



## INFORMATION BULLETIN

# ACID SULFATE SOIL AND ROCK

Publication 655.1\* July 2009

## INTRODUCTION

This bulletin provides guidance to landowners, developers, consultants and other people involved in the disturbance of soil, sediment, rock and/or groundwater about identifying, classifying and managing acid sulfate soils and rock.

Waste acid sulfate soils and rock must be managed in accordance with the requirements of the *Industrial Waste Management Policy (Waste Acid Sulfate Soils) 1999* referred to as 'the Policy'.

### What are acid sulfate soils?

The Policy defines 'acid sulfate soil' as:

'... any soil, sediment, unconsolidated geological material or disturbed consolidated rock mass containing metal sulfides which exceeds criteria for acid sulfate soils specified in Publication 655 entitled 'Acid Sulfate Soil and Rock' published by the Authority in 1999 as amended from time to time or republished by the Authority'.

The metal sulfides are principally pyrite –  $\text{FeS}_2$  – and exposure of them to oxygen and water can generate sulfuric acid. This may result in acidification of soil, sediment, rock, surface water and groundwater. Run-off and leachate from acid sulfate soils can adversely impact aquatic communities, agricultural and fisheries practices and engineering works. Acidic leachate can also dissolve aluminium, iron and other metals from soil and sediment, potentially impacting on the beneficial uses of the environment (established in State environment protection policies (SEPPs)).

## IDENTIFICATION, MANAGEMENT AND REUSE

The Policy sets out the requirements for managing the disposal and reuse of waste acid sulfate soils, and specifies the responsibilities of those involved. This bulletin applies once acid sulfate soil is disturbed on a site and becomes a waste intended for reuse on that site or reuse/disposal offsite.

The *Environment Protection Act 1970* defines 'waste' as:

*'...any discarded, rejected, unwanted surplus or abandoned matter.'*

Where the identification and management of acid sulfate soil and rock is required for the purposes of planning and/or land development (including according to the *Environmental Effects Act (2006)* or the State planning policy framework), the *Victorian Coastal Acid Sulfate Soil Strategy* and *Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils* should also be consulted.

Acid sulfate soils and sediments may occur in different environments to those where rocks with elevated levels of metal sulfides are found. Due to differences in chemical and physical properties, they have distinct identification and assessment requirements. For this reason, parts of this publication distinguish between soils (including sediments) and rocks. However, for the purposes of the Policy, acid sulfate soils, sediments and rocks are all identified by the term 'acid sulfate soil'.

## OVERVIEW

Acid sulfate soils and rocks can affect land use and development. Their classification and management needs to be considered during the planning stage - before land is cleared, drained or construction works begin.

Disturbance of acid sulfate soils and rock can adversely impact land, water and ecosystems in the following ways:

- Environmental quality – affecting soil quality, surface and groundwater quality, and aquatic habitats.
- Agricultural practices – loss of rural productivity, loss of commercial and recreational fisheries, the cost of additional lime and fertilizer requirements and degradation of drainage systems.
- Engineering and landscaping works -- the corrosion of concrete and steel and the design of transport structures (i.e. road or rail), buildings, embankments and drainage systems to avoid impacted areas.
- Human health – skin and eye irritation, contamination of drinking water and occupational health and safety risks.

The potential environmental impact of acid sulfate soils depends on a number of factors, including the following:

\* This replaces publication 655, issued August 1999.

- Exposure to oxidising conditions – acid sulfate soils cannot commence generating acidic discharges unless exposed to oxygen and water.
- The volume, texture and sulfidic characteristics of the soil being disturbed – higher volumes of disturbance, greater porosity (i.e. sands), or higher percentages of sulphide often result in higher rates of acid generation and greater impacts.
- Capacity for self-neutralisation – acidic discharges may be neutralised as they occur, depending on the content and nature of neutralising material present in the soil, including organic material and/or carbonates (e.g. fine-grained shell matter or lime).
- The acid buffering capacity of the receiving environment – for example, some water environments. Acid buffering capacity of soil and water is often limited, so may not provide neutralising capacity in the long term.
- The concentrations of aluminium, iron and other metals in soils or rock and the potential for acidic discharges to dissolve these metals.

These factors will determine the environmental risk posed by acid sulfate soils. Depending on the circumstances, acidic discharges may be harmless in one environment, but hazardous in another. The risk and hazard posed must be assessed on a case-by-case basis.

## ACTIVITIES THAT CAN DISTURB ACID SULFATE SOIL

The following activities may create a disturbance in acid sulfate soil and sediments:

- excavation of land
- lowering the groundwater table
- filling land or stockpiling soil over *in situ* potential acid sulfate soil (PASS) – more than 100 m<sup>3</sup> of fill or stockpiling soil with an average depth of 0.5 m or greater<sup>1</sup>
- planting vegetation or crops that may lower the water table
- coastal or inshore dredging

Activities that may disturb acid sulfate rock and generate finer material include:

- excavating and/or tunnelling
- blasting
- drilling or grinding.

---

1 These activities can force the underlying ASS above the water table at the margins of the added soil or fill.

## OCCURRENCE

### Acid sulfate soils

Generally occur in soil formations that:

- contain elevated concentrations of metal sulfides – either naturally or due to anthropogenic causes.
- were originally deposited in shallow marine or estuarine environments, often appearing as soft, black, dark grey or dark greenish-grey muds.
- are below or above high tide level, but generally between 5 and 20 m AHD<sup>2</sup>.

May be present as:

- PASS – soil that contains unoxidised metal sulfides. This only exists under oxygen-free or waterlogged conditions. If disturbed, it can produce acid
- actual acid sulfate soil (AASS) – soil that has been exposed to oxygen and water, and is already acidic.

Most acid sulfate soils were deposited during the Holocene geological age (the last 10,000 years), for example, the Coode Island Silt formation. However, they may be as old as the Tertiary geological period (more than a million years ago), for example, some of the sandy formations, such as the Brighton Group, that underlie the south-eastern suburbs of Melbourne. Present-day estuarine and marine sediments may also have acid sulfate properties, for example, anoxic sediments in the Hopkins River estuary near Warrnambool.

They may also be present as monosulfidic black ooze (MBO) – a soft, black coloured soil, with high organic content, enriched with iron monosulfide (FeS). MBO commonly occurs on the beds of lakes, swamps, drains and channels. Particular care must be taken when handling it as it tends to oxidise more rapidly than pyrite-based material.

Some mapping of areas with the potential to contain acid sulfate soil in Victoria has been carried out and is included in the *Victorian Coastal Acid Sulfate Soil Strategy* found at [www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil\\_acid\\_sulfate\\_soils](http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_acid_sulfate_soils).

### Acid sulfate rocks

The occurrence of metal sulfides in rocks is not restricted to any particular rock type, depositional environment or age. Metal sulfides can be found in most rocks, however, they generally occur at very low concentrations, where the risk of adverse environmental impact due to acid generation is minimal. At elevated concentrations, the risk becomes higher. They may be concentrated in rocks due to geological processes.

---

2 Australian Height Datum: defined as the mean Australian sea level based on historic data.

Metal sulfides are associated with many ore deposits, including coal, precious metals (e.g. gold, silver, and platinum), base metals (e.g. copper, lead, tin, zinc) and uranium. Acid generation from mine wastes affects many sectors of the mining industry and is one of the most significant environmental issues they face.

In Victoria, for example, metal sulfides are usually associated with gold-bearing sediments found throughout the State. These sediments are usually from Cambrian to Middle Devonian age. Sulfide enrichment is also associated with most coal deposits and has also been found in Silurian aged siltstones that underlie the Melbourne/Ringwood/Kilmore area.

## RISK-BASED APPROACH TO IDENTIFICATION AND CLASSIFICATION

A desktop assessment can be undertaken by a person with limited acid sulfate soil experience or training, but a site assessment and classification must be performed by a suitably qualified and experienced person.

### Desktop and initial field assessment

A desktop and initial field assessment is carried out to determine if acid sulfate soil may be present onsite. It should include the following criteria:

1. Potential for the site to be an acid sulfate soil risk area based on –
  - whether acid sulfate soil has been previously identified at or near the site
  - whether the site is located in a Prospective Land Zone as indicated by the Coastal Acid Sulfate Soil hazard mapsor
  - whether the site, or area to be disturbed, is at or below 5 mAHD and the natural ground surface is below 20 mAHD.
2. Geological information and visual inspection for presence of sulfides. This can be used to assist in the identification of acid sulfate rock. Sulfide minerals in rock usually have either a shiny or dull metallic appearance. If weathered, these minerals may appear tarnished or rusty.
3. Field indicators for soil and water. These are used to assist in the identification of acid sulfate soils. Refer to Appendix 1 for the field indicators list.
4. Field soil pH testing. This provides a quick and useful approach to indicate the likely presence of PASS or AASS. The procedure and interpretation of the pH testing is explained in Appendix 1.

If one or more of the above criteria is observed, then further investigation should be undertaken to confirm whether acid sulfate soils or rock are present.

## SITE ASSESSMENT PRIOR TO DISTURBANCE

Sampling equipment must be chosen to ensure that soil is sampled *in situ* and that minimal amounts of oxygen and water are introduced to the soil profile during or after sampling. A variety of mechanical and manual techniques are available (refer to Ahern et al., 1998).

Table 1 includes sampling frequencies for assessment of acid sulfate soils. For the assessment of rocks, sampling frequencies may be determined by the assessor based on site conditions, provided that a sufficient selection of samples is obtained to adequately characterise and classify the material.

Samples should be collected at each change in soil horizon, or every 0.5 m (including a surface sample), to a total depth of one metre below the proposed development depth, or two metres below the surface (whichever is greater).

A field description of the soil should be noted, including: location, depth, colour, texture, and presence of field indicators (Appendix 1), organic matter or shell fragments. All visible shell fragments must be removed during sampling.

The presence and severity of acid sulfate soils and rocks can be confirmed by laboratory analysis. Samples should be delivered to a NATA-accredited laboratory within 24 hours of collection. If required, they may be frozen, or oven dried to 80-85°C in a fan forced oven and stored in a low-humidity environment, until received by a laboratory. Analytical methods for determination of acid sulfate properties are described in Appendix 2.

Particle size analysis should be undertaken to ensure suitable criteria are used for specific soils.

In addition to assessment for acid sulfate properties, an assessment should also be undertaken for potential contamination by metals and other wastes. Acid sulfate soils that are contaminated with metals or other wastes require management in accordance with the *Environment Protection (Prescribed Waste) Regulations 1998* in addition to management in accordance with the Policy.

**Table 1: Sampling frequency for acid sulfate assessment of waste soil**

Type of disturbance	Extent of site	Sample point frequency
Small volumes (<1000 m <sup>3</sup> ) – prior to disturbance	Volume of disturbance: <250 m <sup>3</sup> 250–1000 m <sup>3</sup> >1000 m <sup>3</sup>	2 boreholes 3 boreholes As for area-based (see below)
Area-based – prior to disturbance	Project area: <1 ha 1–2 ha 2–3 ha 3–4 ha >4 ha	4 boreholes 6 boreholes 8 boreholes 10 boreholes 2 boreholes per ha
Linear (<100 m in width) - e.g. a pipeline	N/A	At 100 m intervals
Stockpiles	N/A	As per EPA publication 1178

### CLASSIFICATION OF ACID SULFATE SOIL

The criteria for determining whether soils and rocks have potential to generate acid, and are therefore classified in accordance with the Policy as acid sulfate soils, are listed in Appendix 3. These criteria are based on soil texture (for soils only) and/or chemical measures. Analytical methods for these measures are explained in Appendix 2.

There are separate criteria for soils and for rocks. If any of the criteria is in excess of the tables in Appendix 3, the material is classified as acid sulfate soil, regardless of whether it is soil or rock.

In the case of soils, the criteria also relate to soil texture. The clay content of soil influences the amount of sulfuric acid generated after soil disturbance. Clay-rich soils generally have a higher natural pH buffering capacity than clay-poor soils. This means that they can neutralise more acid than clay-poor soils. As a result the levels of oxidisable sulfur in the soil, which require management action, vary with clay content. Particle size analysis should be undertaken to ensure suitable criteria are used for specific soils.

### MANAGEMENT MEASURES

Sites that contain, receive or propose to receive waste acid sulfate soils need to be assessed and managed to avoid adverse environmental impacts. You can only dispose of or reuse waste acid sulfate soil at premises that have an appropriate licence under the *Environment Protection Act 1970* or an Environmental Management Plan (EMP) approved by EPA. In accordance with the Policy, onsite management of waste acid sulfate soil may take place where best practice environmental management guidelines, which have been approved by the Authority, are used.

Information obtained during the site assessment will assist in developing project and site specific acid sulfate soils management plans. This information should include knowledge of the lateral and vertical extent of acid sulfate soils, groundwater characteristics and specific geochemical composition.

In situations where acid sulfate soils may be disturbed during development (such as excavation, exposure, dewatering or placement of fill), the site should be managed to avoid and control adverse environmental impacts. If they are excavated and brought to the surface, specific management and handling of the soil will also be required.

The suitability of management measures will depend on the nature and location of the acid sulfate soils. The hierarchy for management is:

- 1 **Avoid disturbance**
- 2 **Minimise disturbance**
- 3 **Prevent oxidation**
- 4 **Treat to reduce or neutralise acidity**
- 5 **Offsite reuse or disposal**

### Common management approaches

Acid sulfate soil management plans may require the implementation of several management strategies in order to be effective. The explanations below give a brief summary of common management approaches within the management hierarchy. For more information consult the *Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils*.

#### Avoid disturbance or drainage of acid sulfate soil

Select areas onsite or alternative sites which do not contain acid sulfate soils.

### Minimise disturbance or drainage of acid sulfate soil

Project works can be designed to minimise the need for excavation or disturbance of acid sulfate soils.

### Prevent oxidation

This may include placing PASS into an anaerobic environment, usually below the water table. However, AASS must not be disposed of below the water table without prior neutralisation or implemented control measures.

### Minimise oxidation rate

This may include covering (capping) exposed material with low permeability soil (such as clay) to reduce oxygen availability and to prevent infiltration of water, reducing the potential for leaching. Additional methods may include securing high-density polyethylene (HDPE) sheeting over acid sulfate soils for short periods, or controlling bacteria and other limiting factors (e.g. alkalinity) by either physical or chemical means to reduce oxidation rate.

### Separate higher risk acid sulfate material from lower risk materials

Strategic excavation of soil to keep high risk and lower risk materials separate can minimise the volume of acid sulfate material requiring management. This may also include sluicing or hydrocycloning techniques (often used during dredging), to separate acid sulfate fines from non-acid sulfate material, followed by treatment and/or disposal of acid sulfate fines.

### Provide an agent to neutralise acid as it is produced

Typically, this would involve mixing the acid sulfate soil with lime or another neutralising agent, at predetermined rates. The rate of lime application must be managed carefully to avoid mobilisation of other compounds in soil such as ammonia. Verification testing should be carried out following treatment to confirm an acceptable rate of neutralisation.

### Contain and treat acid drainage to minimise risk of significant offsite impacts

Typically, this would involve installing a leachate or run-off collection, storage and treatment system, ensuring that leachate or run-off does not infiltrate into local sewers, soil, groundwater or surface water receptors.

### Manage stockpiled materials

Stockpiled acid sulfate soil material needs to be managed to ensure no adverse environmental impacts occur. This may include placement of stockpiles on low permeable bases, application of lime beneath stockpiles, bunding around the storage area, minimising the quantity and duration of material requiring storage, covering with HDPE sheeting to minimise infiltration and limit oxygen exposure, diverting upgradient stormwater run-off, controlling

erosion and collection/treatment of run-off and leachate.

### Reuse of treated acid sulfate soil onsite

Actual acid sulfate material may be reused onsite if it has been treated and has undergone testing to verify the effectiveness of that treatment. You should ensure that the geotechnical properties are acceptable for the desired use. If reburial is planned, the pit walls and base should be limed, at a predetermined rate, prior to backfill. You should prepare and implement an EMP for the management of this waste.

### Offsite disposal of acid sulfate soils

Acid sulfate material may be removed offsite and reused or disposed of in accordance with the Policy.

### Other management approaches

Innovative site-specific management measures should be trialled on a small scale and assessed prior to inclusion in a management plan. Additionally, acid sulfate soils management and any proposed alternative approaches to management, should be approved by EPA prior to implementation.

## DISPOSAL OR REUSE OF WASTE ACID SULFATE SOIL

In accordance with the Policy, off-site disposal or reuse of waste acid sulfate soil may only occur at premises that are:

- licensed to dispose of that type of waste under the *Environment Protection Act 1970*
- or
- where an EMP, prepared in accordance with the Policy, has been approved by the Authority.

An EMP should be prepared for all proposals likely to disturb acid sulfate soils and must be prepared for all sites receiving waste acid sulfate soil.

### Environmental management plans

An EMP is a document signed by the occupier of the premises, or by an officer authorised by the occupier for this purpose, that describes how the occupier will achieve acceptable environmental outcomes, including compliance with the Policy and all other applicable legal requirements by specifying detailed operating conditions. Matters that must be included in an EMP are specified in the Policy and must include a community engagement strategy.

EPA also considers these issues in assessing any application to amend a licence to allow for the disposal or reuse of such soils at a site.

Requirements of EMPs are broadly framed to enable them to be carefully tailored to address the specific issues faced by occupiers on a case-by-case basis.



### Exemptions from EMP requirement

Waste acid sulfate soils sourced from a subaqueous environment, which are intended to be directly disposed of to a marine or estuarine spoil ground do not require an EMP, but still require careful management. Approval of the appropriate regulatory authority must be obtained, oxidation minimised, and disposal conducted in accordance with current best practice for dredging.

An occupier of premises regulated under the *Mineral Resources (Sustainable Development) Act 1990* ('MR Act') or the *Extractive Industries Development Act 1995* ('EI Act'), and exempted under Part 3 of the *Environment Protection (Scheduled Premises and Exemptions) Regulations 2007* is also exempt from the need for an EMP for on-site handling of waste acid sulfate soil sourced from the premises.

The MR and EI Acts require sites to be licensed and have an approved work plan, including an EMP. The Department of Primary Industries is responsible for

the administration and approval of licences and work plans under the MR and EI Acts. It is anticipated that licences and work plans issued pursuant to these Acts would, where necessary, place management requirements on operations consistent with the objectives of the Policy.

### Application for approval of EMP

EPA recommends that before applying for approval of an EMP, you contact the relevant EPA regional office to discuss the contents of the plan and identify other information that may be required.

The *Environment Protection Act 1970* has substantial penalties that apply to individuals, companies and/or directors for pollution of land, surface water and groundwaters.. Everyone involved with acid sulfate soil should ensure they comply with the legislation, relevant State environment protection policies, industrial waste management policy and other environmental requirements.

## FURTHER INFORMATION AND REFERENCES

Additional detailed information on the assessment and management of acid sulfate soils is contained in:

- Ahern CR et al. 2004. *Acid Sulfate Soils Laboratory Methods Guidelines*. Queensland Department of Natural Resources, Mines and Energy, Queensland.
- Ahern, C.R et al. 1998. Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland. QASSIT, Department of Natural Resources, Queensland.
- Australian Government Department of Industry Tourism and Resources, 1995-8. *Best Practice Environmental Management in Mining* (series).
- Dear SE et al., 2002. Soil Management Guidelines. In *Queensland Acid Sulfate Soil Technical Manual*. Department of Natural Resources and Mines, Queensland.
- Department of Environment and Conservation 2009, *Identification and Investigation of Acid Sulfate Soils and Acidic Landscapes: Acidic Sulfate Soils Guidelines Series*. West Australia.
- Department of Sustainability and Environment, in draft 2009. *Victorian Coastal Acid Sulfate Soil Strategy*.
- Department of Sustainability and Environment, in draft 2009. *Victorian Best Practice Guidelines for assessing and managing coastal acid sulfate soils*.
- EPA 2001. *Best practice environmental management: Guidelines for dredging*, EPA publication 691.
- EPA 2007, *Soils sampling guideline (Off-site management and acceptance to landfill)*, EPA publication 1178.
- EPA 2009. *Sampling and analysis of waters, wastewaters, soils and wastes*. EPA publication IWRG701.
- Miller S, Robertson A, Donahue T 1997, *Advances in Acid Drainage Prediction using the Net Acid Generation (NAG) Test*, 4th International Conference on Acid Rock Drainage, Vancouver, BC
- Sobek AA, Schuller WA, Freeman JR, Smith RM 1978, *Field and Laboratory Methods Applicable to Overburdens and Minesoils*, USEPA Publication EPA-600/2-78-054
- Standards Australia series AS 4969, 2008/9, *Analysis of acid sulfate soil – Dried samples – Methods of test*.

These publications should be consulted when assessing the likely occurrence, extent and management options for acid sulfate soils and rock.

Where documents are reviewed or updated, the most recent version should be used.

### EPA Contact

Please see the 'Contact Details' page of EPA's website [www.epa.vic.gov.au](http://www.epa.vic.gov.au).

## APPENDIX 1: INITIAL FIELD ASSESSMENT FOR ACID SULFATE SOIL

### Field indicators for soil

Field indicators for AASS include:

- water of pH <5.5 in groundwater or adjacent streams, drains, groundwater or ponding on the surface
- unusually clear or milky blue-green drain water within or flowing from the area (aluminium released by the acid sulfate soils acts as a flocculating agent)
- extensive iron stains on any drain or pond surfaces, iron-stained water or ochre deposits
- any jarositic (jarosite is a pale yellow mineral deposit which can precipitate as pore fillings and coatings on fissures) horizons or iron oxide mottling in auger holes or recently dug surfaces; with a fluctuating water table, jarosite may be found along cracks and root channels in the soil – however, jarosite is not always found in actual acid sulfate soils
- jarosite present in surface encrustations or in any material dredged or excavated and left exposed
- corrosion of concrete and/or steel structures
- dominance of mangroves, reeds, rushes and other swamp-tolerant vegetation – including estuarine occurrences of swamp paperbark (*Melaleuca ericifolia*), swamp mahogany (*Eucalyptus robusta*) and swamp oak (*Casuarina glauca*).

Field indicators for PASS include:

- typically waterlogged, soft muds (soft, buttery texture) or estuarine silty sands
- mid to dark grey to dark greenish-grey coloured soils or sediments
- offensive odour, predominantly due to 'rotten egg gas' (H<sub>2</sub>S).

### Field indicators for groundwater

Groundwater indicators for acid sulfate soils are:

- pH <5.0
- elevated dissolved sulfate
- dissolved mass-based chloride:sulfate ratio (Cl:SO<sub>4</sub>) < 4.0.

The presence of these indicators may not necessarily be due to the presence of acid sulfate soils and further assessment should be conducted if one or more of these indicators are present.

### Field pH tests

Field pH tests are carried out to indicate the likely presence of PASS or AASS. The tests may be conducted in the field by a trained practitioner, or in a NATA-accredited laboratory.

The test involves measuring soil pH before and after oxidation using the following parameters:

pH<sub>F</sub> – measure of soil pH of a soil:water paste

pH<sub>FOX</sub> – measure of soil pH after rapid oxidation with hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>)

Effervescence (or reaction rate) – a visual measure of the vigorousness of the oxidation reaction where: 1 = slight; 2 = moderate; 3 = high; and 4 = extreme.

Interpretation of the results and actions required are summarised in Table 2. Even if only one positive result is obtained, the required action should be followed.

Detailed information of the testing technique is presented in the *Acid Sulfate Soils Laboratory Methods Guidelines 2004*.

**Table 2: Interpretation of field pH results**

pH <sub>F</sub>	pH <sub>FOX</sub>	ΔpH	Reaction Rate	Action required
≥ 5.0	≤ 5.0	≤ 2	1-2	If no other field indicators or acid sulfate soil risk indicators are present, no further action is required
> 4.0 and < 5.0	> 3.0 and < 5.0	> 2	≥ 2	PASS may be present, further assessment is required
≤ 4.0	≤ 3.0	> 2	≥ 2	AASS or PASS are likely to be present, further assessment is required

## APPENDIX 2: ANALYTICAL METHODS FOR ACID SULFATE ASSESSMENT

Prior to analysis, the most appropriate method for analysing acid sulfate soil or rock should be selected.

### Selection of analytical methods

Selection of appropriate assessment, sampling and analytical methods should be based on characterisation of the material in terms of the unconfined (or uniaxial) compressive strength of an intact sample of the material. These estimates can be determined using simple field techniques as follows:

- Soil and sediments – geological material that has an unconfined compressive strength less than 25 megapascals (MPa), that is, an intact sample can be deeply cut with a knife, crumbled with a pick, or flattened or powdered with a hammer. Materials in this category include soil, sediment and very weak rock, which are estimated to behave as soil under field and analytical conditions. Assess using the risk based approach and analytical methods for acid sulfate soil.
- Rock – geological material that has an unconfined compressive strength greater than 25 MPa, that is, an intact sample can at most be shallowly cut or scratched with a knife, indented deeply with a pick, or shattered into many small fragments with a hammer. Materials in this category include weak through to very strong rocks which are estimated to behave as rock materials under field and analytical conditions. Assess using the risk based approach and analytical methods for acid sulfate rock.

### Analytical methods for soil

Analysis of acid sulfate soils should include determination of existing and potential acidity and acid neutralising capacity.

Potential acidity is assessed using one of the following methods:

- $S_{CR}$  or  $S_{POS}$  – measures sulfide content and is used to calculate potential sulfidic acidity
- TSA or TPA – measures acidity from sulfide oxidation minus self-neutralising capacity

Existing acidity is assessed (if  $pH_f$  is  $<5.5$ ) using one of the following methods:

- TAA – measures recently generated and soluble acidity
- Acid-soluble sulfur (SNAS and SRAS) – measures acidity retained on non-soluble minerals.

Acid-neutralising capacity (ANC) measures the self-neutralising capacity of the soil.

The net acidity calculation requires conversion of all results into either %S or mol  $H^+$ /tonne units. Net acidity is calculated by the following method:

$$\text{Net acidity} = \text{Potential acidity} + \text{actual acidity} + \text{retained acidity} - (\text{ANC}/\text{FF})$$

where FF = fineness factor, assumed to be 1.5 for safety.

A positive net acidity indicates that the soil has the potential to generate acid. A negative net acidity indicates that a soil is unlikely to generate significant amounts of acid.

Either the 'suspension peroxide oxidation combined acidity sulfur' (SPOCAS) or 'chromium reducible sulfur' ( $S_{CR}$ ) suite methods may be used to determine net acidity. Detailed information on methods of analysis can be found in Standards Australia series AS 4969 (2008/9) *Analysis of acid sulfate soil*.

Different analytical suites provide different types and levels of information on the soil chemistry. A combination of analyses may be required and a detailed knowledge of soil chemistry is necessary. Professional advice on appropriate laboratory methods should be sought prior to commencement of laboratory analysis. As a general guide:

- the SPOCAS suite is effective for coarser textured sediments
- the  $S_{CR}$  suite is effective for assessing soils with lower percentages of sulfide and for soils containing organic material.

Whichever method of analysis is chosen, it is recommended that a minimum of 10 per cent of samples are analysed using the other method for QA/QC purposes.

### Analytical methods for rock

Analysis of acid sulfate rock should include determination of the net acid generation (NAG) and net acid production potential (NAPP) methods.

The NAG method provides a direct measure of the acid potential of sulfidic rock using:

- final NAG pH – this is the pH of a slurry of the sample that has been oxidised; and
- NAG value – this is the measure of acidity after oxidation of the sample (in kg  $H_2SO_4$ /tonne of rock).

The NAPP method uses two tests to derive the NAPP value. It is similar to acid base accounting (ABA) and uses:

- Acid neutralising capacity (ANC) – which is a direct measure of the amount of acid the sample can neutralise and is expressed in kilograms of sulfuric acid per tonne of rock
- Maximum potential acidity (MPA) – which is calculated from the total amount of sulfur in a sample and is an estimate of the maximum acidity a rock can generate.

The NAPP value is then calculated as follows:

$$\text{NAPP} = \text{MPA} - \text{ANC}$$

Detailed information on methods of analysis can be found in the Miller et al. (1997) and USEPA Method EPA-600/2-78-054.

### APPENDIX 3: CRITERIA FOR ACID SULFATE SOILS

There are separate criteria for soils and rocks. If any of the criteria are exceeded in the appropriate table, the material is classified as acid sulfate soil.

#### Criteria for classification of acid sulfate soil

Texture based criteria for determining whether soils are classified as acid sulfate soils are provided in Table 3.

**Table 3: Texture based action criteria for classification of acid sulfate soil**

Soil or sediment texture <sup>1</sup>	Approximate clay content (%)	Net acidity criteria (1-1000 tonnes)		Net acidity criteria (>1000 tonnes)	
		(%S) (oven-dry basis)	mol H <sup>+</sup> /tonne (oven-dry basis)	(%S) (oven-dry basis)	mol H <sup>+</sup> /tonne (oven-dry basis)
Sands to loamy sands	<5	0.03	18	0.03	18
Sandy loams to light clays	5-40	0.06	36	0.03	18
Medium to heavy clays and silty clays	>40	0.1	62	0.03	18

(Source: Acid Sulfate Soils Technical Manual: Soil Management Guidelines, 2002)

#### Notes

1. Soil or sediment texture is defined in the *Australian Soil and Land Survey – Field Handbook*, McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990), 2nd ed.
2. The %S and mol H<sup>+</sup>/tonne values should be determined using the net acidity calculation from either the SPOCAS or S<sub>CR</sub> methods outlined in the Standards Australia series AS 4969 (2008/9) *Analysis of acid sulfate soil*.

#### Criteria for classification of acid sulfate rock

The criteria for determining whether rocks have the potential to generate acid are given in Table 4.

**Table 4: Criteria for classification of acid sulfate rock**

Final NAG pH <sup>3</sup>	NAPP <sup>3</sup> (kg H <sub>2</sub> SO <sub>4</sub> / tonne)	Classification
<4.5	Positive	Potentially acid forming
>4.5	Negative	Non acid forming

#### Notes

1. Final net acid generation (NAG), pH, NAG value and NAPP calculations are to be determined by the methods given in Miller et al. (1997) and USEPA Method EPA-600/2-78-054.



### APPENDIX 4: FLOW CHART FOR DECISION-MAKING AND ASSESSING REGULATORY OBLIGATIONS

