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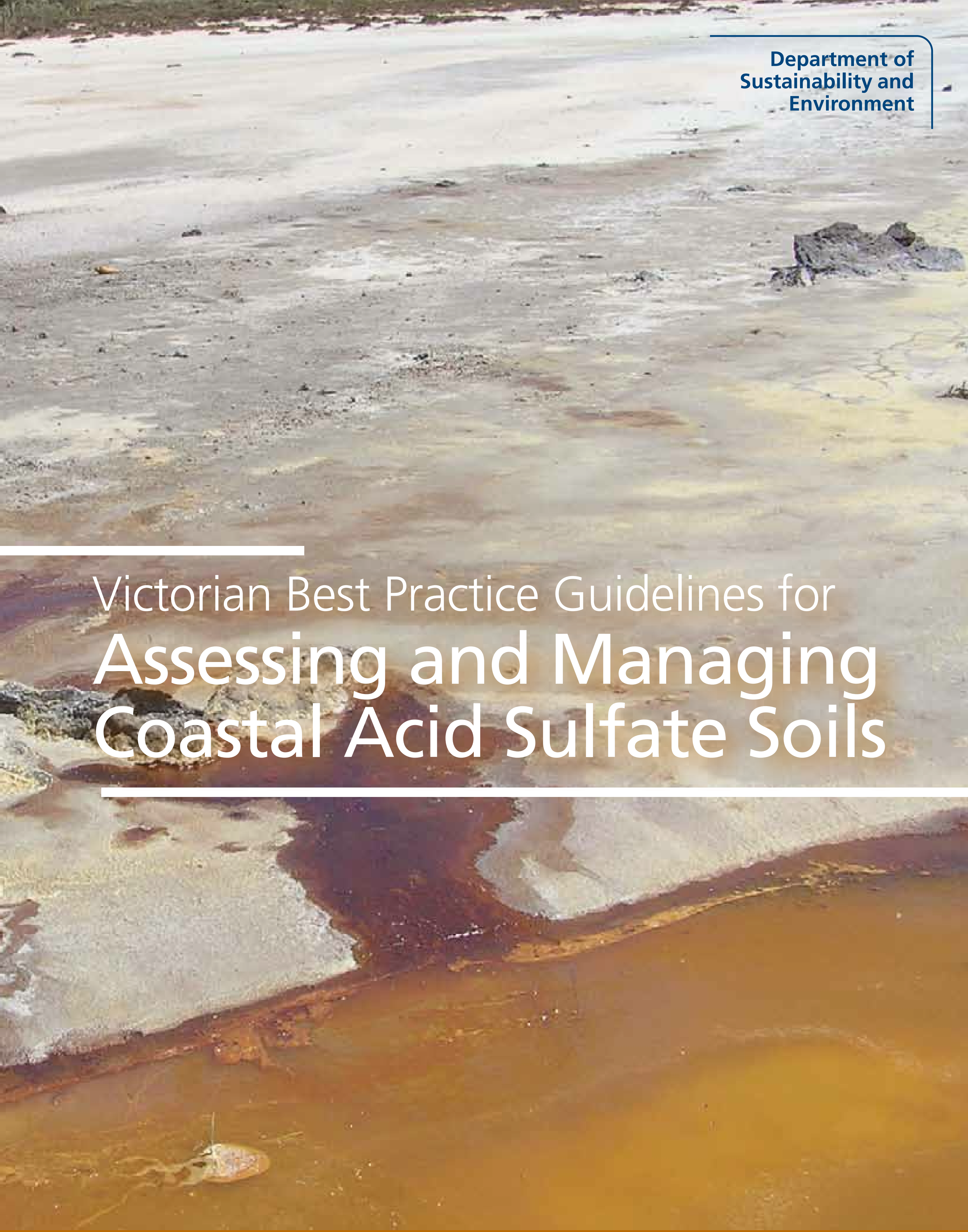

Victorian Best Practice Guidelines for
Assessing and Managing Coastal Acid Sulfate Soils

Australian Government

State Government Victoria

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Acronyms

AASS	actual acid sulfate soil
AHD	Australian height datum
ANC	acid neutralising capacity
ASRIS	Australian soil resource information system
ASS	acid sulfate soil
ASSMAC	Acid Sulfate Soils Management Advisory Committee
AWT	accelerated weathering trial
BPMG	best practice management guidelines
CASS	coastal acid sulfate soil
CASSMP	Coastal Acid Sulfate Soil Management Plan
CASS Strategy	Victorian Coastal Acid Sulfate Soils Strategy
Cl	chlorine
DPI	Department of Primary Industries (Victoria)
DSE	Department of Sustainability and Environment (Victoria)
EC	electrical conductivity
EES	Environmental Effects Statement
EMP	Environmental Management Plan
EPA	Environment Protection Authority (Victoria)
IWMP	Industrial Waste Management Policy (Waste Acid Sulfate Soils)
MBO	monosulfidic black ooze
PASS	potential acid sulfate soil
pH_{FOX}	pH measurement based on peroxide test results in the field
S	sulfur/oxidisable sulfur
S_{CR}/CRS	chromium reducible sulfur
SEPP	State Environment Protection Policy
SO_4	sulfate
S_{POS}	peroxide oxidisable sulfur
TAA	total actual acidity
TDS	total dissolved solids
VCS	*Victorian Coastal Strategy 2008*

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Introduction

Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils (BPMG) has been produced to guide landowners, developers, planners and decision makers through a risk identification approach that will assist them to make decisions about the assessment and management of coastal acid sulfate soils (CASS).

These guidelines implement the actions and objectives of the *Victorian Coastal Acid Sulfate Soils Strategy 2009* (CASS Strategy). The CASS Strategy aims to help protect the environment, humans and infrastructure from the adverse impacts associated with CASS disturbance. The CASS Strategy and the BPMG apply to the potential development of new sites of CASS disturbance, not to the rehabilitation of existing sites if CASS has already been disturbed.

Acid sulfate soils (ASS), which include CASS, occur naturally in coastal and inland settings. These soils contain metal sulfide minerals, which, if drained, excavated or exposed to air, can react with oxygen and water to form sulfuric acid. The formation of acid can corrode concrete and steel. CASS can contaminate food; it can also lead to the release of other contaminants, such as heavy metals, which, when combined with acid, can cause harm to plants and animals, and contaminate drinking water.

CASS disturbance is likely to result in acid production, which has associated environmental, health, engineering, social and economic impacts. This document guides decision makers through a process that will enable them to identify the risks associated with CASS disturbance. Site investigation requirements and considerations for a CASS management plan (CASSMP) are also outlined.

These guidelines will assist in making decisions that are consistent with the principles for managing CASS in Victoria as outlined in the CASS Strategy. Where acid sulfate soil is to be disturbed and managed for the purpose of disposal and/or reuse, the *Industrial Waste Management Policy (Waste Acid Sulfate Soils)* NoS125 1999 (IWMP), *Environment Protection (Industrial Waste Resource) Regulations* 2009 and *Information Bulletin 655.1 – Acid Sulfate Soil and Rock* 2009 (EPA publication 655.1) must also be consulted.

Note:
CASS Policy in Victoria

These guidelines are the first action in the implementation of the *Victorian Coastal Acid Sulfate Soil Strategy 2009*. Work is progressing on the other actions within the Strategy, including determining the most appropriate mechanisms for CASS risk management through the Victorian Planning Provisions. Where appropriate, the CASS risk process outlined in these guidelines will be reflected in the planning system and a process for approval of CASS management plans identified.

In the immediate term, these guidelines will enable informed decision making about the standard of hazard assessment expected in Victoria in relation to managing coastal acid sulfate soils.

The State Government will continue to provide assistance with interpretation of CASS issues and these guidelines. A first port of call is the DSE call centre, which can be reached on 13 61 86.

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Decision-making Principles

The CASS Strategy recommends that the following principles guide decision making in relation to management of CASS in Victoria.

1. **Avoid** disturbing CASS.
2. **Ensure** that any use and/or development proposed near or on potential CASS can demonstrate that it will avoid any disturbance.
3. **Take a precautionary (risk management) approach**[1] when planning and managing high risk activities in areas with the potential to contain CASS.
4. **Discourage** the intensification of use and/or development in areas with the potential to contain CASS.
5. **Assess** impacts and risks of CASS on any land, waterway and water body with a connection to a CASS risk area, and consider the cumulative effect of any use and/or development proposal in areas with the potential to contain CASS.
6. **Assess** risks and impacts on the basis of the CASS Strategy and the BPMG.
7. **Consider** the potential risks and impacts to the environment, humans and infrastructure from disturbing CASS.
8. **Remediate** detrimental effects arising from past and current disturbances of CASS.

Source: Victorian Coastal Acid Sulfate Soils Strategy, Department of Sustainability and Environment, 2009.

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[1] The precautionary principle of sustainability advocates taking action now, despite a level of uncertainty to minimise future risks. The principle may lead to a decision not to take action or not to proceed with a proposal because of a high level of uncertainty about beneficial outcomes.

4

The CASS risk identification and assessment process

The CASS risk identification process is designed to guide any person through a decision-making process for any development or activity proposed on land that has been identified as having the potential to contain CASS.

There are four stages[2] to the risk identification and assessment process; they are outlined in Figure 1 (below).

Stage A: Preliminary CASS hazard assessment.

Stage B: Detailed site soil sampling program and assessment.

Stage C: Surface/ground water sampling program and assessment.

Stage D: CASS hazard assessment.

The impacts of disturbing CASS will vary between sites and can affect the environment beyond the title boundaries of a disturbed site. It is the responsibility of the owner of the site to initiate investigations to determine whether CASS is present, and whether it will not be disturbed at the site and/or in areas beyond the boundaries of the site. This may require detailed site investigations offsite as well as onsite.

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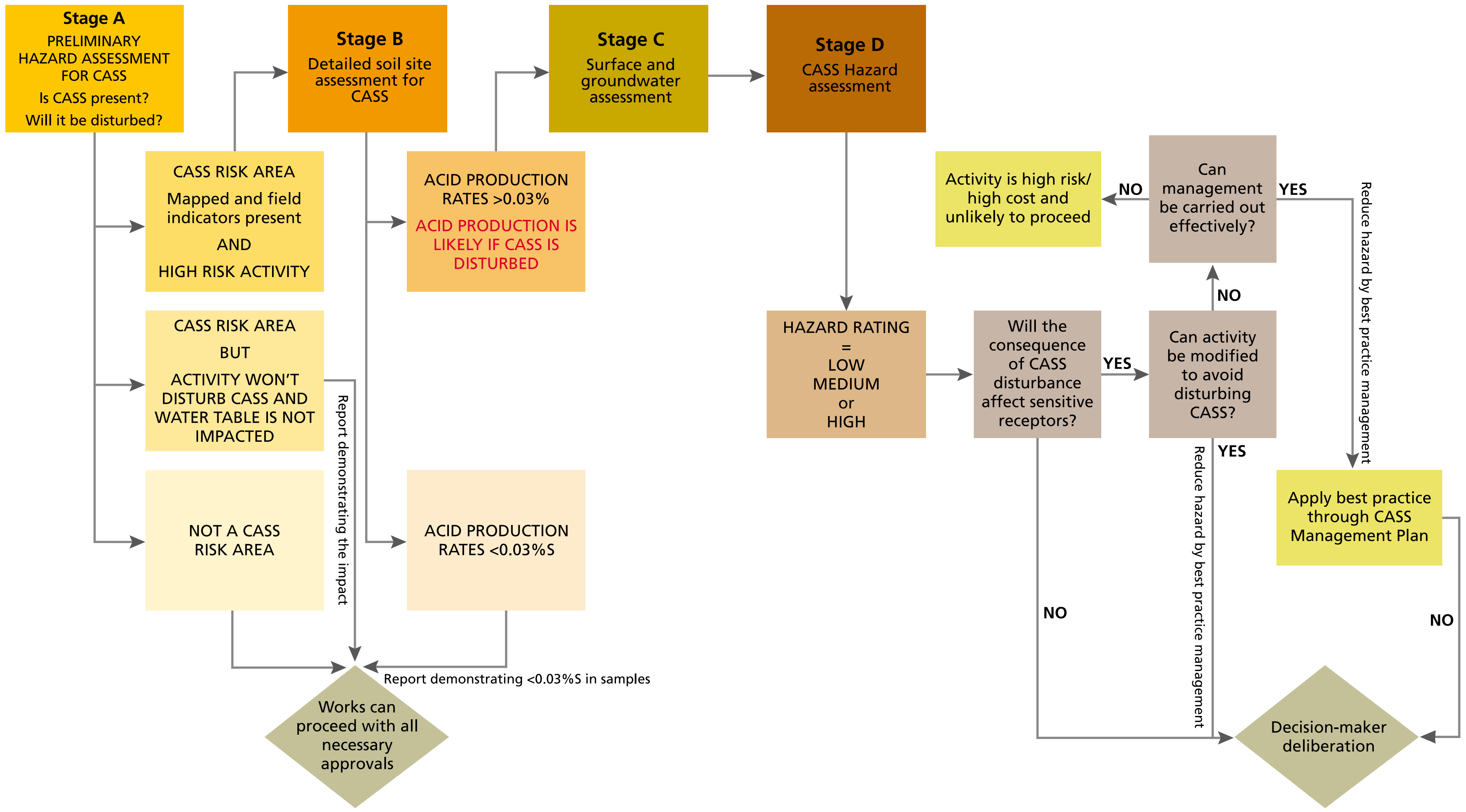
[2] Each stage of the process should be approved by the relevant decision maker; approvals may vary depending on the project characteristics and the requirements of each different phase. Obtaining approval remains the responsibility of the project proponent.

Figure 1: Flow diagram for the Victorian Coastal Acid Sulfate Coils (CASS) risk identification process



This document is a guide for how to implement each phase of the CASS risk identification process.

4.1 Who is best suited to carry out a CASS risk assessment?

A detailed soil site assessment for CASS, surface and groundwater assessment and the preparation of a CASS management plan has to be undertaken by an appropriately qualified and experienced practitioner. A suitably qualified person is a professionally accredited soil scientist[3] or a person with five or more years recognised experience in acid sulfate soil assessment and management.

A preliminary CASS hazard assessment may be undertaken by a person with limited ASS experience or training.

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[3] Such as the Certified Professional Soil Scientist (CPSS) accreditation scheme administered by the Australian Society of Soil Science Inc. (ASSSI) **http://www.cpss.com.au/**

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Stage A: Preliminary hazard assessment for CASS

Stage A of the CASS risk identification process determines the likelihood of CASS being present at a site (CASS risk area) and whether CASS will be disturbed (high risk activity).

Stage A involves undertaking a desktop assessment and may also involve a field inspection. The desktop assessment is a review of available information about the site to determine whether a high risk activity is proposed in a CASS risk area.

5.1 High risk activities

A high risk activity, an activity that may disturb CASS, can include

- excavating soil/sediment (> 1000 m^3)
- extracting or lowering groundwater
- filling land or stockpiling soil (more than 100 m^3 with an average depth of 0.5 m) over *in situ* potential acid sulfate soils (PASS); these activities can force the underlying ASS above the water table at the margins of the added soil or fill
- planting of vegetation (crops or plantation) that may potentially lower the water table
- coastal or inshore dredging.

5.2 CASS risk areas

A CASS risk area is an area

1 where acid sulfate soils have been previously identified at or near the site

or

2 an area identified by mapping as prospective land that has the potential to contain CASS

and

- displaying geomorphic indicators for CASS

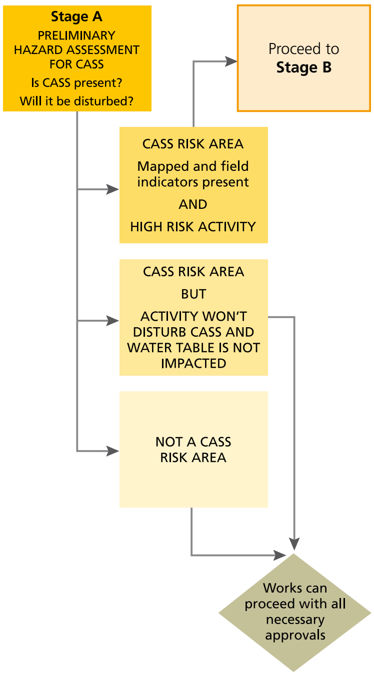
and/or

- displaying soil and water field indicators for CASS(Table 1).

5.2.1 CASS mapping

The most current maps that indicate potential occurrence of acid sulfate soil in Victoria are publicly available and can be sourced from: **www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_acid_sulfate_soils**. The website and maps are updated as new information becomes available.

These maps are also available on the Australian Soil Resource Information System (ASRIS) website at **www.asris.csiro.au/index_ie.html**.



Refer to diagram on page 5.

Note:
Mapping

Mapping land with the potential for CASS occurrence utilised a geomorphic approach. This approach identified areas of higher sea level during the mid-Holocene geological period of Earth (about 10,000 years ago). The higher sea levels resulted in the laying down of sediments that often contain appreciable contents of iron sulfide, usually in the form of pyrite. This geomorphologic mapping was correlated with data derived from comprehensive ground-truth testing of mapped areas. Note that, at the scale of investigations conducted, the boundaries of maps defining areas with the potential for containing CASS provide a guide only.

5.2.2 Geomorphic indicators

If an area has been mapped as having the potential to contain CASS, it must then be assessed to determine if geomorphic indicators of CASS are present. Geomorphic indicators for CASS may include one or more of the following:

1. sediments of recent geological age (Holocene, i.e. last 10,000 years)
2. land and soil at elevations less than 10 m AHD
3. sediments and tidal lakes of marine origin
4. coastal wetlands and swamps, waterlogged or scalded areas, interdune swales or coastal sand dunes (if deep excavation or drainage is proposed), coastal sand sheets
5. areas where the dominant vegetation is mangroves, reeds, rushes, and other swamp tolerant, salt tolerant or marine vegetation such as those mentioned in Appendix A
6. areas identified in geological descriptions or in maps as bearing sulfidic minerals, coal deposits or former marine shales or sediments (geological maps, available at **http://new.dpi.vic.gov.au/earth-resources/geology**, and accompanying descriptions may need to be checked)
7. older estuarine sediments of Pleistocene age (only an issue if these have been preserved in an anaerobic state since they were laid down).

Source: Corangamite Catchment Management Authority training manual, *Acid Sulfate Soils 2008–12.*

More information on CASS occurrence indicators is provided in Appendix A.

5.2.3 Soil and water field indicators

Undertake a field inspection of the site to determine whether any soil and water indicators of CASS are present. The objective of a field inspection is to consider visible soil and groundwater characteristics. A field inspection may also include some basic surface water, groundwater and/or soils analysis. Use the geomorphic criteria to ensure that the areas most likely to have acid sulfate soils are thoroughly investigated during the inspection.

When conducting a field inspection investigate for the presence of actual acid sulfate soils (AASS) and potential acid sulfate soils (PASS) as the field indicators of each type are different. Commonly, AASS are found overlaying PASS, and both AASS and PASS may be covered by non-acid sulfate alluvial topsoil.

Table 1 outlines basic soil and water field indicators of the presence of potential and actual acid sulfate soil.

If soils or associated water bodies demonstrate one or more of the indicators described in Table 1, it can be assumed that acid sulfate soils are present. If this is so, undertake a detailed assessment (Stage B, Figure 1).

Table 1: Landscape, soil and water field indicators for the presence of acid sulfate soil[4]

Soil type	Indicators
acid sulfate soils (ASS)	***Landscape characteristics*** • Dominance of mangroves, reeds, rushes and other marine, estuarine or swamp-tolerant vegetation. • Low lying areas, back swamps, scalded or bare areas in coastal estuaries and floodplains. • Sulfurous (rotten egg) smell after rain following a dry spell or when the soils are disturbed.
actual acid sulfate soil (AASS)	***Landscape and other characteristics*** • Scalded or bare low lying areas. • Corrosion of concrete or steel structures. ***Soil characteristics (one, some or all)*** • Field soil pH ≤ 4. • Presence of shell with or without orange-yellow staining or coating. • Any jarositic (jarosite is a pale yellow mineral deposit that 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. ***Surface 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) and/or • extensive iron stains on any drain or pond surfaces, or iron-stained water and ochre deposits. ***Groundwater characteristics*** • Groundwater pH < 5.0. • Elevated dissolved sulphate and/or • dissolved mass-based chloride:sulfate ratio (Cl:SO4) < 4.0.
potential acid sulfate soils (PASS)	***Soil characteristics*** • Waterlogged soils – soft muds (soft, buttery texture, blue-grey or dark greenish-grey colour) or estuarine silty sands. • 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 when tested with the field peroxide test (pHFOX) and/or • offensive odour, predominately due to rotten egg gas (H2S). ***Water characteristics*** • Water pH usually neutral but may be acid.

Source: ASSMAC, Assessment Guidelines, August 1998, and EPA, Information Bulletin, 655.1, 2009.

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[4] The presence of these indicators may not necessarily be due to the presence of acid sulfate soils; if one or more of these indicators are present conduct further assessment.

A field soil pH assessment provides a quick, useful indication of the likely presence and severity of ASS and PASS. Concentrate field pH testing in Stage A (Figure 1) on areas where the site characteristics indicate that acid sulfate soils may be present. More information on field soil pH tests is described in Appendix B.

5.3 Outcomes of the Stage A preliminary assessment

Three possible outcomes of Stage A preliminary assessment are these.

1. The area is a CASS risk area and the activity proposed is a high risk activity. If this is the case, carry out a detailed soil site assessment (Stage B).
2. The area is a CASS risk area but the proposed activity will not disturb CASS or impact on the watertable. There appears to be very low risk of CASS disturbance. Submit proof that the proposed activity will not disturb CASS, along with an approval application required for the proposal.
3. The area is not a CASS risk area. Works can proceed in accordance with all necessary approvals.

Checklist for Stage A

1 Determine whether the proposed activity is a high risk activity.

If it is, ask these questions.

2 Has CASS previously been identified at or near the site?

or

3 Is the area identified by mapping as land that has the potential to contain CASS?

and

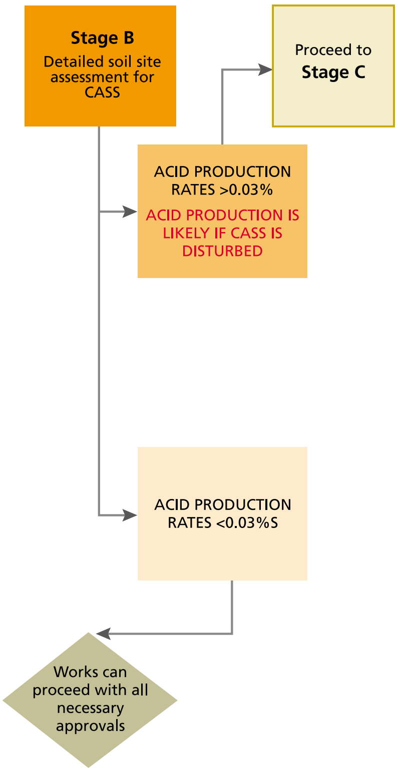
4 Does the area display geomorphic indicators for CASS and/or soil and water field indicators for CASS (Table 1).

If you answer YES to all of the above questions you need to prepare a detailed soil site assessment for CASS (Stage B).

If your answer is NO, then include the outcomes of your preliminary hazard assessment for CASS as part of any approvals required.

6

Stage B: Detailed soil site assessment for CASS



Refer to diagram on page 5.

If the Stage A outcome identifies that a high risk activity is to be undertaken in a CASS risk area, undertake a detailed soil site assessment (Stage B).

Stage B soil site assessment determines the presence of CASS, measures the potential acid production rate of that soil if present and investigates the potential impacts if CASS is disturbed.

The results of this assessment need to include a measure of the acid production rate in %S of the soils. This is consistent with the standard measures specified in *Australian Standard* AS 4969 series and in guideline documentation used in other Australian states.

The level of potential environmental impact caused by disturbance of CASS is dependent on the CASS characteristics at the site, the type of disturbance proposed and the sensitivity of the surrounding environment. The results of the site investigations, including soil sampling and laboratory analysis, will provide baseline data for future monitoring programs at the site.

6.1 Planning a detailed soil site assessment

The Stage B detailed soil site assessment requires the development of a sampling program that will determine the occurrence and characteristics of site soils. Sample locations must be chosen to ensure adequate coverage of the proposed site to determine the location, extent and range of characteristics of CASS within the site. Document the site investigations as part of the overall site assessment; this information will help provide an understanding of the potential impacts if CASS is disturbed.

Information that will assist in planning the Stage B assessment includes:

1. the results of the Stage A desktop and field assessment
2. details of the nature and size of the area to be assessed (including offsite areas) and details of the proposed works
3. map(s) of the site that show site features, including environmentally sensitive areas, sampling locations and areas that may contain CASS
4. geological logs of soil sampling points and lithological information of the site and the surrounding area's stratigraphy (if available) that may be related to any potential CASS impacts

5. 2D vertical transect model of the site and surrounding areas
6. information from the *Atlas of Australian Acid Sulfate Soils* (*ASRIS*), which provides accessible information regarding the attributes of soils and waters (access at **www.asris.csiro.au**)
7. descriptive information gathered during Stage A field investigations, including photographs of the site, landform, vegetation and soil descriptions (together with information supporting geolocation, e.g. identifiable features and spatial coordinates using GPS).

6.2 The soil assessment program

An suitably qualified and experienced practitioner is the person to conduct a soil site assessment. Such a person is a professionally accredited soil scientist[5] or a person with five or more years recognised experience in acid sulfate soil assessment and management.

6.2.1 Sampling density

The number of soil sampling locations required will depend on the nature, depth and size of the disturbance proposed. Most CASS investigations will require a sufficient sampling density to enable an understanding of the occurrence and extent of CASS across the site (in three dimensions, where applicable). In determining the structure of the sampling regime it is important to consider the future land use and development stages.

EPA publication 655.1 provides a guide to sampling frequency requirements, which is reproduced below (Table 2). If identification and management of CASS is required for the purposes of disposal and/or reuse, the EPA sampling guidelines must be followed.

Table 2: Sampling frequency for acid sulfate soil

Type of disturbance	Extent of site	Sample frequency
Small volumes	Volume of disturbance:	
(< 1000 m^3)* – prior to disturbance	< 250 m^3	2 boreholes
	250–1000 m^3	3 boreholes
	> 1000 m^3	As for area-based (see below)
Area-based – prior to disturbance	Project area: < 1 ha	4 boreholes
	1–2 ha	6 boreholes
	2–3 ha	8 boreholes
	3–4 ha	10 boreholes
	> 4 ha	2 boreholes per ha
Linear (< 100 m wide) – e.g. a pipeline	N/A	At 100 m intervals
Stockpiles	N/A	As per EPA publication IWRG702, *Soil Sampling*

Source: EPA, 2009

* To assist in conceptualising this size, an Olympic swimming pool is 2500 m^3 (50 m long x 25 m wide x 2 m deep).

It is also necessary to consider the following soil sampling density requirements.

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[5] Such as the Certified Professional Soil Scientist (CPSS) accreditation scheme administered by the Australian Society of Soil Science Inc. (ASSSI); see **www.cpss.com.au/**.

- The number of sampling points in the survey need to be sufficient to generate a detailed map of soil net acidity and stratigraphy at a better than 1:10,000 scale, which is considered adequate to accurately and efficiently plan engineering works and manage ASS disturbance.
- Extend depth of sampling at each site to a minimum of 2 metres below ground surface and a minimum of 1 metre past the proposed maximum depth of excavation onsite, whichever is deepest. If the proposed maximum depth of excavation is unknown, seek an estimate from project managers and receive it before sampling commences. The only exceptions to the above guidelines are in cases in which:
  - bedrock is reached before the minimum depth of sampling, or
  - sampling equipment consistently fails to retrieve a usable sample to the minimum depth and alternative sampling methods are ineffective or unavailable.
- Note that if either of these cases is applied to a site, a detailed explanation of the conditions is required.
- The minimum number of soil samples retained from each location for analysis is one sample at least every 0.5 m, including a surface sample.
- At least one sample must be collected from each soil horizon.
- Record a detailed field description of each of the soil samples, including location, depth, colour, texture and presence of field indicators (Table 1), organic matter or shell fragments.
- For samples collected for laboratory testing, remove all visible shell fragments during sampling and prior to sealing the sample for preservation.

6.2.2 Field testing

It is recommended that field pH testing (pH_F and pH_{FOX}) be undertaken to determine the location and extent of PASS and AASS horizons. Field pH testing guides the selection of the samples for more detailed laboratory analysis and can help identify changes in sample chemistry between sampling and laboratory analysis (see Appendix B: Field Soil pH Tests).

6.2.3 Sample size

Contact a laboratory prior to sampling to determine the volume of soil required for chemical and physical analysis. Specific preservation and holding times may be required for different analyses.

6.2.4 Sampling equipment

Choose sampling equipment that ensures that soil is sampled with minimal disturbance and that introduces minimal amounts of oxygen or water to the soil profile before and after sampling. A variety of mechanical and manual techniques are available.

6.2.5 Sample handling and storage

The sulfur compounds present in acid sulfate soil can be volatile in nature, so take care during sampling, preservation and storage to minimise the chance of changes in chemistry between sampling and analysis.

Field handling procedures are described in Australian Standard (AS) 4969.1 (AS 4969.1, 2008). More details of laboratory procedures are found in the Australian Standards AS4969-0 to AS4969-14, EPA publication 655.1 and in *Acid Sulfate Soils Laboratory Methods Guidelines* (Ahern et al., 2004). Deliver samples to an NATA accredited laboratory.

6.2.6 Soil texture and buffering capacity

Soil texture will influence the potential impacts associated with disturbance of ASS. Coarse textured soils (e.g. sands) can oxidise more readily than finer textures soils (e.g. silts and clays).

The results of Stage B detailed soil site assessment should provide information on the texture (particle size and buffering capacity) of the sampled soil. If more detailed textural analysis is required, samples can be analysed for soil buffering capacity and particle size distribution at a specialised laboratory.

The buffering capacity of soil is its ability to naturally resist pH change. This will affect the potential impacts of oxidation of CASS. Clays with a high cation exchange capacity (CEC) tend to have a higher buffering capacity than sands or other soils with low CEC. The presence of organic matter can also increase the buffer capacity of soil. Highly effective buffering compounds in some soils are calcium carbonate and Ca-Mg carbonate minerals (e.g. calcareous sand, fine shell, exoskeletons) (Dear et al., 2002).

6.2.7 Laboratory testing and analysis program

To determine net acidity of CASS in %S, laboratory testing of the soil samples is required (Appendix B). Analytical methods for determining the properties of ASS are described in EPA publication 655.1 and in *Australian Standard Methods* (AS 4969 series). Particle size distribution, CEC and total metals concentration analyses might also be required.

Carry out all laboratory testing to conform with the National Association of Testing Authorities (NATA) accredited standards for acid sulfate soil analysis and to the *Australian Standard Methods* (AS4969 series).

Sampling of soil in submerged settings may need to test for monosulfidic black ooze (MBO). Specialised sampling, preservation and analytical techniques for MBO are described in the *Guidelines for the Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland* (Ahern et al., 1998).

6.3 Action criterion level

Consistent with other Australian states and territories, Victoria has adopted the value of 0.03 %S net acidity (oven dried basis) as the action criterion level to define whether there is a need to manage the soils as acid sulfate soil. Use the highest measured %S net acidity values from the soil sampling program as the basis for determining whether the critical level of 0.03 %S net acidity has been met or exceeded. It is not appropriate to use the mean or average of a range of %S values to describe the CASS characteristics of a whole site.

The figure of < 0.03 %S is the minimum action criterion and does not consider soil texture and buffering capacity. The most conservative threshold has been assumed as the determining value. Texture specific action criteria are provided in EPA publication 655.1 for small disturbances only (< 1000 tonnes).

6.4 Interpreting and reporting the results

The outcomes of the Stage B process should determine the existence and nature of CASS. Base the assessment on the results of laboratory testing, including net acidity calculations and the sum of existing plus potential acidity for a given volume of CASS.

If CASS is identified at the site and is likely to be disturbed by the proposed works (i.e. the net acidity is greater than the action criterion of 0.03 %S), then undertake Stage C surface and groundwater assessment to better understand potential impacts on the surrounding water and environment.

The measure of acid production rates (the sum of existing and potential %S) will be used in Stage D to determine the CASS hazard assessment. This will apply when the net acidity is greater than the action criterion of 0.03 %S

If net acidity results are less than 0.03 %S, works may proceed in accordance with all necessary approvals.

Submit the results of the soil site assessment along with other approvals to justify why further CASS assessment is not required. Include in this report maps of the site showing site features, sample locations, sample descriptions and laboratory tests that were carried out as part of the Stage B soil site assessment.

Checklist for Stage B

1 Engage a qualified person to carry out soil site assessment.

2 Use standards described above to plan soil assessment and sampling program.

3 Ensure that sample handling and analysis are undertaken in accordance with relevant Australian Standards.

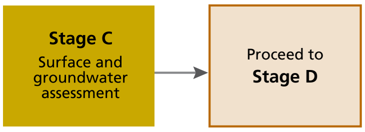
4 Include in the results of this assessment a measure of the net acid production rate in %S of the soils.

5 If the net acid production rate is greater than the action criterion of 0.03%S conduct further assessment of surface and groundwater (Stage C). The net acid production rate %S calculated will also be used in Stage D to determine CASS hazard.

6 If the net acid production rate is less than the action criterion 0.03 %S, works can, with all necessary approvals, proceed.

7

Stage C: Surface and groundwater assessment programs



Refer to diagram on page 5.

Stage C is the development of a surface water and/or groundwater sampling program and assessment. If the Stage B soil assessment finds CASS and the potential acid production rates of the soil are greater than the action criteria level of 0.03 %S, undertake sampling of surface and/ or groundwater.

7.1 The Surface Water Assessment Program

A surface water sampling program is required to understand any water or drainage systems and the potential for the CASS disturbance to impact these systems.

7.1.1 Surface water investigation

The number of water sampling locations and frequency of sampling required will depend on the scale of the works proposed, the characteristics of the waterbody and the nature of the potential impacts associated with the CASS disturbance. Sampling locations may be located upstream and downstream of the site, as well as adjacent to any site where water discharge or seepage is likely to occur.

Water samples, which need to be representative of the water column of the water body under investigation, may require sampling from different depths within the water column. Where stratification of the waterbody is likely, it is necessary to take individual samples from each of the stratified layers.

7.1.2 Sample handling and storage

When sampling water, fill containers to the top to exclude air and chill immediately to minimise chemical activity. Samples must remain at a temperature < 4°C until reaching a laboratory, and must reach a laboratory within specified holding times.

Different analytes require different sample volumes and storage and preservation techniques. Contact a NATA accredited laboratory prior to sampling to determine the volume, preservation and holding time requirements of surface water sampling and analysis.

More details are provided in AS 5667, *Water Quality – Sampling.*

7.1.3 Sample analysis

When presenting water quality measurements, include, as a minimum, the following indicators for surface and groundwaters:

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

The measurement of pH and EC may be taken in field, at the same time as the sample is collected, with appropriately calibrated equipment

Note:

Surface water testing

Where there is the potential for impact to groundwater or surface water as a result of wet weather, runoff, seepage or discharge, include a wet weather sample in the program. Sampling frequencies will be influenced by rainfall pattern and drain or creek flow characteristics.

Automatic, event-controlled, sampler or submersible dataloggers are useful for monitoring water quality changes during wet weather as changes can be rapid and difficult to monitor with standard field instruments.

Soluble iron and aluminium analyses are required only in circumstances where:

- there is a level of uncertainty with mitigation strategies
- major volumes of material containing high concentrations of sulfide are to be disturbed
- drainage from the site may directly affect commercial aquaculture, fish breeding grounds or highly valued ecosystems.

If mitigation strategies, including neutralisation, are likely to result in significant changes in carbonate levels in surface water or groundwater, or if drainage from the site is likely to directly affect commercial aquaculture, fish breeding grounds or highly valued ecosystems, undertake carbonate, bicarbonate and dissolved oxygen analysis.

7.1.4 Interpretation of water quality results

Assess all data collected against the water quality objectives of the State Environment Protection Policy (SEPP) (Waters of Victoria) and its schedules. Provide an indication of:

- the general health of the system and the extent to which the system is already subject to impact of acid sulfate soils or other environmental impacts
- the likely short and long term effects on the system from the proposed works or disturbance
- the likely impacts on the health of the ecosystem, people or animals and buildings and structures from poor water quality.

7.2 The Groundwater Assessment Program

Changing groundwater levels in areas where CASS is present can expose AASS and PASS layers to oxygen and water; it can also generate sulfuric acid, which may impact on the quality of groundwater and associated surface water. It is important to gain an understanding of groundwater hydrology in the area of the proposal and to assess whether the proposed activity may impact on groundwater.

7.2.1 Groundwater investigations

The scale of groundwater investigations will depend on the duration and extent of the proposal and the scale of potential impacts on groundwater levels. Ensure that groundwater assessments are consistent with EPA Publications 668, *Hydrogeological Assessment (groundwater quality) Guidelines* and 669, *Groundwater Sampling Guidelines.*

If groundwater impacts could be significant (i.e. large areas or deep groundwater drainage), complete the following site specific investigations (see Note: Groundwater assessments).

- Determine the depth to the watertable with an indication of the scale of variations (e.g. seasonal, tidal, etc.).
- Identify environments that are dependent on groundwater, e.g. wetlands, springs, rivers and creeks and any likely groundwater recharge areas.
- Identify the hydraulic characteristics of the aquifer (hydraulic conductivity, aquifer thickness, type, porosity, storage and transmissivity), groundwater gradient and flow direction and soil permeability.
- Identify any existing groundwater users, density of bores and extraction volumes onsite and on surrounding sites.
- Identify current groundwater quality and the likely changes if CASS disturbance were to take place.

Note: Groundwater assessments

Groundwater and surface water can be connected in a number of ways. Although it is not always obvious, surface water in many rivers, dams, creeks, lakes and wetland areas is likely to be connected to groundwater resources in a number of ways including

- groundwater flowing into rivers and streams to contribute to base flow
- surface water recharges groundwater through seepage
- extraction of groundwater to supplement surface water flow.

Sites where surface water is linked to the groundwater may have a larger area of impact if CASS is disturbed.

Other groundwater users have the potential to affect the potential impacts of CASS disturbance. If the existing groundwater use is low the impact of a potential disturbance on existing groundwater users is likely to be low; however, groundwater ecosystems also need 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 may be minimal.

If large scale adverse impacts due to disturbance of CASS are indicated by the groundwater investigation modelling of the changes to the groundwater system and possible groundwater to surface water interaction scenarios may be required.

Developed a systematic sampling strategy carry out the investigations listed above and to understand the groundwater system and any potential impact of the proposal.

The appropriate number of sampling locations and frequency of sampling will be depend on the scale of the proposed activity, the nature of the potential impacts and the existing uses of the groundwater resource. For large scale groundwater disturbances and proposals establish dedicated piezometers to monitor changes in groundwater table and water chemistry. Where large scale or long term disturbance is anticipated, consider the installation of semicontinuous water level recorders. Plan and consider the water sampling infrastructure in any approval process prior to investigations being carried out.

Water samples from different depths within the water column will be required and will need to be representative of the local hydrogeological conditions. Take individual samples from each monitoring point.

7.2.2 Sample handling and storage

When sampling water, fill containers to the top to exclude air and chill immediately to minimise chemical activity. Samples must remain at a temperature < 4°C until reaching a laboratory, and must the laboratory within specified holding times.

Different analyses require different sample volumes and storage and preservation techniques. Contact a NATA accredited laboratory prior to sampling to determine the volume, preservation and holding time requirements of groundwater sampling and analysis.

7.2.3 Interpretation of water quality results

Assess all data collected against the water quality objectives of the SEPP (Groundwaters of Victoria). Baseline data should provide an indication of:

- the general health of the system and the extent to which the system is already subject to impact of acid sulfate soils or other environmental impacts
- the likely short and long term effects on the system from the proposed works or disturbance
- the likely impacts on the health of the ecosystem, people or animals and buildings and structures from poor water quality.

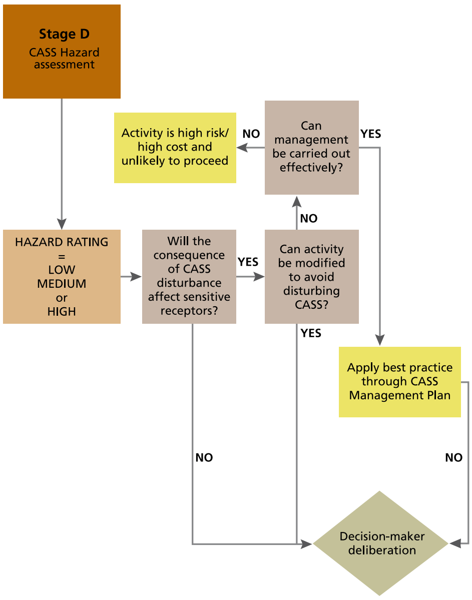
These results will inform Stage D of the CASS risk identification process (Figure 1). The results, along with the Stage B detailed soil assessment and Stage D CASS hazard assessment, will guide suggested management measures that have to be undertaken to manage impacts associated with the disturbance.

Check list for Stage C

1 Engage a qualified person to carry out surface and groundwater assessment.
2 Plan the surface and groundwater assessment and sampling program using standards described above.
3 Ensure that sample handling and analysis are undertaken in accordance with relevant Australian Standards.
4 Measure the results of these assessments against the water quality objectives of the State Environment Protection Policy (SEPP) Waters of Victoria and its schedules, and the State Environment Protection Policy (SEPP) Groundwaters of Victoria.
5 The results will inform the consideration of management of CASS hazard identified in Stage D.

8

Stage D: CASS hazard assessment



Refer to diagram on page 5.

If the Stage B assessment finds soils that exceeds the acid sulfate soil action criterion (0.03 %S), then a Stage D assessment must be carried out.

The purpose of a Stage D assessment is to determine the level of hazard associated with the CASS disturbance and to use the hazard rating to determine the planning and management strategies that can be implemented to prevent any adverse impacts due to the CASS disturbance.

Table 3 presents the CASS hazard ratings (low, medium, high). A hazard rating is based on laboratory results from the Stage B assessment (existing and potential acidity as %S) and the tonnes of CASS to be disturbed in the proposal. There is a general correlation between the level of treatment required (reported as liming rate) and the potential environmental risk.

The results of the Stage D assessment may trigger action outlined in other environmental protection and control legislation, such as the *Environment Effects Act 1978* (Vic.) and the *Environment Protection and Biodiversity Act 1997* (Vic.). Ultimately, it is the responsibility of a proponent to ensure that the project will not result in environmental damage under any relevant Australian or Victorian regulation or legislation.

8.1 The CASS hazard table

The CASS hazard table (Table 3) outlines the requirements of an assessment of hazard based on the percentage sulfur (%S) of the soil and the estimate of tonnes of soil to be disturbed. The Hazard table guides the level of management needed to reduce risks to the environment, infrastructure and human and animal health. These management options are further informed by answering the questions posed in section 8.2, which help to fully identify the risks of disturbing the CASS hazard.

The following hazard requirements are those outlined in Table 3.

8.1.1 Low or medium hazard

CASS disturbance may proceed with management strategies planned as part of the works. The CASS risk identification process outlines a number of questions that need to be considered to outline the potential impacts and to determined an appropriate management response.

8.1.2 High hazard

Avoid disturbance of CASS. In cases where avoidance is not possible, proposals may only proceed with careful management that is documented in an Environmental Management Plan (EMP). The EMP must include the considerations of a CASSMP (described in section 9) and demonstrate that the CASS risk assessment process has been completed. Ensure that the EMP effectively demonstrates that the questions posed in section 8.2, 'Considerations for Management of CASS Hazards', have been addressed as much as possible and that the proposed action has attempted to avoid disturbing CASS.

Table 3: CASS hazard table (after Ahern et al., 1998)

	Based on Stage B soil site assessment results to determine existing acidity plus potential acidity (reported as S%)													
Disturbed CASS (tonnes) to the nearest tonne	**0.03**	**0.06**	**0.1**	**0.2**	**0.4**	**0.6**	**0.8**	**1**	**1.5**	**2**	**2.5**	**3**	**4**	**5**
	Hazard and Liming rates *– tonnage of pure fine agricultural lime required to completely neutralise the acidity.*													
1 – 4	0	0	0	0	0	0.03	0.04	0.05	0.1	0.1	0.1	0.1	0.2	0.2
5 – 9	0	0	0	0.05	0.1	0.1	0.2	0.2	0.4	0.5	0.6	0.7	0.9	1.2
10 – 49	0	0.03	0.05	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.2	1.4	1.9	2.3
50 – 99	0.1	0.1	0.2	0.5	0.9	1.4	1.9	2.3	3.5	4.7				
100 – 199	0.1	0.3	0.5	0.9	1.9	2.8	3.7	4.7						
200 – 249	0.3	0.6	0.9	1.9	3.7									
250 – 349	0.4	0.7	1.2	2.3	4.7									
350 – 499	0.5	1.0	1.6	3.3										
500 – 599	0.7	1.4	2.3	4.7										
600 – 749	0.8	1.7	2.8											
750 – 899	1.1	2.1	3.5											
900 – 999	1.3	2.5	4.2											
1000 – 1999	1.4	2.8	4.7											
2000 – 4999														
5000 – 9999														
≥ 10000														

🟫	High hazard (activity may only proceed with an approved environmental management plan)
🟧	Medium hazard (management possible)
🟨	Low hazard (management possible)
0.5	Liming rates (in italics) – The estimate of the amount of pure fine agricultural lime in tonnes (t) required to completely neutralise the acidity (existing and potential) of the disturbed CASS.

- If neutralising materials other than agricultural lime ($CaCO_3$) are used, liming rates must be modified according to the neutralising value and the fineness of the material being used.

8.2 Considerations for management of CASS hazards

Considerations for determining the level of risk and appropriate management response for a proposal are as follows (refer to Figure 1).

8.2.1 Will the consequence of CASS disturbance affect sensitive receptors?

Sensitive receptors, or areas of high ecological value, that may be affected include RAMSAR or internationally significant wetlands, groundwater that discharges to surface water, drinking water resources, groundwater and surface water resources, fish breeding areas, major fish production areas, recreational and swimming areas. The environmental value of these receptors and the consequences of adverse impacts from disturbed CASS need to be considered.

The impact of any acid production due to CASS disturbance will depend on the potential acidity that could be generated and the sensitivity of the environment surrounding the proposed activity. The extent of potential impacts, onsite and offsite, should have been determined as part of the Stage B and C assessments.

Small CASS disturbances (i.e. low and medium rated CASS hazard proposals) in areas of high ecological value can have a significant impact if the disturbance is not appropriately managed.

The cumulative impacts of small disturbances in the area also need to be taken into account as part of this consideration. In particular, the sum of many small disturbances can be quite large so that consideration of any one proposal needs to be done in the context of existing disturbances of CASS and future proposals that may disturb CASS. Examples include:

- excavation for one underground single car garage may be a low hazard, but a whole suburb of such excavations may result in a high hazard
- one bore in coastal ground water table for domestic use or livestock watering may have a small localised *in situ* disturbance (caused by the cone of depression), but several bores may have a large cumulative effect on the water table, particularly during drought or when changes in land management changes water extraction rates.

If it is determined that the potential consequence of the CASS disturbance will cause serious or long term impacts to receiving environments or sensitive receptors, review the proposal and, if necessary, amend it to avoid CASS disturbance (see Figure 1).

8.2.2 Can the activity be modified to avoid disturbing CASS?

A summary of the principles for management of CASS (from section 3) are to:

- avoid disturbing CASS
- plan and design the proposed activity in order to avoid entirely or at least minimise the disturbance of CASS
- mitigate and isolate impacts of any CASS disturbance
- develop a CASS management plan to guide how CASS will be managed.

If the activity can be modified in order that CASS is not disturbed, then, in line with all other necessary approvals, the activity may proceed. Submit proof that the proposed activity will not disturb CASS along with any approvals required for the proposal. Note that if CASS is disturbed during construction and requires management for disposal or reuse, the IWMP and EPA publication 655.1 will apply.

If the activity cannot be modified to avoid disturbing CASS then the following consideration applies (Figure 1).

8.2.3 Can management be effectively carried out?

If an activity can not be modified to avoid CASS disturbance, the implementation of management measures and potential mitigation activities might be difficult to carry out in practice or might be very costly for the specified proposal. Elements of management and mitigation activities, such as earthworks, equipment hire, water monitoring, and the cost and practicality of carrying out management activities, may need to be considered. Detail on potential management and mitigation techniques are described in section 14. If the implementation of mitigation and management is prohibitive to the proposal, the proposal may not proceed in its current form and must be reviewed to avoid CASS disturbance (see Figure 1).

For all activities that require management, use best practice CASS management throughout the development of a CASS management plan (section 13).

Check list for Stage D

1 Engage a qualified person to carry out CASS Hazard Assessment.
2 Use the Stage B soil site assessment results to determine existing acidity plus potential acidity (reported as S%).
3 Use the CASS hazard table determine the CASS hazard rating (high, medium, low).
4 Use the Stage C surface and groundwater assessment to inform the consideration of management of CASS Hazard.
    - Will the consequence of CASS disturbance affect sensitive receptors?
    - Can the activity be modified to avoid disturbing CASS?
    - Can management be carried out effectively?
5 Based on the above considerations prepare a CASS management plan.

9

Developing a CASS management plan

If the hazard rating from the Stage D assessment is low or medium and the considerations (section 8.2) have been addressed, management of CASS is possible. Prepare a CASS management plan (CASSMP) to demonstrate how CASS will be managed throughout the proposal.

The CASSMP is the framework for the ongoing management and monitoring of impacts from CASS throughout the site works that covers the construction and operational phases of an activity or project.

Ensure that the CASSMP:

- considers the onsite and offsite impacts of the proposed activity
- is developed in consultation with local councils and relevant land managers
- is integrated into the design layout and engineering of each component of a project, which may require planning of the sequencing of a project, for example the staging of a large project, in order that the area disturbed, at any one time, is restricted and any potential impacts can be limited and easily managed
- describes the contingency procedures to be implemented if the management procedures prove to be unsuccessful
- integrates contingency strategies into the procedure and schedules of the construction and/or operational phases of the project
- considers other relevant factors (as outlined in the Stages B and C assessments), such as hydrology, aquatic and terrestrial ecology, social and economic issues.

9.1 Components of a CASS management plan

A CASSMP must, where relevant, contain the following components.

9.1.1 Site overview

In an overview of the physical characteristics and environmental attributes of the site, include:

- a description of the soil stratigraphy, surface hydrology and hydrogeology of the site
- details of the presence of sensitive environmental receptors, including surface water bodies on or surrounding the site (this might include details of which minor or major catchment the proposal is in and presence of RAMSAR or nearby significant sites within that catchment)
- details of any groundwater bores on or surrounding the site
- a description of current and historical land use in the area.

9.1.2 CASS occurrence

Accompany a description of the occurrence of CASS at the site with maps and figures, and include:

- vertical and spatial distribution of CASS onsite and, potentially, offsite
- a map of the distribution of CASS (three dimensional diagrams and maps may be used) at the site
- detailed results and interpretations of the CASS assessment.

9.1.3 Proposal description

In an overview of the proposed works, include detailed descriptions of:

- any dewatering and drainage works, including receiving waterways
- any soil excavation works
- delineation of any clay and peat lenses and horizons that may affect dewatering or excavation of soil (which may or may not contain elevated sulfur concentrations)
- details of any planned temporary aboveground storage of CASS, if proposed
- details of reuse/disposal options for excavated CASS.

9.1.4 CASS management strategy

A description of the management strategies that will be used to minimise impacts from the proposal include:

- strategies for preventing the oxidation of metal sulfides, including avoiding the disturbance of CASS by redesigning layout of the excavations to limit oxidation
- planned treatment strategies for CASS and any stormwater and acidic leachate that might be generated, including neutralisation of CASS with the use of lime or reburial of PASS
- watertable management strategies for onsite and offsite before, during and post disturbance
- containment strategies for contaminated stormwater and acidic leachate associated with the oxidation of CASS to ensure that untreated water does not enter the environment both in the short and long term.

9.1.5 Timing of environmental management activities

Include in the CASSMP details on how the planned management activities integrate with different components of the projects, including construction and other environmental management activities. Note key project milestones.

9.1.6 Performance criteria

Set criteria for all stages of the project, including during and post construction, to monitor the effectiveness of CASS management strategies and monitoring programs. Performance criteria must consider all relevant aspects of soil, groundwater and surface water management.

Also, specify in the plan the frequency and performance criteria associated with verification testing.

9.1.7 Monitoring program

Design the monitoring program to provide feedback to the project manager on the effectiveness of the management strategy and to provide an early warning of the development of any environmental degradation or impact to surface water, groundwater and soils, both during the projects and for a period of time after completion. Tailor the monitoring program to the specific proposal and be sure to include:

- proposed location of monitoring points and frequency of monitoring; locations might include treatment ponds and leachate containment structures as well as groundwater and surface water monitoring locations and soil stockpiles
- details of sampling and analytical parameters, including field and laboratory monitoring and all laboratory reports
- details of procedures to be undertaken in the event that monitoring indicates that thresholds are being exceeded.

A greater frequency of monitoring might be required to assess the impacts of events that could affect the predictable behaviour of surface water and groundwater, such as heavy rain, prolonged periods of low rainfall and tidal fluctuations.

Incorporate in any ongoing water monitoring strategies close monitoring of higher risk proposal activities and measure the outcomes of any management strategies that are carried out. As the impact of the proposal becomes more predictable, the frequency of the monitoring may be able to be reduced. Include criteria for assessment of ongoing monitoring data in the CASSMP; also include specification of the baseline data and appropriate standards (e.g. SEPP [Waters of Victoria] [Groundwater of Victoria] and Prevention and Management of Contamination of Land), ANZECC Water Quality Guidelines and any other site specific water quality objectives.

9.1.8 Contingency procedures

A contingency plan needs to be developed as part of the CASS Management Plan in order to manage impacts in the event of management strategies failure. Develop the contingency plan on a site specific basis, and include details of trigger levels, and remedial and restorative actions. Remedial actions should address:

- any failure to achieve performance monitoring criteria for management strategies or quality objectives for treatment strategies
- any failure to implement any proposed acid sulfate soil management strategies
- any failure of mitigation strategies.

The plan should also consider the onsite storage of additional lime.

If monitoring results continue to identify severe failure of the management strategy to meet agreed standards or if remedial actions fail, cease operation of the project and take action to restore the site to a condition equivalent to that prior to commencement of the project.

The restorative actions taken, which may be triggered by the proponent or relevant authority, will depend on the assessment of the cause of the failure. In the case of ineffective implementation of the CASS management strategy, have the management plan independently assessed to ensure that it can be effectively implemented. Monitoring frequency may increase initially, after restorative actions are taken, to ensure compliance with standards or performance levels. If the management strategies themselves have been ineffective, review the management plan; include an assessment of the outcomes of remedial actions. Consult with relevant government agencies if changes to the management plan are required to carry out restorative activities.

If there are no suitable management strategies that can be implemented so that the site can be restored to meet the specified performance criteria, undertake remedial actions and continue regular monitoring at agreed intervals until remediation, to the extent practicable, has been completed and the site poses no significant risk to the environment. Remedial activities and changes to the site work plan must be approved by relevant government agencies.

Be sure to include in the contingency plan details of information that will need to be provided if changes have to be made to the management plan. Information might include

- details of the changes
- why the changes have occurred
- a plan for their implementation.

9.1.9 Consultation and approvals

Include records and outcomes of consultations with relevant authorities in relation to recommended management processes and associated works in the CASSMP. Also include all approvals and record of approvals processes associated with CASS management and mitigation.

10

Best practice management strategies for coastal acid sulfate soils

Consider the following best practice management strategies in the development of a CASSMP. In managing risk and selecting preferred management strategies it is ultimately the responsibility of the site owner or proponent to conduct the project in a manner that will not result in environmental damage. This is the case even in situations where all relevant approvals have been obtained.

Further details on the best practice CASS management strategies identified in this document are provided in equivalent guideline documents available in other states, including:

- *NSW Acid Sulfate Soils Manual* (Stone et al., 1998)
- *Soil Management Guidelines – Queensland Acid Sulfate Soil Technical Manual* (Dear et al., 2002)
- *Treatment and Management of Soils and Water in Acid Sulfate Landscapes* (DEC, 2009).

The management strategies listed below are numbered in order of priority. In the first instance, avoid disturbance of CASS at all sites.

1. Avoid disturbance of CASS at all sites.
2. Minimise disturbance.
3. Prevent oxidation.
4. Treat to reduce or neutralise acidity.
5. Offsite reuse or disposal.

In some cases, management strategies other than those listed may be considered where sufficient information is provided on the methodology, implementation and scientific basis of the strategy.

Unacceptable CASS management practices include:

- the use of receiving waters (marine, estuarine, brackish or fresh) as the primary means of diluting or neutralising CASS or associated treatment of acidic leachates
- long term stockpiling of CASS above the permanent water table (with or without treatment).

10.1 Avoid disturbance

If the CASS risk assessments (Stages A, B and C) confirm the presence of CASS, the preferred management approach is to avoid disturbance of the CASS. If Stage B soil investigations indicate that CASS is not evenly distributed across the site, it may be possible to relocate the proposed works to areas where CASS is not present. Alternatively, proposals can be redesigned so that CASS remains undisturbed. For a subdivision development, for example, the locations where CASS is present may be designated as open space, or a pipeline may be installed at a shallower depth.

10.2 Minimise disturbance

This section outlines management strategies that can be used to minimise CASS disturbance.

10.2.1 Minimise disturbance of soils

Similar to avoidance strategies, the highest risk CASS areas can be avoided in favour of disturbing areas of CASS with lower sulphide concentrations or areas that present a lower risk to the environment (low or medium hazard categories as determined in Stage D CASS hazard assessment).

10.2.2 Minimise disturbance of groundwater

Avoid activities that result in large scale or long term fluctuation in groundwater levels, particularly lowering of the groundwater table or, if used, carefully planned to minimise the extent or length of time the groundwater table is raised or lowered.

10.3 Prevent oxidation

It is critical to minimise the duration of exposure of disturbed sulfidic soil material in order to prevent generation and transport of acid. The amount of time it takes for acid to leach from a disturbed soil depends on the texture, mineralogy, temperature, moisture content and bacterial activity of the soil. Sandy sediments, which have little natural buffering capacity, generally oxidise and leach very rapidly (potentially within a few hours). Finer grained sediments, such as clays, may take longer to produce significant quantities of acid.

Management strategies that may prevent or limit oxidation of sulfides and generation of potential acidity are described below.

10.3.1 Stage projects to prevent oxidation

The careful staging of all disturbances is recommended so that, wherever possible, sulfidic sediments and PASS are exposed to oxygen for the minimum amount of time possible to limit oxidation of the sulfide minerals (see Note: Stockpiling).

Soils or soil layers with existing acidity (AASS,indicated by field $pH_F < 4.5$) are more difficult to manage once disturbed. Usually, some addition of a neutralising agent will be necessary when disturbing these soils. By minimising exposure times or by staging the disturbance of these sediments the scale of neutralisation activities and therefore potential risks associated with exposure may be reduced.

Table 4: Suggested short term stockpiling durations based on soil texture (after Dear et al., 2002)

Type of material (McDonald et al., 1990)	Approx. clay content %	Duration of stockpile
Coarse (sands to loamy sands)	≤ 5	Overnight (18 hours)
Medium (sandy loams to light clays)	5–40	2.5 days (70 hours)
Fine (medium to heavy clays and silty clays.	≥ 40	5 days (140 hours)

10.3.2 Cover *in situ* acid sulfate soils to prevent oxidation

If groundwater levels are not affected by earthworks, undisturbed *in situ* PASS can be covered with clean fill to raise the construction surface so that disturbances are carried out in fill materials and not within CASS layers. This must be done with care (see Note: Covering CASS with fill) as some filling activities may disturb *in situ* ASS by:

- changing groundwater hydrology so that acid may be mobilised and transported
- displacing or extruding previously saturated PASS above the groundwater table and exposing these soils or sediments to oxygen.

A minimum depth of fill for residential development cannot be specified as suitable levels of fill will be determined by the depth to ASS, concentrations of sulfides, flood levels, proposed land use and depths of any future disturbance. Carry out a geotechnical assessment to confirm requirements for filling. From a risk minimisation point of view, it is always preferable to use clean non-ASS fill rather than using treated ASS onsite.

Note:
Stockpiling

Minimise the duration of stockpiling of untreated CASS by preparing an earthworks strategy that documents the timing of soil volumes to be moved, treatment locations and capacity of those areas to accept materials. Stockpiling may require double handling of material and the use of specific stockpile management strategies that may increase management costs. It is important to account for risks from wet weather and to plan for other contingencies, such as dust generation and sediment erosion.

Regular monitoring of stockpiled materials (for pH_F and pH_{FOX}) may be conducted to identify any potential oxidation or acid generation of the stockpiled CASS. It is very important to note that monosulfidic black oozes (MBO) cannot be stockpiled.

Laboratory tests may be used to provide an indication of potential oxidation times of exposed materials. These tests may include leach testing or accelerated weathering analyses (Australian Soil Classification – Isbell, 1996).

10.3.3 Placement of CASS to prevent oxidation

Mitigation strategies might involve the reburial of excavated PASS material before it has begun to oxidise by utilising one of the following options.

- The over-excavation of non-acid sulfate soil areas of a site within planned constructions to provide capacity for disposal of the sulfidic material at the bottom of a constructed void preferably below a permanent watertable. Prepare cut and fill budgets to ensure that there is adequate capacity to maintain the sulfidic material in anaerobic conditions in the void.
- The construction of an artificial wetland or water body into which excavated acid sulfate soils may be placed below the watertable. This management option is only practical in situations where it can be demonstrated that an anaerobic reducing environment can be permanently maintained.
- Designation of a specific burial area where PASS may be buried (temporarily or permanently) below the permanent watertable. The buried material may be covered with non-CASS material.

Any reburial strategy monitoring will be required to ensure that the CASS sediments remain unoxidised or saturated, and that watertable levels remain elevated, following placement of the CASS. Sediments that already contain acidity (AASS) may not be reburied without prior treatment and verification, as the acid may impact groundwater during reburial. Any stockpiling that is planned as part of a reburial strategy must be planned to minimise the duration of stockpiling and to avoid acid generation (see Note: Stockpiling).

10.3.4 Raise the watertable to prevent oxidation

In some circumstances, the soils can be maintained in a reducing environment by raising the water table or flooding the soils to create a surface saturated layer. This option is practical only where AASS are not present and where an appropriate water balance can indefinitely be artificially maintained, even in drought conditions. Careful assessment of potential adverse impacts such as mosquito breeding or waterlogging of vegetation must be considered.

10.4 Treatment to neutralise acidity

Treatment of disturbed CASS with alkaline materials, e.g. lime, is commonly used to manage the acidity. Sufficient alkaline material is physically incorporated into the soil to neutralise existing acidity and to neutralise acidity as it is generated. Careful calculation of the amount of neutralising agent(s) is needed to ensure that all existing acidity that is present and all potential acidity that may be generated from complete oxidation of the sulfides can be treated.

If poorly managed and too little or too much neutralising material is used this method can present significant risks to the environment.

Note:
Covering CASS with fill

Placing fill over acid sulfate clay soil may result in subsidence of the fill material. The CASS may be pushed upwards outside the filled areas into oxidising environments, or the fill materials may sink into the acid sulfate soil, which would result in land instability.

This can also be an issue where fine grained CASS is placed above the groundwater table and buried under clean sands (e.g. dredging sites). Investigate historic dredging sites for the presence of such materials prior to making changes to land use that may cause such subsidence.

In these cases, geotechnical and hydrological investigations may be necessary to assist in developing management strategies that include any pre-loading activities or modification of groundwater levels as a result of emplacement of fill.

Do not use untreated ASS as pre-load material (see Note: Stockpiling).

Source: Dear et al., 2002

The most common material used to neutralise acidic sediments is agricultural lime (aglime as $CaCO_3$). The calculations for the neutralising requirements are based on the analytical results of existing acidity and potential acidity. The bulk density (t/m^3) value of the soil must also be obtained. If the bulk density of the soil at the site is not known, standard or average bulk density values may be used. These values are usually based on the soil texture and can be found in common soil science references. The calculation of liming rate incorporates a safety factor of 1.5, which allows for the potential for inefficient mixing and the slow reaction rate of agricultural lime (ASSMAC, 1998). The safety factor of 1.5 is applied to good quality fine agricultural lime with a neutralising value of 100. The neutralising value can be obtained from the product supplier. Under the fertiliser regulations (Agricultural and Veterinary Chemicals [Control of Use] [Fertilisers] Regulations 2005), the product must be labelled but it is not required that the label state the product's neutralising value (see www.dpi.vic.gov.au). Where the neutralising value does not equal 100, adjust the safety factor accordingly. Conversion tables are provided in Appendix C to help convert commonly used units of acidity to liming rates in kilograms $CaCO_3$/tonne soil.

For treatment of large volumes of material, carry out neutralisation on a constructed treatment or liming pad. Spread a guard layer of neutralising agent onto the surface of the treatment pad and compacted beneath a clay layer. This will reduce the risk of infiltration of acidic leachate that may be generated during the treatment process. Soils can be neutralised using other mixing methods or, alternatively, the soils can be neutralised as they are emplaced. To ensure sufficient mixing, it is recommended that *in situ* mixing be carried out at a maximum depth of 0.3 metres at any one time. Mixing may need to be carried out in stages to ensure that all neutralised soils are well mixed with lime. Where *in situ* mixing is carried out, detailed material location records must be kept using maps and GPS coordinates to enable appropriate verification of liming.

10.4.1 Drainage lines

In order to aid the neutralisation of acidic stormwater runoff and to neutralise acidic water from acidified groundwater inflows neutralising agents can be incorporated into artificial drainage lines in contained treatment areas. Such design measures will prevent development of highly acidic waters and the transport of mobilised metals. By treating acid as close to its source as possible, the volumes of contaminated waters requiring treatment should be minimised, which will reduce treatment costs and environmental risks. It must be noted, however, that treatment is likely to result in salt and possibly metals being precipitated. If so, further management will be required to ensure that the environment is not contaminated. Give consideration to the remobilisation of sediments during storm events and how this can be managed to prevent mobilisation.

Alternatively, drainage from a treatment area may be directed, via a graded surface, to a sump that has been constructed with low permeability sides and base. Lime may be incorporated into the sides and base to aid in treatment of drainage.

This method of water treatment may not be effective over the long term, and metallic sludges are often produced which require ongoing removal and disposal.

Further details on neutralisation strategies are provided in the *Queensland Soil Management Guidelines*, (Dear et al., 2002).

10.4.2 Offsite reuse or disposal

Offsite disposal of CASS in Victoria must comply with the requirements of EPA publication 655.1 and the IWMP. Offsite reuse and disposal is the least preferred management option for large disturbances; consider all other options prior to investigating disposal options.

All offsite movements of CASS need to be documented. Required information includes, but is not limited to the date and time material left source site, soil pH at source site, truck registration number, volume or tonnage, time material arrived at receipt site, soil pH at receipt site and date and time soil was buried. Other documentation may need to be kept to comply with EPA requirements for waste transport.

In accordance with EPA publication 655.1 offsite disposal or reuse of CASS may occur only at premises:

- that are licensed to dispose of ASS under the *Environment Protection Act 1970*
- where an environmental management plan, prepared in accordance with EPA guidance, has been approved by the EPA.

10.5 Other strategies

Proponents need to be aware that, as well as those discussed above, there are other options available for CASS management. The chosen management method must address the specific issues associated with CASS occurrences at the proposal site. It must be demonstrated that the method will be successful in mitigating or managing all potential impacts associated with the CASS disturbances.

These options include, but are not necessarily limited to, hydraulic separation, controlled oxidation, vertical mixing, reburial of soils with existing acidity and aboveground capping. Details of these techniques can be found in the following documents:

- *NSW Acid Sulfate Soils Manual* (Stone et al., 1998)
- *Soil Management Guidelines – Queensland Acid Sulfate Soil Technical Manual* (Dear et al., 2002)
- *Treatment and Management of Soils and Water in Acid Sulfate Landscapes* (DEC, 2009).

11

Water management

Any management strategy that results in the generation of water (runoff, dewatering) must include a water management strategy as part of the proposed CASSMP. Water generated may include, but may not be limited to:

- groundwater excavated with saturated sediments
- surface water from drainage systems or waterway diversions
- runoff and stormwater generated from rainfall
- vehicle washdown waste water and other waste water
- leachates associated with treatment or management strategies, including dust suppression waters
- any other water generated on or around the location of CASS material.

Potential water quality issues that might be associated with CASS disturbance are generation of acidity, acidic discharges, monosulfidic black ooze, soluble iron and other heavy metals, as well as changes in bicarbonate, carbonate and dissolved oxygen levels. In all water management strategies, include measures for:

- containing and managing within the site boundary using bunds and levees where appropriate, and/or
- treatment of water to meet acceptable water quality criteria prior to discharge offsite to a natural or external water body or wastewater system, such as a sewer.

Acceptable water quality criteria must be specified in the CASSMP. An automated monitoring system may be used in appropriate situations for measurement of field parameters (pH, EC, redox, temperature and dissolved oxygen).

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Glossary of terms

acid base accounting (ABA): a comparison of the acid producing components and the acid neutralising components of the soil to enable the calculation of net acidity

acid neutralising capacity (ANC): a measurement of a soil's ability to buffer or neutralise acidity. ANC is measured as % $CaCO_3$

acid sulfate soils (ASS): soils and sediments, usually located in low-lying coastal areas that contain metal sulfides (usually iron sulfides) or their oxidation products. Types includes PASS, AASS, MBO and CASS

acidify: addition of acid resulting in a decrease of pH

actual acid sulfate soil (AASS): an acid sulfate soil that has already become acidified ($pH < 4.0$) as a result of inorganic sulphide oxidation. Typically, the formation of AASS has resulted from the partial or complete oxidation of PASS due to disturbance, natural or human induced

alluvial: material deposited by or in transit in flowing water

anaerobic: without or excluding oxygen

Australian height datum (AHD): the datum used for the determination of elevation in Australia; used to determine a national network of elevation benchmarks and tide gauges; sets the mean sea level as zero mAHD

buffering capacity: the ability of soil to resist changes in pH

cation exchange capacity (CEC): total amount of exchangeable cations a particular material or soil can absorb at a particular pH; units are milliequivalents per 100 g of material or centimoles of charge per kilogram of exchanger

chromium suite: an ABA approach to calculate net acidity that uses the chromium reducible sulfur method to determine the potential sulfidic acidity of the soil; also referred to as S_{CR} suite

clay: mineral soil particles finer than 0.002 mm; when used as a soil texture classification, soil contains at least 35% clay

discrete sample: an individual sample collected from a specific location or depth that will not be combined with another sample for analytical purposes

electrical conductivity (EC): the ability of a material to conduct an electric current; units are Siemens per centimetre

existing acidity: acidity that is already present in soils, usually due to the oxidation of sulfides; includes measurements of actual acidity (TAA) and retained acidity (SNAS and SRAS)

horizon: individual soil layer, based on colour, texture, structure and pH, which differs from those above and below

monosulfidic black ooze (MBO): a category of acid sulfate soil, usually dark-grey to black in colour, that has a gel-like texture and is enriched by highly reactive iron monsulfides (FeS) (Sullivan et al., 2002

net acidity: the result obtained when the values of the various components of potential and existing acidity and acid neutralising capacity are substituted into the ABA equation; calculated as

net acidity = potential sulfidic acidity + existing acidity – (acid neutralising capacity/fineness factor)

oxidation: the loss of electrons by electron transfer to other ions

peat: an organic soil in which organic matter is partly decomposed by water, heat and microbes; it may also be partly carbonised and mineralised

pH: logarithmic index for the concentration of hydrogen ions in a solution; used as a measure of acidity.

pH_F: pH of a soil:water paste measured in the field (see Appendix B)

pH_{FOX}: pH of a soil:liquid mixture measured after oxidisation of the soil using hydrogen peroxide; usually measured in the field (see Appendix B)

potential acidity: a measurement of the acidity that may be generated if sulphide minerals were to oxidise; measured by titration (TSA) or calculated from S_{CR} or S_{POS} measurements

potential acid sulfate soil (PASS): soil that contains sulfidic material that has not been oxidised but that will generate acidity if oxidises; typically undisturbed PASS has pH that is near neutral (pH ~ 7)

reducing: (*see anaerobic*)

S_{CR}: chromium reducible sulfur method for measurement of reduced inorganic sulphide; method not subject to interferences from organic sulfur

S_{POS}: peroxide oxidisable sulfur method to measure sulphide content following a peroxide digest; method can be affected by the presence of organic sulfur

SPOCAS suite: an ABA approach used to calculate net acidity using the suspension peroxide oxidation combined acidity and sulfur (SPOCAS) method to determine the sulfide concentration of the soil

sulfidic material: mineral or organic material that contains oxidisable metal sulfides

sulfuric material: mineral or organic material that contains sulfuric acid from whole or partially oxidised metal sulfides

texture: the size of particles in the soil; texture is divided into six groups, depending on the amount of coarse sand, fine sand, silt and clay in the soil

topsoil: part of the soil profile, typically the A1 horizon, that contains material that is usually darker, more fertile and better structured than the underlying layers

titratable actual acidity (TAA): a measure of the soluble and exchangeable acidity present in soil; measured in units of mol H+/tonne

titratable peroxide acidity (TPA): a measure of the acidity following peroxide digestion of the sample; measured in units of mol H+/tonne

titratable sulfidic acidity (TSA): the difference in TPA and TAA (TSA = TPA – TSA); measured in units of mol H+/tonne

Appendix A: CASS occurrence indicators

Soil morphology as an indicator of CASS occurrence

Several morphological and visual indicators can suggest the presence of AASS or PASS. Sulfide oxidation products, such as iron stains on surfaces or along the edges of water bodies, can indicate that AASS is present or that oxidation of PASS is taking place.

The presence of AASS can be associated with iron precipitates, such as jarosite (a pale yellow earth mineral), which can occur in pore spaces, cracks and root channels. Yellow jarositic mottling may also be present in auger holes and on recently dug surfaces.

The occurrence of PASS may be indicated by waterlogged soft muds (buttery texture) or sediments deposited in estuarine environments. Soils may be dark grey to greenish grey and may have a rotten egg or methane odour.

Other physical indicators include corroded concrete or steel structures, fish kills, fish with red spot disease, stressed vegetation and scalded soil surfaces. Typical settings where AASS or PASS may be found include mangroves, estuaries and swamps.

Vegetation that is typical of these ecological settings can also be used as indicators. Vegetation types that might indicate the presence of AASS or PASS include areas where the dominant vegetation is mangroves, reeds, rushes and other swamp tolerant, salt tolerant or marine vegetation such as:

- Swamp paperbark (*Melaleuca ericifolia*)
- White mangrove (*Avicennia marina*)
- Swamp mahogany (*Eucalyptus robusta*)
- Swamp oak (*Casuarina glauca*)
- Common reed (*Phragmites australis*)
- Salt paperbark (*Melaleuca halmaturorum*).

Acid tolerant plant species may be common where AASS may be present. These include:

- Native spike rushes (*Eleocharis* spp)
- *Nymphaea* and *Eleocharis* genera (acid tolerant water plant species that survive to pH levels less than 3)
- Cape waterlily (*Nymphaea caerulea*)
- Native waterlily (*Nymphaea gigantea*).

Water chemistry as an indicator of CASS occurrence

Low pH and elevated sulfate (SO_4) in groundwater, streams and drain waters may be indicators of pyrite oxidation. Unusually clear or milky blue-green water may be caused by metals released as products of pyrite oxidation and acid generation. Aluminium, in particular, can act as a flocculent that will result in low turbidity due to settling of fines.Surface water or groundwater that has been affected by AASS is often at pH < 5, while groundwater in PASS areas is not likely to be affected. Other indicators for groundwater that may be affected by AASS are elevated concentrations of dissolved SO_4 and a dissolved mass-based chloride:sulfate ($Cl:SO_4$) ratio of < 4.0.

Environmental factors other than sulphide oxidation can also lead to groundwater or surface water with low pH and elevated SO_4; if the indicators are present, carry out a detailed chemical investigation to determine if sulphide oxidation is the cause.

Swamp paperbark (*Melaleuca ericifolia*) – PHOTO BY DENIS COX

Mangroves - PHOTO BY DENIS COX

Swamp mahogany (*Eucalyptus robusta*) – PHOTO BY DENIS COX

Common reed (*Phragmites australis*) – PHOTO BY DENIS COX

Native spike rushes (*Eleocharis spp*) – PHOTO BY WARREN WORBOYS, © Royal Botanic Gardens Melbourne

Nymphaea – PHOTO BY JANUSZ MOLINSKI, © Royal Botanic Gardens Melbourne

Appendix B: Acid sulfate soils testing

Field pH tests (pH_F and pH_{FOX})

The field pH (pH_F) and field pH peroxide (pH_{FOX}) tests have been developed to provide a fast and inexpensive, field-based means of identifying the likelihood of ASS. Although these tests provide an indication of the possibility of the presence of AASS or PASS, they are purely qualitative, so the occurrence of either AASS or PASS will need to be confirmed with laboratory testing.

Field pH tests can be carried out as part of Stage 1 or Stage 2 site investigations. If field testing is carried out as part of a Stage 2 assessment, conduct both pH_F and pH_{FOX} at 0.25 m intervals along the soil profile to a minimum of 2 m below ground surface and a minimum of 1 m past the proposed maximum depth of excavation (whichever is deepest) onsite at each sample location. Carry out at least one pH test in each soil horizon. Approximately 1 teaspoon of soil is needed to carry out both pH tests.

If the tests can't be performed in the field onsite, conduct them within 24 hours of soil sample collection and ensure that appropriate sample handling procedures are used (see section 6.2.5). Samples suspected of containing monosulfides (MBO) will have to immediately undergo field pH testing in the field.

Container usage

- Use only clean, dry glass or ceramic testing containers as heat is often produced during the peroxide reaction.
- Each test and each sample tested will require the use of different containers. Individual containers may be difficult to handle in and transport from field.
- If containers are to be re-used, make sure they are thoroughly washed and rinsed in deionised water (tap water is not suitable) and dry them completely with lint-free cloth.

The peroxide field test is based on artificially accelerating oxidation of sulfidic material to release potential acidity. The peroxide reacts with sulfides to produce sulfuric acid (H_2SO_4), which may react with neutralising agents such as carbonates and clay minerals in the sample to produce a fizz. The final pH and reaction vigour (fizziness) can then be interpreted to qualitatively assess soil or sediment materials (Table Appendix B1). If any one of the results is positive, then follow the required action.

It is important to note that, with field peroxide tests:

- peroxide is an extremely corrosive chemical that must be handled, transported, diluted, stored and applied to soil with extreme care
- field peroxide results can produce misleading results due to the oxidation of organic matter
- a further indication of the oxidation of sulfides in this reaction is the formation of red-orange (iron) precipitate.

The methods for field pH testing are provided below. Complete descriptions of the methodology are provided in the *Acid Sulfate Soils Laboratory Methods Guidelines* (Ahern et al., 2004).

Table Appendix B1: Field peroxide test results interpretation (any result triggers the required action) (after EPA, 2009a)

pHF	pHFOX	pH	Effervescence*	Action required
≥ 5.0	≤ 5.0	≤ 2.0	None–moderate (0–2)	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	> 2.0	moderate to high (2–3)	PASS may be present; if so, further assessment is required.
≤ 4.0	≤ 3.0	> 2.0	moderate–extreme (> 2)	AASS or PASS are likely to be present; if so, further assessment is required.

* Levels of effervescence are none (0), slight (1), moderate (2), high (3), extreme(4).

pH_F method

The pH_F test is designed to indicate the existing pH of a soil in the field. Any oxidation subsequent to the soil's removal from the ground will not reflect the true field pH. In some instances, in less than 5 minutes, monosulfidic material may start to oxidise and substantially affect the pH_F results.

The procedure for the field pH test (pH_F) is outlined below.

1. Calibrate battery powered field pH meter according to manufacturer's instructions.
2. Prepare sample containers on a flat, stable surface. Make sure the containers are marked with the depths so there is no confusion about the top and bottom of the profile. Use separate containers for the pH_F and pH_{FOX} tests as contamination may occur when the pH_{FOX} reactions are violent. As the soil and water paste is inclined to stick to the container walls, it is best to use shallow, broad test containers as this makes cleaning easier.
3. Conduct tests on the soil profile at intervals of 0.25 m or less and ensure that at least one test is carried out per horizon.
4. Place approximately ½ teaspoon of that soil into the pH_F testing container for the corresponding depth test. It is important that the two subsamples for pH_F and pH_{FOX} come from the same depth and that they are similar in characteristics. Do not, for example, take ½ teaspoon of soil from the 0–0.25 m depth that is grey mud while selecting ½ teaspoon from the same depth that is a yellow mottled sample.

5. Place enough deionised water (or demineralised water if deionised water is not available; tap water is not acceptable) in the container with the soil to make a paste similar to grout mix or white sauce. Stir the soil and water paste with a skewer, strong tooth pick or similar to ensure that all soil lumps are removed. Do not leave the soil samples in the test tubes without water for more than 10 minutes, any longer and there is a risk of sulfide oxidation.
6. Immediately place the spear point pH electrode (preferred method) into the sample and ensure that the spear point is totally submerged in the soil and water paste. Never stir the paste with the electrode because this will damage probe.
7. Wait for the pH reading to stabilise, and then record the pH measurement on a data sheet.
8. If the probe is to be used for subsequent samples, clean it thoroughly and keep it dry between samples.

pH_{FOX} method

It is recommended that 30% hydrogen peroxide (H_2O_2) be used in the pH_{FOX} test (see Note: Health and safety).

Note:
Health and safety

Hydrogen peroxide is an extreme corrosive and a powerful oxidising agent (Contact rating 4; Reactivity rating 3), so take care when handling and using it. Wear safety glasses and gloves when handling and using peroxide. Clearly label all chemical bottles, refer to Material Safety Data Sheets (MSDS) prior to use, and keep the sheets with the chemicals at all times. Adhere to all appropriate health and safety precautions. Keep peroxide in the fridge when not in use.

Sodium hydroxide (NaOH), used for peroxide buffering, is highly corrosive, so exercise safety precautions during use. Refer to Material Safety Data Sheets (MSDS) prior to use, and keep them with the chemicals at all times. Adhere to all appropriate health and safety precautions.

It is recommended that only a small amount of hydrogen peroxide is buffered at one time. Only buffer the amount to be used in the field for about a month. This must be kept in a fridge, well labelled, and only small quantities to be taken into the field at one time. This will ensure the longevity of the peroxide and minimise the need to take large quantities of hydrogen peroxide and NaOH into the field.

Allow buffered hydrogen peroxide to come to room temperature prior to use in the field.

The procedure for the field pH peroxide test (pH_{FOX}) is outlined below.

1. Adjust the pH of the hydrogen peroxide to pH 4.5–5.5 before going into the field. This can be done by adding a few drops of dilute NaOH, stirring, and checking the pH with the electrode regularly until the correct range is reached (see Note: Health and safety). NaOH can raise the pH quickly or slowly, so the pH needs to be monitored. Recheck the pH after allowing the peroxide to stand for 15 minutes. The pH of the peroxide that has already been buffered may change over time. It is important to check the pH of the peroxide in the morning before departing to the field. It is recommended that you have a small quantity of NaOH in the field kit so the peroxide can be buffered if required. Allow peroxide to reach room temperature prior to use.
2. Calibrate battery powered field pH meter according to manufacturer's instructions.
3. Prepare sample containers on a flat, stable surface. Make sure the containers are marked with the depths so there is no confusion about the top and bottom of the profile. Use separate containers for the pH_F and pH_{FOX} tests as contamination may occur when the pH_{FOX} reactions are violent. It is important to use heat-resistant containers for the pH_{FOX} test as the reaction can generate considerable heat (up to 90°C). It is recommended that a tall, wide container is used for this test as considerable bubbling may occur, particularly on highly sulfidic or organic samples.
4. Conduct pH_{FOX} tests on the soil profile at intervals of 0.25 m or at least one per horizon, whichever is less.
5. Place approximately ½ teaspoon of the soil into the pH_{FOX} test tube for the corresponding depth test. It is important that the two subsamples for pH_F and pH_{FOX} come from the same depth and that their characteristics are similar in. Do not, for example, take ½ teaspoon of soil from the 0–0.25m depth that is grey mud while selecting ½ teaspoon from the same depth that is a yellow mottled sample.
6. Add a few millilitres of 30% H_2O_2 (adjusted to pH 4.5–5.5) to the soil (sufficient to cover the soil with peroxide) and stir the mixture. Do not add more than a few millilitres at a time. This will prevent overflow and wastage of peroxide.
7. Rate the reaction of soil and peroxide using the fizz scale (see below and Table Appendix B1).
8. Approximately 15 minutes is a ideal time to wait for any reactions to occur. If a high percentage of sulfides are present, the reaction will be vigorous and may occur almost instantly. In this case, it may not be necessary to stir the mixture. Careful watch will be needed in the early stages to ensure that there is no cross contamination of samples in the containers. If the reaction is violent and the soil and peroxide mix is escaping from the container, a small amount of deionised water (or demineralised water; not tap water) may be added (using a wash bottle) to cool and calm the reaction. Usually, this controls overflow. Do not add

too much deionised water as this may dilute the mixture and affect the pH value. It is important to use only a small amount of soil otherwise violent reactions will overflow and the sample will be lost.

9. Steps 6 to 8 may be repeated until the soil:peroxide mixture reaction has slowed. This will ensure that most of the sulfides have reacted. In the lab this procedure would be repeated until no further reaction occurs, however in the field, best judgement is recommended. Usually one or two extra additions of a few millilitres of peroxide are sufficient.
10. If there is no initial reaction, individual containers containing the soil:peroxide mixture can be placed into a hot water bath (especially in cooler weather) or in direct sunlight. This will encourage the initial reaction to occur. When the sample starts to 'bubble', remove the container immediately from the hot water or sunlight.
11. Wait for the soil:peroxide mixture to cool (may take up to 10 minutes). The reactions often exceed 90°C. Placing an electrode into these high temperature situations may result in damage to the probe and inaccurate readings. Check the manufacturer's instructions for the optimal temperature range for operation of the pH meter and probe. Note that a more exact pH is achieved if a temperature probe is also used, however this may be impractical in some field situations.
12. Use an electronic pH meter (preferred method) to measure the pH_{FOX}. Place a spear point electrode into the sample, ensuring that the spear point is totally submerged in the soil:peroxide mixture. Never stir the mixture with the electrode. This will damage the probe.
13. Wait for the reading to stabilise and record the pH_{FOX} measurement on a data sheet.
14. If the probe is to be used for subsequent samples, clean it thoroughly and dry it between samples.

Rating pH_{FOX} test reactions

The rate of the pH_{FOX} reaction provides a qualitative indication of the amount of sulfide present, where rating of 1 may indicate a low percentage of sulfide, while a rating of 4 indicates a high percentage of sulfide. This rating scale is not appropriate for the identification of acid sulfate soil; detailed laboratory testing must be conducted if the test results in a reaction. The fizz test is subject to interferences, including manganese and organic acids, which may also trigger a fizzing reaction. Reactions with organic matter tend to be more frothing and do not tend to generate as much heat as sulfidic reactions. Manganese reactions may be violent, but do not tend to lower the pH_{FOX}.

Table Appendix B2 indicates the reaction scale for pH_{FOX} tests

Table Appendix B2. Soil reaction rating scale for the pH_{FOX} test

Reaction rate	Description
0	No reaction
1	Slight reaction
2	Moderate reaction
3	High reaction
4	Extreme reaction, with gas evolution and heat generation (usually > 80°C)

Interpretation of pH testing results is provided in Table Appendix B1.

Incubation of soil material and accelerated weathering trials (AWT)

The formal Australian Soil Classification (Isbell 2002) test for identification of sulfidic material is to conduct an accelerated weathering trial (AWT). Samples are incubated for eight weeks to determine whether pH drops to < 4.0 and/or jarosite mottles have formed which if they have, implies that the pH has dropped below 3.5). Collection and storage of moist samples in chip trays and artificially maintaining moisture and heat produces similar conditions and can similarly be used as a diagnostic test for the presence of sulfidic material and guidance on potential reaction times for oxidation of materials. AWT are recommended for use only as a qualitative indicator; the results are not suitable for the identification of acid sulfate soils.

Laboratory methods

The following descriptions are taken from the EPA publication 655.1. More information of Laboratory methods for analysis of acid sulfate soil are provided in the Australian Standard Series 4969 (AS 4969).

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 (S_{NAS} and S_{RAS}) – 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.

Net acidity = Potential acidity + actual acidity + retained acidity – (ANC/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 suite) or chromium reducible sulfur (S_{Cr} suite) methods may be used to determine net acidity, though the S_{Cr} suite is preferred.

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. Seek professional advice on appropriate laboratory methods prior to commencement of laboratory analysis. As a general guide:

- the SPOCAS suite is effective for coarser textured sediments and soils that do not contain or are not suspected to contain organic material
- 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 quality control (QC) purposes.

Appendix C: Common acid sulfate soil conversion tables

Table Appendix C1: Acid sulfate soil conversion factors

Reported units	Convert to	Conversion factor
kg H_2SO_4/t	%S	÷ 30.59
mol H^+/t	%S	÷ 623.7
kg $CaCO_3$/t	mol H^+/t	x 19.98
% $CaCO_3$	%S	÷ 3.121

Table Appendix C2: Acid sulfate soil conversions for liming rates

S (%)	moles H+/kg (S % x 0.6237)	moles H+/t or moles H+/m^3 (S % x 623.7)	kg H2SO4/ tonne or kg H2SO4/m^3 (S % x 30.59)	kg lime/tonne soil or kg lime/m^3 Safety factor = 1.5
0.02	0.0125	12.47	0.61	0.94
0.03	0.0167	18.71	0.92	1.4
0.06	0.0374	37.43	1.84	2.8
0.1	0.0624	62.37	3.06	4.7
0.2	0.1247	124.7	6.12	9.4
0.3	0.1871	187.1	9.18	14.0
1.0	0.6237	623.7	30.6	46.8
5.0	3.119	3119	153.0	234.0

(based on 1 mol pyrite (FeS_2) producing 2 mol sulfuric acid and corresponding liming rates)

Notes

- Assumes a bulk density of 1.0 g/cm^3 or 1 tonne/m^3 (bulk density range can be 0.7–2.0 g/cm^3 and as low as 0.2 for peats). Where bulk density is > 1 g/cm^3 or 1 tonne/m^3, then the correction factor for bulk density will increase for lime rates/m^3 soil (e.g. 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).
- Based on use of pure fine grained aglime with neutralising value or effective neutralising value of 100 where neutralising material that has a neutralising value not equal to 100 is to be used, additional calculations are required.

Appendix D: Recommended sampling equipment

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, although tube splitting tools may be used. • Generally not suited for saturated sands due to sample loss.
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 it is hard to remove sample from tube, although tube splitting tools may be used. • Limited use on wet sands due to sample loss.
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. • Spiral augers are unsuitable for acid sulfate soil sampling due to sample mixing.
Wash bore drilling combined with a driven Standard Penetration Test (SPT) split tube sampling (this is not a recommended sample technique)	• 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 (e.g. vibrocore)	• Recommended for and ideal on wet sands, muds and soft soils because it gives 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.

Source: ASSMAC, 1998.

The incorporation of oxygen and water into any sampling technique or pre-sampling ground clearance technique may alter the chemistry of the soils and is not recommended. If ground clearance is required to ensure that sampling activities do not encounter buried services or infrastructure, the use of less invasive manual sampling techniques, such as jarret augering or manual push tubing, is recommended.

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