards or targets will require remedial action. This remedial action may involve changes to the management plan or more significant changes to the design or operation of the proposal.

If acid sulfate soil management has been successful, the monitoring information will be important in requesting an early release of any relevant outstanding bonds or acid sulfate soil management obligations.

6.5 Contingency Plan

A contingency plan must be developed to manage impacts should the management strategies fail. The contingency plan should be developed on a site-specific basis in consultation with the relevant government authorities. The contingency plan is an integral component of the acid sulfate soil management plan that must be developed prior to approval or commencement of the project. The contingency plan may have two phases.

Phase 1: Remedial Action
If monitored results indicate the agreed standards or performance indicator levels are not being achieved due to failure or ineffectiveness of the management strategy, then immediate remedial action will be required. These remedial actions may apply to individual components of the construction or operation stage of the project that are responsible for the breach of agreed standards. For instance remedial action may include storage of additional lime on site during construction with access to appropriate application equipment that can be engaged for immediate use should pH levels fall in any affected waterbodies on site.

Phase 2: Restoration Action
When remedial action fails or monitoring results identify severe failure of the management strategy to meet agreed standards, the project should cease to operate and action taken to restore the site to a condition equivalent to that prior to the commencement of the project.

The decision to implement contingency plans may be triggered by the proponent or by relevant government agencies. Prior to the actions being implemented, an assessment should be undertaken as to whether the problem is:

a) related to ineffective implementation of acid sulfate soil management strategies;
   If this is the case, the management plan should be audited to ensure that it can be implemented effectively. Monitoring should increase to ensure compliance with standards or performance levels.
b) related to management strategies themselves being ineffective;
   If this is the case, the management plan should be reviewed, including an assessment of the outcomes of remedial actions. Consultation with relevant government agencies should occur if changes to the management plan are proposed.
c) due to there being no suitable management strategies that can be implemented so that the project meets agreed standards or performance levels.
   If this is the case, rehabilitation actions should be undertaken and regular monitoring at agreed intervals should continue until the rehabilitation action has been completed and the situation poses no significant risk to the environment.

Should management strategies require modifications, the relevant government authorities should be provided with the following information:

- Details of the changes
- Why the changes have occurred
- Plan for their implementation.

In some cases a change to the management strategy may require a change to the approval.

6.6 Consider the precautionary principle

When designing an acid sulfate soil management plan, the precautionary principle should be considered. Where there are doubts, be conservative. Always follow best practice. Where there are uncertainties, undertake trials or pilot studies to increase knowledge and the predicability of outcomes. There is a responsibility on those proposing to undertake the works, the consultants advising them and any approval authority in making a decision, to ensure that if there are uncertainties, both the short and long term implications of the worst case scenarios are considered.

Making an application for an approval

7.1 Check what approvals are required

Before undertaking any works which disturb acid sulfate soils, it is the responsibility of those undertaking the works to check to determine if an approval is required from council. The SEPP 14 - Coastal Wetlands Maps should be checked to determine if any protected wetland areas are likely to be disturbed requiring an approval and the preparation of an EIS. Schedule 3 of the EP&A Regulation should also be checked to see if the proposed works are designated under this regulation triggering the need for an EIS. A Statement of Environmental Effects (SEE) or Environmental Impact Statement (EIS) should accompany any development application for an approval to undertaken works that disturb acid sulfate soils.

Even when an approval is required from council, other approvals may also be required from other relevant agencies. Applicants should check with council staff prior to lodging an application (or commencing works) to determine what other approvals are required. Government authorities may need to be consulted regarding approvals to undertake the works. If a development application is required as well as an approval listed in Table 7.1, after July 1 1998, the application may be considered to an "integrated development" and the integrated development provisions of Part 4 of the EP&A Act will apply.

Table 7.1 The approval that has been integrated with development approvals

Agency	*Approval*
Environment Protection Authority	Licensing of activities that are likely to pollute waters
Department of Land and Water Conservation	Water licences, bore licences and levee approvals or approval of works within 40m of a river or creek bank
National Parks and Wildlife Service	Consents to destroy known Aboriginal artefacts or Aboriginal Places
The Heritage Council	Approval to undertake works to an item protected by a Permanent Conservation Order or an Interim Conservation Order
The Roads and Traffic Authority	Approval to undertake work in a road corridor, including new connections
Mine Subsidence Board	Works in a Mine Subsidence District
NSW Fisheries	Approval to cut marine vegetation or dredge or undertake aquaculture

If government agencies, councils, county councils or drainage unions are undertaking works which do not need development consent from councils, a Review of Environmental Factors (REF) should be prepared to determine if significant impacts are likely, and if likely, then a full EIS must be prepared and considered prior to undertaking the works. No works should be undertaken until the likely environmental consequences of the works have been properly considered by the relevant authority.

The onus is on those undertaking the works to ensure that adequate information is provided with the application for the approval authority to make a decision. If there is inadequate information or unsubstantiated claims are made about the proposal, delays may result when the proponent is requested to undertake additional investigations. For most proposals which disturb acid sulfate soils, as a minimum, it is recommended that liaison be undertaken with the local offices of Department of Land and Water Conservation, Environment Protection Authority, NSW Fisheries and NSW Agriculture (where the development specifically relates to agricultural land or purposes). To expedite the approval process, a copy of correspondence from these agencies should accompany application for approval. Where major projects are proposed, it may be more efficient to convene a meeting involving council, all relevant government agencies and key industry or community representatives at the outset to ensure all concerns are properly addressed in the application.

7.2 Strategic approach

a. Joint applications

Where a development involves or may impact upon a number of properties in an area, proponents should investigate the feasibility of preparing and lodging a joint application for the proposed works and ongoing management. This approach is particularly recommended where a number of property owners are jointly responsible for a drainage system or where flood mitigation works impact on a number of properties. However proponents should be aware that if an amendment is required subsequently to the approval, written support will be required from each of the applicants who were parties to the original joint application.

b. Property approach rather than individual works

Where a property is likely to involve a number of works (eg a number of drains, laser levelling, dams, roads) over a period of time, rather than seeking approval for each individual work or activity, it is recommended that the proponent prepares a strategy for managing the property as a whole and submit a single application for the whole property or farm plan. It is recommended that the plan should also include maintenance plans and rehabilitation works to restore any degraded components of the property.

This approach is recommended as it promotes better overall management of the property and provides council with a more complete overview of the likely cumulative impacts with other drains and works as well as the ongoing maintenance and management.

7.3 Information required with an application

If acid sulfate soils are found at a proposed site and are likely to be disturbed, the information from the preliminary assessment phase should be used to develop a soil and water assessment program. An assessment will need to be made of the potential for acid generation, the likely quantities of acid which may be generated, whether it is likely to be discharged to any natural waterways or wetlands and the vulnerability of those wetlands and water systems. This information along with a description of the proposed works to be undertaken, is necessary for the proponent to understand the potential on-site and off-site environmental risks arising from the proposal and for the decision maker to decide on the acceptability of those risks prior to giving an approval.

The information to accompany an application for an approval of works that affect acid sulfate soils should include the following:

- a) a description of the general location - baseline information
- b) a description of the proposed works with an outline of an acid sulfate soil management plan
- c) a assessment of potential impacts
- d) a justification for undertaking the works

a. Description of the general location

In order to understand the overall context within which the proposal is to be undertaken so that an appropriate assessment and management strategy can be designed, an understanding should be gained of the existing environment including:

1. an overview of the topography of the site and surrounding area
    - a) an overview of the past, current and likely future landuse in the area
    - b) identify the extent, distribution and characteristics of acid sulfate soils likely to be affected
    - c) an indication of any existing soils issues or degradation
    - d) the rainfall characteristics

2. an overview of the terrestrial or aquatic ecology in the areas
    - a) present dominant communities; if land clearing has occurred, an indication of past vegetation characteristics if known
    - b) any fishing and aquaculture industries including fish habitat areas

3. an overview of the natural and constructed drainage systems affecting the site including:
    a) the general hydrology of the area including water flows, tidal and flooding patterns
    b) the function and purpose of any drains, levees, floodgates or dams likely to affect the site
    c) an outline of any stormwater or flood management plans or works likely to affect the site
    d) any existing users of the drains or natural waterbodies in the vicinity of the site
    e) any existing land uses or activities which may be drawing down the groundwater
    f) an overview of the general water quality in any natural or constructed drainage or natural system likely to be affected by the works

If risks to the environment are moderate to high, then detailed baseline information will be required. Table 7.2 provides a summary of the types of information that should be provided.

Table 7.2 Baseline site, soil and water characteristics

Site conditions	▪ landform element; elevation (m AHD) with assessment of the reliability of the elevation data (eg, surveyed from known benchmark, topographical map) ▪ climatic information (rainfall, evapotranspiration) ▪ acid scalds or other forms of land degradation
Soils	Soil profile description or bore log. It is recommended that soil profile description be reported in accordance with the NSW Soil Data Card system (available from DLWC). For soil layers or horizons (minimum thickness 0.1m), record at least: ▪ upper and lower depth of soil layers ▪ texture, structure, ripeness, colour (refer Munsell Soil Colour Charts), amount, colour and character of mottles, jarosite mottles, presence and type of concretions, segregations or coarse fragments (eg, shells, gypsum) ▪ field pH_F, peroxide pH_{FOX} and /or approved laboratory ASS laboratory methods, conductivity, bulk density, neutralising requirements (kg lime/tonne or m^3), soil moisture status
Surface water	▪ surface drainage patterns; depth; flow rates and direction of flow; fluctuations (tidal influences, flooding, seasonal) ▪ discharge capacity of surface drains and water interchange with natural waterbodies likely to be affected by disturbance of acid sulfate soils on site ▪ natural wetland systems ▪ pH; Total Dissolved Solids [TDS] or Electrical Conductivity [EC], $Cl^-:SO_4^{2-}$
Groundwater	▪ groundwater depth; direction of groundwater movement ▪ seasonal variability and fluctuations (tidal influence, seasonal) ▪ location of recharge zones ▪ pH, Total Dissolved Solids [TDS] or Electrical Conductivity [EC], $Cl^-:SO_4^{2-}$)
Ecology	▪ existing terrestrial vegetation communities and their general condition; Note the presence of acid tolerant plants, marine vegetation or mangroves ▪ existing aquatic ecology and their general condition
Socio-economic	▪ past and present land and water use ▪ characteristics of the community in the area ▪ likely trends in land use and economic activity in the future

Based on this information, a soil map should be prepared indicating the distribution and sulfide content of the acid sulfate soil across the area to be disturbed and/or influenced by changes in groundwater level. Additional information on soil survey and data collection can be found in the NSW Department of Land and Water Conservation’s *Environmental Impact Assessment Practice Guidelines: Soil and Landscape* (1997).

Surface natural or built drainage systems should be mapped summarising basic hydrological information including flood and tidal characteristics and any interrelationship to the natural wetlands. The general health of these drainage systems should be indicated along with the location of any aquaculture industries and important fishing areas. If groundwater is to be affected, a groundwater map should be provided summarising depths, quality and flow information.

b. Description of proposed works

In order to undertake an assessment of the likely impacts of the proposal, a clear description including maps and diagrams of the proposed works should be provided. Details of all works that involve land formation, excavation or extraction of soil or extractive material or the lowering of the watertable which have the potential to affect acid sulfate soils should be provided.

The types of information required so an assessment can be undertaken include the following:

1. a clear statement as to the purpose or need for the proposed works
2. outline the alternatives considered to achieve the "purpose" and justify the selection of the proposed strategy or works
3. outline the intended land use or strategy and the proposed short and long term management
4. describe the location, scale and nature of any works to be undertaken which will disturb acid sulfate soils
    a) outline the proposed timetable for undertaking the works (including measures to minimise opportunities for the unintentional oxidation of sulfidic material)
    b) the total volumes of materials (soil or water) to be excavated or disturbed
        i) if disturbed material is to be retained on site, the locations where it will be placed and its potential use
        ii) if disturbed material is to be removed from the site, identify its proposed use and the locations where it will be placed or used
5. describe the Acid Sulfate Soils Management Plan
    a) describe the proposed measures to mitigate against potential effects of acid sulfate soils on the works including any engineering or landscaping issues
    b) describe the proposed measures to mitigate against potential effects of acid sulfate soils on the environment
    c) describe the proposed measures to remediate any existing acid sulfate soils problems on the site
    d) describe the proposed monitoring program
    e) outline any proposed field of pilot trials to validate the proposed mitigation strategy
    f) outline any contingency plans to remediate or restore the area should the mitigation strategy fail to comply with performance objectives.

c. Assessment of potential impacts

The assessment of potential impacts on the environment should focus on issues critical to the sustainable management of the proposal and to provide adequate information to decision-makers. The level of assessment should match the likely level of impacts on the environment and the community. In the assessment of the impacts, the flow-on, indirect or cumulative impacts associated with the disturbance of acid sulfate soils may also need to be considered.

If relevant, consultation should be undertaken with experts in terrestrial and aquatic ecology, economics, social and transport disciplines to ensure that a comprehensive assessment is undertaken of all key issues. Issues that may need to be investigated and reported on include the following:

1. Acid sulfate soils

a) identify the extent, distribution and characteristics of acid sulfate soils
b) assess the total potential for generation of acid taking into consideration the scale and nature of the works
c) estimate the likely acid to be generated taking into consideration the proposed mitigation strategy
    i) if disturbed material is to be retained on site, consider the locations where it will be placed and its potential use
    ii) if disturbed material is to be removed from the site, consider the likely off-site impacts from the proposed use and the locations where it will be placed or used

d) assess the adequacy of mitigation strategies taking into consideration the level of certainty in relation to the proposed mitigation technique and site characteristics
   i) to manage the acid sulfate soil over the short and long term
   ii) to manage any acid produced so that water quality performance criteria will be met and maintained.

2. Water issues

a) *Surface water hydrological issues*
   i) identify any works likely to change the surface water drainage patterns over the short and long term
   ii) describe the relationship of the works to the drain, natural waterbody or wetland and the likely extent in the changes in hydrology
   iii) consider the extent of the generation and export of acid leachate as a result of the works
   iv) consider the likely impact on the water quality in the drain, natural waterbody or wetland
   v) outline proposed mitigation measures to manage any adverse impacts
   vi) assess the likely effectiveness of the measures in mitigating impacts

b) *Groundwater issues*
   i) identify any works likely to disturb the watertable over the short and long term as a direct or indirect result of the works
   ii) describe the relationship of the works to any aquifer and any likely changes in the groundwater levels or flows as a result of the works
   iii) consider the likely impacts of any changes in groundwater on the generation and export of acid leachate
   iv) consider the likely impact on the groundwater quality
   v) consider the likely impact of a degradation in water quality on any users (including any interrelated wetlands)
   vi) outline proposed mitigation measures to manage any adverse impacts
   vii) assess the likely effectiveness of the measures in mitigating impacts

c) *Water leachate issues*
   i) outline measures to collect, treat and discharge/use the water likely to be generated as a result of the works
   ii) outline the proposed performance criteria for the treatment
   iii) consider the likely impacts from the treatment, storage, discharge or use of the treated water
   iv) if treated water is to be discharged, clearly identify any discharge points and proposed time of discharge in relation to any tidal movement, flood gate opening or environmental flow levels
   v) identify any cumulative water quality impacts resulting from other urban, infrastructure or agricultural activities affecting the drainage system
   vi) outline proposed mitigation measures to manage any adverse impacts
   vii) assess the likely effectiveness of the measures in mitigating impacts

3. Ecology issues

a) *Terrestrial ecology issues*
   i) describe the relationship of the proposed works to any existing vegetation on the site
   ii) identify any areas where vegetation is to be cleared and where vegetation is to be planted; describe the characteristics of the vegetation, in particular in relation to groundwater levels.

iii) if threatened species, populations or ecological communities or their habitats or critical habitats are likely to be affected, an 8 Part Test will need to be undertaken, and a Species Impact Statement if the impacts are likely to be significant
iv) consider the impact on acid generation of the change in vegetation regimes
v) consider the likely impact on any ecological community from changes in groundwater levels or water quality as a result of the proposed works
vi) outline measures to protect any existing peat communities/layers overlaying potential acid sulfate soils especially from bushfires, drying or shrinking
vii) outline proposed mitigation measures to manage any adverse impacts
viii) assess the likely effectiveness of the measures in mitigating impacts

b) *Aquatic ecology issues*
i) describe the relationship of the proposed works to any aquatic vegetation, instream aquaculture industries, fish breeding grounds or other important aquatic habitats
ii) identify any areas where the aquatic ecology is likely to be affected by the works or changes in water quality; describe the characteristics of the aquatic ecology
iii) if threatened species, populations or ecological communities or their habitats or critical habitats are likely to be affected, an 8 Part Test will need to be undertaken, and a Species Impact Statement if the impacts are likely to be significant
iv) consider the likely impact on any aquatic community from changes as a result of the proposed works - in water quality, aquatic habitat quality, changes in stream or drain flows or patterns, changes in tidal patterns and regimes, etc
v) outline proposed mitigation measures to manage any adverse impacts
vi) assess the likely effectiveness of the measures in mitigating impacts

4. Strategic issues
i) outline the relationship of the works to any drainage network or natural waterway system
ii) outline the relationship of the works to any drainage, estuary, flood, river or catchment management plan
iii) consider the cumulative impacts of activities in the vicinity of the site and the past history of the waterways
iv) assess the contribution of the proposed works to increase or decrease any regional acid sulfate soil problem

5. Other issues which may need to be considered

a) ***Economic factors***
Consider the potential impacts
i) on the economic potential of the land directly affected by the works
ii) on local industries and employment directly or indirectly affected by the proposal, for example commercial fishing industries, tourism and recreational fishing, agriculture or aquaculture
iii) on the property value of the land directly affected by the works or on adjoining land or leases
iv) on water users from any degradation of water quality (ground or surface)
v) from the need to upgrade, construct or maintenance infrastructure such as flood gates, drain maintenance etc
vi) from the rehabilitation of degraded areas
vii) from funding arrangements, rate relief or other incentives

b) ***Community issues***
Consider the potential impacts
   i) on human health associated with change in water quality
   ii) from any increased amenity from the rehabilitation of degraded areas
   iii) from any change in community cohesion.

c) ***Transport and chemical issues***
If large quantities of neutralising agent are required for management, consider the potential impacts from the transport and storage of the material.

d) ***Approvals and standards***
All activities associated with the management of acid sulfate soil must comply with all relevant legislation and standards.

d. Project justification

The application for approval of a proposals must provide a justification for disturbing acid sulfate soils including:

a) justify undertaking the works in the manner proposed
b) justify the selection of the proposed site over other alternatives and a weighing up of the relative beneficial and adverse impacts. Issues to be considered include:
   i) the long term implications for sustainable management of acid sulfate soils on the site
   ii) the likely affects on aquatic or terrestrial ecology
   iii) the level of risks associated with construction and operational management of the works
   iv) the equity of impacts - who benefits and who pays in the short and long term
c) a statement justifying the undertaking of the works in relation to in the broader context, for example in relation to any strategic plan for the property or catchment, any existing cumulative water quality problem or remediation action program.

In justifying the undertaking of the proposal, the principles of ecologically sustainable development should be taken into consideration

THE PRINCIPLES FOR ECOLOGICALLY SUSTAINABLE DEVELOPMENT

In 1997, the Environmental Planning and Assessment (EP&A) Act was amended making one of the objectives of the Act ecologically sustainable development. In exercising any responsibilities under the Act, as an applicant or as consent authority, the four principles should be kept in mind. The following expands on the definition in the EP&A Act.

Ecologically sustainable development requires the effective integration of economic and environmental considerations in decision making processes. Ecologically sustainable development can be achieved through the implementation of the following principles and programs:

Precautionary principle: Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by:

a) careful evaluation to avoid, where practicable, serious and irreversible damage to the environment; and
b) an assessment of the risk-weighted consequences of various options

Intergenerational equity: The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.

Conservation of biodiversity and ecological integrity: The conservation of biological diversity (including genes, species, populations and their communities) and ecological integrity should be a fundamental consideration.

Improved valuation and pricing of environmental resources: Environmental factors should be included in the valuation of assets and services, such as:

a) “polluter pays” that is those who generate pollution and waste should bear the cost of containment, avoidance or abatement
b) the user of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any wastes
c) environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms which enable those best placed to maximise benefits and to minimise costs to develop their own solutions and responses to environmental problems.

8. Determination by the approval authority

8.1 Factors to consider when making a determination

If development approval is required under Part 4 of the Environmental Planning and Assessment Act, the consent authority must consider the heads of consideration under section 79C (under the recent amendment to the Act). These heads require consideration:

a) the provisions of any planning instruments (such as LEPs or DCPs) or matters prescribed in a regulation
b) likely impacts of the development, including environmental impacts on both the natural and built environment and social and economic impacts.
c) the suitability of the site for the proposed development
d) any issues raised in submissions
e) any other relevant matters

If the proposal is assessed under Part 5 of the Act, then consideration must be given to all matters "likely to significantly affect the environment", in making a determination.

In either case, the approval authority has to consider the likelihood of the works resulting in the oxidation of acid sulfate soils and the adequacy of any management strategy. It is recommended that a performance-based approach be taken, as the management of acid sulfate soils and their potential effects can be achieved in a number of ways.

a. Confirming the presence of acid sulfate soils

All proposed works complying to the criteria in an Acid Sulfate Soils Planning Map must:

a) verify the existence and extent of acid sulfate soils on the site
b) provide an assessment of the impacts of the proposal on acid sulfate soils
c) provide an acid sulfate soils management plan (if triggered by the *action criteria*), and
d) provide council with sufficient information to assess the proposal.

The assessment should be performed in accordance with Sections 3-7 of the guidelines. The use of existing soil assessments for a particular site is acceptable provided that the previous soil assessment meets the requirements of the guidelines and fully consider the area to be disturbed by the proposed development.

b. Acceptability of the risk from disturbing acid sulfate soils

The following issues should be considered in assessing the acceptability of potential environmental risks of a project proceeding and whether to approve the proposal:

1. how acceptable are the impacts considering their scope, extent and duration taking into consideration biophysical, social and economic factors?
2. how sensitive is the environment to the impacts?
   a) natural sensitivity eg biodiversity issues relating to aquatic and terrestrial threatened species, populations or communities and their habitats or other areas of natural heritage significance
   b) induced sensitivity because of cumulative impacts of acid sulfate soil disturbance
1. what is the level of certainty in predicting outcomes? Was the soil and water assessment adequate to determining the presence of acid sulfate soils? What was the level of certainty with regard to engineering or hydrological constraints? Are the provisions in the acid sulfate soil management plans adequate?
2. how reversible are the impacts? (consider factors relating to type of impacts and sensitivity of the receiving environment)
3. does the proposal and the potential impacts conform with existing plans, policies, standards and programs or meet the requirements of all standards and regulations

4. is the proposal in line with community values? What is the level of public concern or outrage? Will one sector of the community be disadvantaged to the advantage of others? What will be the impact of the proposal on future generations?
5. is the proposal using environmental resources efficiently in terms of renewable and non-renewable inputs to the project and outputs from the project? Is the proposal adding value to the community resources for present and future generations?

Applicants should consider these performance based assessment criteria when submitting applications for approval.

c. Engineering and landscaping issues

Engineering and landscaping constraints associated with acid sulfate soils should be properly considered as they relate to:

1. foundations of buildings, underground water and sewerage pipes, pier and bridge pylons, concrete slabs, steel fence posts; any other concrete, iron, steel and aluminium alloys;
2. the use of acid sulfate soils for landfill and landscaping and the potential impacts on plant growth in relation to erosion control and landscaping;
3. the load bearing capacity of acid sulfate soils including the potential affect of subsidence on road and building foundations and the potential impacts of compaction on groundwater levels.

d. Consideration of the strategic context

The proposal should be consistent with any strategic initiatives developed for the area such as criteria established to consider regional, catchment or cumulative issues. The project assessment and design should have regard for any relevant:

1. integrated management plans prepared to manage acid sulfate soils in an area
2. interim or final water quality objectives for the river system
3. catchment or subcatchment estuary, flood or drainage management plan.

e. Project justification

The application for approval of a proposal that will disturb acid sulfate soils must provide a justification for disturbing acid sulfate soils. The justification should include:

1. a statement of the objective and purpose of the works to be undertaken
2. a statement justifying the selection of the proposed works over other alternatives and a weighing up of the relative beneficial and adverse impacts.
3. a statement justifying the undertaking of the works in relation to in the broader context for example any strategic plan for the property or catchment.

8.2 Concluding Recommendations

The approval authority and the proponent must assess the potential risk(s) that the proposal may pose to the environment in accordance with the principles of Ecologically Sustainable Development. Caution is urged where uncertainty exists about the ability of a proposal to adequately manage acid sulfate soils or where sensitive environments may be adversely affected by acid discharges. It may be necessary to refuse consent to proposals in accordance with the precautionary principle where risks are unacceptably high or the environmental impact may be significant.

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APPENDIX 1. Field pH and the Peroxide Test

1. Field pH Test

The field pH (pH_F) of actual acid sulfate soils tends to be ≤ 4 while the field pH of potential acid sulfate soils tends to be neutral. Field pH provides a useful quick indication of the likely presence and severity of "actual" acid sulfate soils. The field pH is a qualitative method only that cannot be used as a substitute for laboratory analysis in the identification of acid sulfate soils for assessment purposes.

Field pH readings should be taken at regular intervals down the soil profile. It is recommended this test be done every 0.25 m down the profile but at least every 0.5 m interval or horizon whichever is the lesser.

- pH readings of pH ≤4, indicates that actual acid sulfate soil are present with the sulfides having been oxidised in the past, resulting in acid soil (and soil pore water) conditions.
- pH values >4 and <5.5 are acid and may be the result of some previous or limited oxidation of sulfides, but is not confirmatory of actual ASS. Substantial exchangeable/soluble aluminium and hydrogen ions usually exist at these pH values. Other factors such as excessive fertiliser use, organic acids or strong leaching can cause pH >4 - <5.5. Field pH alone cannot indicate potential ASS as they may be neutral to slightly alkaline when unoxidised.

In order to test for potential acid sulfate soils that contain unoxidised sulfides, peroxide is used to rapidly oxidise the iron sulfides (usually pyrite), resulting in the production of acid with a corresponding drop in pH.

Notes on pH equipment

Preferably a battery powered, field pH meter with a robust, spear point, double reference pH electrode should be used. The probe can be inserted directly into soft wet soils or soil mixed up into a paste with deionised water. Care must be exercised not to scratch the electrode on sandy or gravely soils. The probe should be standardised prior to use and regularly during use against standard solutions according to the manufacturers instructions.

Alternatively, an approximate 1:5 soil:deionised water suspension can be made up in small tubes, hand shaken and pH of the solution measured. pH test strips can be used to give an approximate value (pH +/- 0.25). Raupach soil pH test kits should be used with caution as they can give erroneous results. Both these latter methods are based on mixed indicator solutions that give a pH dependant colour and are subject to interferences .

2. Field Peroxide pH Test

To test for the presence of unoxidised sulfides and therefore potential acid sulfate soils, the oxidation of the soil with 30% (100 volume) hydrogen peroxide can be performed in the field. The most common method is:

- a small sample of soil is placed in a small glass container (eg short clear centrifuge tubes or clear tissue culture clusters) and a small volume of peroxide is dropped onto the soil.

Note: Allow the digested solution to cool after the reaction.
A pH probe will only measure to 60°C.

The reaction should be observed and rated. In some cases, the reaction may be instantaneous; in others, it may take 10 minutes or more. Heating over hot water or in the sun may be necessary to start the reaction on cool days, particularly if the peroxide is cold.

Potentially positive reactions includes one or more of the following:

- change in colour of the soil from grey tones to brown tones
- effervescence
- the release of sulfurous odours
- a substantial depression in pH below pH_F
- pH < 3

The strength of the reaction is a useful indicator. The peroxide test is most useful and reliable with clays and loams containing low levels of organic matter. It is least useful on coffee rock, sands or gravels, particularly dredged sands with low levels of sulfidic material (eg <0.05 % S). With soils containing high organic matter (such as surface soils, peats, mangrove/estuarine muds and marine clays), care must be exercised when interpreting the reaction as high levels of organic matter and other soil constituents particularly manganese oxides can also cause a reaction.

Note of caution with the use of peroxide

30 % hydrogen peroxide is a strong oxidising agent and should be handled carefully with appropriate eye and skin protection. This test should be only undertaken by trained operators.

The pH of analytical grade peroxide may be as low as 3 as manufacturers stabilise technical grade peroxide with acid, The peroxide pH should be checked on every new container and regularly before taking to the field and adjusted to 4.5 - 5.5 with a few drops of 0.1M NaOH if necessary. False field pH_{FOX} readings could result if this step is not undertaken.

3. pH after oxidation

The measurement of the change in the pH $_{FOX}$ following oxidation can give a useful indication of the presence of sulfidic material and can give an early indication of the distribution of sulfide down a core/ profile or across the site. The pH after oxidation test is not a substitute for analytical test results.

If the pH $_{FOX}$ value is at least one unit below field pH $_{F}$, it may indicate potential acid sulfate soils. The greater the difference between the two measurements, the more indicative the value is of a potential acid sulfate soils. The lower the final pH $_{FOX}$ value is, the better the indication of a positive result.

- If the pH $_{FOX}$ < 3 and there was a strong reaction to the peroxide, there is a high level of certainty of a potential acid sulfate soils. The more the pH $_{FOX}$ drops below 3, the more positive the presence of sulfides.
- A pH $_{FOX}$ 3-4 is less positive and laboratory analyses are needed to confirm if sulfides are present. Sands particularly may give confusing field test results and must be confirmed by laboratory analysis.
- For pH $_{FOX}$ 4-5 the test is neither positive nor negative. Sulfides may be present either in small quantities and be poorly reactive under quick test field conditions. In some cases, the sample may contain shell/carbonate that neutralises some or all acid produced by oxidation. In other cases, the pH $_{FOX}$ value may be due to the production of organic acids and there may be no sulfides present. In these cases, analysis for sulfur using the POCAS method would be the best to check for the presence of oxidisable sulfides.
- For pH $_{FOX}$ >5 and little or no drop in pH from the field value, little net acid generating ability is indicated. Again, the sulfur trail of the POCAS method should be used to check some samples to confirm the absence of oxidisable sulfides.

Care is needed with interpretation of the result on highly reactive soils. Some soil minerals other than pyrite react vigorously with peroxide, particularly manganese but may only show small pH changes. When selecting soil for testing it is advisable to avoid material high in organic matter as the oxidation of organic matter can lead to the generation of acid. However, pH of soils containing organic matter and no pyrite do not generally stay below 4 on extended oxidation. In general, positive tests on 'apparently well drained' surface soils should always be treated with caution and followed up with laboratory confirmation.

The field peroxide tests can be made more consistent if a fixed volume of soil (using a small scoop) is used, a consistent volume of peroxide is added and left to react for an hour, and the sample is made up to a fixed volume with deionised water before reading. However, such procedures take time in the field and are more suited to a 'field shed' situation. When effervescence (sometimes violent) has ceased, a few additional mL of peroxide should be added until the reaction appears complete. If the reaction is violent, it is recommended that deionised water be added to cool and dilute the reaction. The test may have to be repeated with a small amount of water added to the soil prior to peroxide addition. The
pH ^{FOX} of the resultant mixture is then measured.

4. Reporting the results

All pH $_{F}$ and pH$_{FOX}$ results along with the strength of reaction should be tabulated by site and depth and reported in the ASS report. An example of a recording sheet is attached.

Table A1.1 Field pH and peroxide results

Proj/Experiment: **OFFICER:** **Date Collected:** **Profile ID:**

Oven No. Date In Oven: Date Out: Date In Freezer: Description:..

Lab No.mm	**SAMPLE NO**	**Core SAMPLE DEPTH**	**SAMPLED** (Must Tick)	**DEPTH pH**	**pH_F**	**pH_{FOX}** Duplicate	**Eff.** Reaction	**EC_F**	**Segr/Frag** SS = shell J = Jarosite R= roots	
		0-0.1		**0.1**						
		0.2-0.3		**0.3**						
		0.5-0.6		**0.6**						
		0.8-1.0		**1.0**						
		1.3-1.5		**1.5**						
		1.8-2.0		**2.0**						
		2.3-2.5		**2.5**						
		2.8-3.0		**3.0**						
		3.3-3.5		**3.5**						
		3.8-4.0		**4.0**						
		4.3-4.5		**4.5**						
		4.8-5.0		**5.0**						

Final Water Height:
Water EC (dS/m=mS/cm**):**
(1000uS/cm= 0.1dS/m)