



Identification and investigation of acid sulfate soils and acidic landscapes

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This guideline may be applicable to decision-making authorities, proponents, consultants and other interested parties involved in the planning, development and use of areas potentially containing acid sulfate soils. The Department of Environment Regulation (DER) should be consulted regarding policy issues not covered in this guideline or where further clarification and explanation is required.

DER would like to acknowledge the guidelines and manuals produced by the following committees and organisations that were used in the development of this guideline:

- Queensland Acid Sulfate Soils Investigation Team
- Queensland Acid Sulfate Soil Management Advisory Committee
- NSW Acid Sulfate Soils Management Advisory Committee
- National Committee for Acid Sulfate Soils (NatCASS)
- Southern Cross University

This guideline forms part of a comprehensive statutory and policy framework for the identification, assessment and management of acid sulfate soils in Western Australia.

The Acid Sulfate Soils Guideline Series contains the following guidelines:

- *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015)
- *Treatment and management of soils and water in acid sulfate soil landscapes* (DER 2015)

Other guidelines include:

- *Is my house built on acid sulfate soils?* (DER 2015)

Copies of these guidelines are available from DER's website at www.der.wa.gov.au/ass

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- *Identification and investigation of acid sulfate soils and acidic landscapes* (March 2013)

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Purpose

The purpose of this guideline is to provide practical guidance in relation to the minimum level of investigation required to:

- identify the presence or the absence of acid sulfate soil (ASS) in areas likely to be disturbed by a proposed development or other project; and, if present
- define the nature and extent of ASS and the amount of existing and potential acidity it contains in order to determine appropriate management measures.

This document provides information on the identification and investigation of ASS. Guidance on management measures for ASS can be obtained from the document entitled '*Treatment and management of soils and water in acid sulfate soil landscapes*' (DER 2015).

This guideline should be used in conjunction with any other relevant guidelines (including DER's *Contaminated Sites* guidelines), Australian Standards and information sources as well as professional experience and judgment to develop the most appropriate investigation program for a site.

Introduction

Acid sulfate soils (ASS) are naturally occurring soils, sediments and peats that contain iron sulfides, predominantly in the form of pyrite materials. These soils are commonly found in low-lying land bordering the coast or estuarine and saline wetlands and freshwater groundwater-dependent wetlands throughout Western Australia.

In an anoxic state, these materials remain benign and do not pose a significant risk to human health or the environment. However, disturbing ASS, and exposing it to oxygen, has the potential to cause significant environmental and economic impacts including:

- fish kills and loss of biodiversity in wetlands and waterways;
- contamination of groundwater resources by acid, arsenic, heavy metals and other contaminants;
- loss of agricultural productivity; and
- corrosion of concrete and steel infrastructure by acidic soil and water.

Projects involving the disturbance of ASS must therefore assess the risk associated with disturbance by considering potential impacts. Successful management of ASS depends on the results of a detailed investigation to determine the most appropriate management strategy for a site. Wherever possible, in areas containing ASS, management measures should be governed by the guiding principle of avoiding disturbance over any other measure.

Activities that have the potential to disturb ASS, either directly, or by affecting the elevation of the watertable, need to be managed appropriately to avoid environmental harm. An acid sulfate soil management plan (ASSMP) should be prepared and implemented, following advice provided in '*Treatment and management of soils and*

water in acid sulfate soil landscapes' (DER 2015), to effectively manage potential impacts of such activities.

If ASS are not managed appropriately, environmental harm may be caused, as defined in the *Environmental Protection Act 1986*. Additionally, areas of ASS that have been disturbed where the disturbance has resulted in concentrations of contaminants in soils, sediments and/or waters that are above background concentrations and present, or have the potential to present, a risk of harm to human health, the environment or any environmental value, may be classified under provisions of the *Contaminated Sites Act 2003*. Such impacts should be remediated wherever possible.

1 Background information

1.1 Acid sulfate soils formation

In Australia, the soils/sediments which are of most concern are those which formed within the last 10,000 years, after the last major sea level rise. When the sea level rose and inundated the land, sulfate in the seawater mixed with land sediments containing iron oxides and organic matter (Figure 1). The resulting chemical reaction produced large quantities of iron sulfides in waterlogged environments.

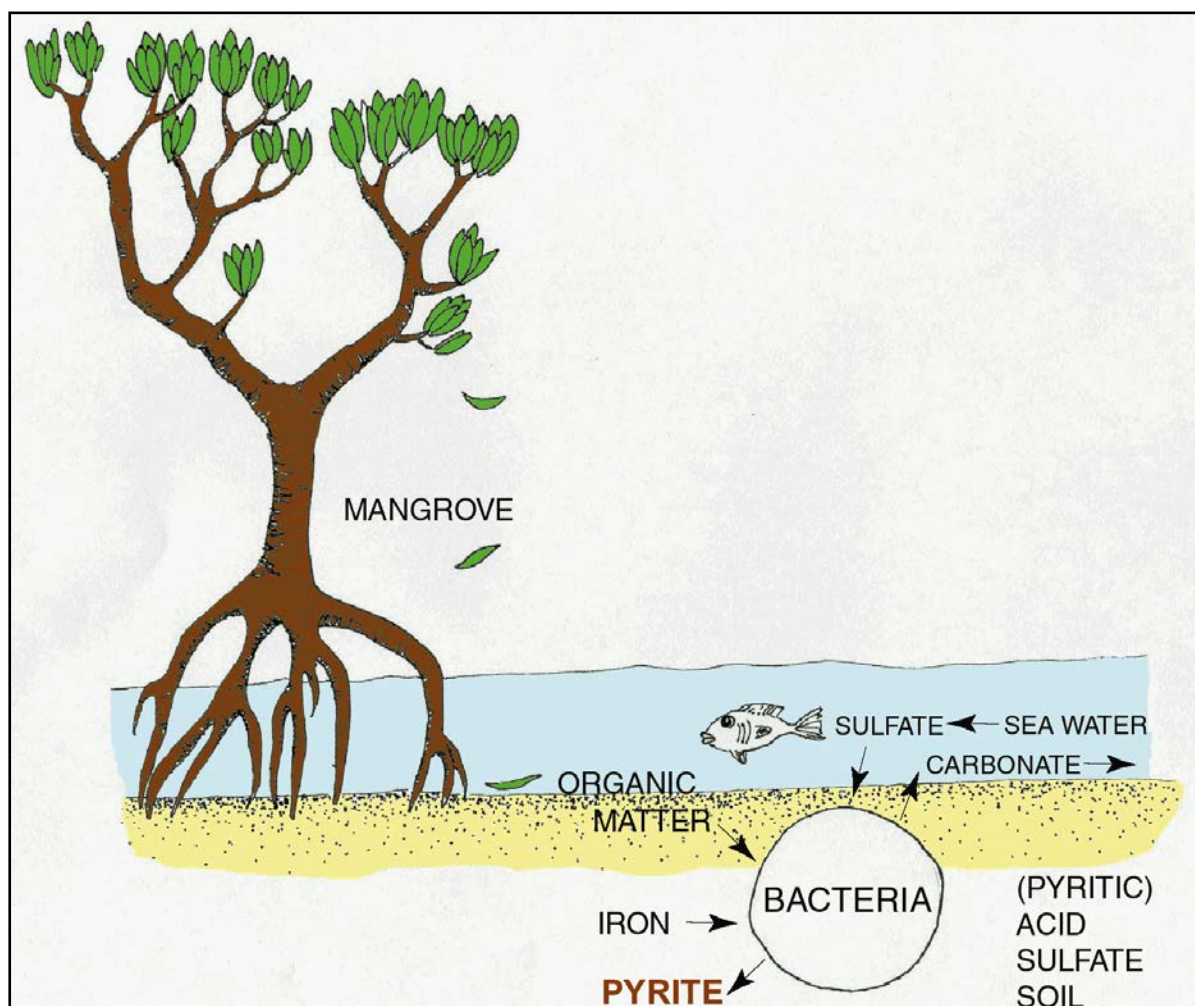


Figure 1: Iron sulfides such as pyrite, are formed in sediments of coastal lowlands where there is sufficient sulfur present. The sulfides are stable until exposed to air at which point they produce sulfuric acid.

In Western Australia, acid sulfate soil materials also often occur in sediments associated with fresh, groundwater-dependent wetlands and beneath the watertable in podzolised sandy soil profiles on the Swan and Scott coastal plains. For the purposes of this guidance, the term 'acid sulfate soils' or 'ASS' includes both sulfidic soil materials (referred to in this document as potential acid sulfate soils or PASS) and sulfuric soil materials (referred to in this document as actual acid sulfate soils or AASS).

- **Potential acid sulfate soils (PASS)** are soils or sediments which contain iron sulfides and/or other sulfidic minerals that have not been oxidised. The field pH of these soils in their undisturbed state is more than pH 4 and is commonly neutral to alkaline (pH 7 to pH 9). These soils or sediments are invariably saturated with water in their natural state. The waterlogged layer may be peat, clay, loam, silt, or

sand and is usually dark grey and soft but may also be dark brown, or medium to pale grey to white.

- **Actual acid sulfate soils (AASS)** are soils or sediments which contain iron sulfides and/or other sulfidic minerals that have undergone some oxidation. This results in low pH (i.e. pH <4) and often a yellow and/or red mottling (jarosite/iron oxide) in the soil profile. AASS commonly also contain residual un-oxidised sulfide minerals (i.e. potential acidity) as well as existing acidity.

1.2 Distribution of ASS in Western Australia

ASS are widespread around coastal regions of the state and are also locally associated with freshwater wetlands and saline, sulfate-rich groundwater in some agricultural areas.

In Western Australia, shallow ASS are known to be present in the following general locations:

- riverine, estuarine and coastal lowland areas, such as mangroves, brackish lakes, tidal flats, salt marshes, salt pans, swamps and seasonally-inundated plains;
- wetland areas;
- beneath the watertable in podsolised sandy soils that contain limited amounts of carbonate minerals; and
- saline inland areas¹.

Particular areas of concern in Western Australia include:

- peaty wetlands in the Perth metropolitan area such as in the suburbs of Stirling, Gwelup, Bayswater and Ashfield;
- estuarine, floodplain, damp land and seasonal wetland areas between Perth and Dunsborough, including the Peel-Harvey estuarine system, Leschenault and the Vasse-Wonnerup estuarine system;
- high groundwatertable areas of the Swan Coastal Plain and Scott Coastal Plain;
- tidal, intertidal and supratidal flats along the northern coastline, including the Pilbara and Kimberley coasts; and
- parts of the Wheatbelt where secondary land salinisation has occurred.

DER has produced ASS risk maps for the Swan Coastal Plain, the Albany-Torbay region, Geraldton, the lower south west, the Pilbara coastline and estuaries in the Kimberley. For more information see [2.1 Risk maps](#).

In general, ASS can be found in the areas listed in [Table 1](#).

³ The extent of inland ASS is largely unknown and research into their behaviour to date is limited.

Table 1. Areas where ASS are generally found.

| | |
|--|---|
| a) Areas depicted on geology and/or geomorphological maps as 'geologically recent' such as: | |
| i) | shallow tidal flats or tidal lakes |
| ii) | shallow estuarine, or shallow marine deposits |
| iii) | stranded beach ridges and adjacent swales |
| iv) | interdune swales or coastal sand dunes |
| v) | coastal alluvial valleys |
| vi) | wetlands (groundwater dependant and perched) |
| vii) | floodplains |
| viii) | waterlogged areas |
| ix) | scalded areas |
| x) | sump land |
| xi) | marshes |
| xii) | swamps |
| b) Areas depicted in vegetation mapping as: | |
| xiii) | mangroves |
| xiv) | wetland-dependent vegetation such as reeds and paperbarks (<i>Melaleuca</i> spp.) |
| xv) | areas where the dominant vegetation is tolerant of salt, acid and/or waterlogged conditions e.g. mangroves, salt couch, swamp-tolerant reeds, rushes, paperbarks and swamp oak (<i>Casuarina</i> spp.) |
| c) Areas identified in geological descriptions or in maps as: | |
| xvi) | bearing iron sulfide minerals |
| xvii) | former marine or estuarine shales and sediments |
| xviii) | coal deposits |
| xix) | mineral sand deposits |
| d) Areas known to contain peat or a build-up of organic material. | |
| e) Areas where the highest known watertable level is within three (3) metres of the surface. | |
| f) Land with elevation less than five (5) metres above Australian height datum (AHD). | |
| g) Any areas in Western Australia (including inland areas ¹) where a combination of all the following pre-disposing factors exist: | |
| xx) | organic matter |
| xxi) | iron minerals |
| xxii) | waterlogged conditions or a high watertable |
| xxiii) | sulfidic minerals |

1.3 Other potentially problematic acid generating substrates

Some types of soils or subsurface substrates, whilst perhaps not fitting the traditional description of ASS, nonetheless have some acid generating potential and can release a significant amount of acidity and/or iron when disturbed. These soils, which are outlined below, have many of the same properties as ASS and should be investigated and managed as ASS would be.

1.3.1 Bassendean sand units – pale grey sands and iron cemented organic rich sands (coffee rock)

The sandy soil of the Swan Coastal Plain consists of sandy aeolian sediments primarily of the Bassendean Dune System (BDS). These sandy soils developed on dune sands and are classified as podosols in recognition of their highly leached near surface horizons (horizons A² and E³) overlying a sub-surface horizon (B horizon⁴) enriched by compounds of organic matter, aluminium and iron. Aerobic podosols occur on well-drained dunes where the groundwater table is at least two metres below ground and [aquic](#) podosols are common in poorly-drained low-lying areas of the BDS.

These podosols are dominated by quartz sands with a clay content generally <1% and, therefore, have a poor buffering capacity. The minimal buffering capacity that they do have is provided by organic matter, allophane, kaolin, gibbsite and iron-oxides which have large surface areas with exposed hydroxyl. Primary minerals (feldspar, ilmenite etc.) are minor constituents of these soils and are sand-size and essentially insoluble so they do not provide any effective buffering capacity.

Synchrotron XRD⁵ and electron-microscopy investigations of BDS soils indicate that pyrite is widely distributed in sediments below the watertable. These pyrites are present as extremely small single crystals (less than 1µm in diameter) that are extremely reactive when exposed to oxygen due to their large surface areas. The amount of pyrite in BDS soil profiles is generally low with chromium reducible sulfur levels commonly less than 0.02%S (which is below the nationally recognised action criterion of 0.03%S for managing sandy ASS). However, experience has shown that dewatering or other disturbance of the BDS often results in acidification of the shallow groundwater aquifer and the mobilisation of iron, aluminium and other metals into the groundwater system and/or the surrounding environment.

Research suggests that the primary source of this acidification is the variably cemented iron and/or organic rich sands (commonly referred to as 'coffee rock'). These sands may be shallow (B horizon), but may also form deeper within profiles (particularly in areas mapped as 'moderate to low risk of ASS occurring within three metres of natural soil surface but high to moderate risk of ASS beyond three metres of natural soil surface'). Coffee rock forms by the precipitation of humates and iron from groundwater, mainly in the zone of watertable fluctuation, and may vary in colour between bright orange, orange-brown and dark brown to black. Pyrite framboids

² A HORIZON: The surface soil horizons, where there is often accumulation of organic matter. They are usually darker in colour than the lower horizons. If they are lighter in colour than the lower horizons, then the horizons have lower silicate clay content.

³ E HORIZON: 'E', being short for eluviated, is most commonly used to label a horizon that has been significantly leached of its mineral and/or organic content, leaving a pale layer largely composed of silicates. These are present only in older and well-developed soils.

⁴ B HORIZON: Subsoil horizons consisting of one or more mineral layers differing to the A Horizon by: clay, iron, aluminium or organic matter concentrations; structure and/or consistence; and colour.

⁵ X-ray diffraction (XRD) is used to examine various aspects of minerals and materials characterisation and processing. The set of peaks produced for a particular phase can be used as a 'fingerprint' to identify particular mineral or other pure, crystalline material. Multiple phases can exist in the one sample simultaneously

(diameter 10-20 μ m), together with microcrystalline pyrite single grains, have been found in some coffee rock horizons in the Swan Coastal Plain⁶.

Laboratory analyses indicate that coffee rock horizons contain stored potential acidity in a number of forms. They may contain inorganic sulfides, including di-sulfides (pyrites) and iron mono-sulfides, as well as potential acidity stored in poorly crystalline and easily hydrolysable iron and manganese oxides. Oxygen transported into such layers, by either convective transport or direct exposure to air by lowering of groundwater levels, can result in the oxidation of such minerals and the generation of acidity.

Investigations have identified sulfur concentrations of up to 0.72 per cent weight for weight (w/w) in coffee rock horizons. As with all potentially acidic soil materials when waterlogged the coffee rock unit itself may be acidic to slightly alkaline (field pH of 4.1 to 9.0/ pH_{KCl} of 3.2 to 8.3).

The shallow groundwater aquifers associated with coffee rock/sand profiles typically also contain dissolved hydrogen sulfide and organic carbon. Due to the geochemical complexity of acid storage and release in coffee rock soil profiles, current investigation techniques may be underestimating the amount of acid-generating potential within these profiles, which typically possess nil to negligible buffering capacity.

1.3.2 Dredging

Many estuaries in urban areas, including canal estates, waterways and marinas, are dredged periodically to keep them navigable and for the purpose of flood mitigation. Dredging involves the removal of unconsolidated or friable sediment materials from an underwater environment, typically using a dredge cutter or other similar equipment. Sediments are dislodged from the bottom of the waterway then removed by mechanical buckets or hydraulic pumping. Hydraulic dredges remove and transport sediments as slurry which is deposited at a designated treatment or disposal area. The excess water is usually discharged as wastewater at the dredge spoil treatment or disposal site and requires significant treatment. Hydraulic dredges may be equipped with rotating blades, augers, pumps (air operated submersible pumps) or high pressure water jets to loosen the sediment.

Hydraulic dredging is common in coastal or estuarine environments where there is significant accumulation of silty organic alluvium (typically <65 μ m but can be up to 2000 μ m) which contain sedimentary sulfides, mainly as acid volatile sulfides (AVS), pyrites and metal complexes. The dredging process causes these sediments to become re-suspended higher in the water column and, upon contact with these oxygenated waters, the sulfides within the sediments oxidise immediately. This causes instant de-oxygenation of the water column and then significant physical and biochemical changes to occur in the aquatic environment that may result in mobilisation and increased bioavailability of contaminants.

Dredging operations have the potential to cause environmental impact both at the dredge site and the disposal site, in particular where maintenance dredging of navigational channels is required on a periodic basis. Where maintenance dredging is proposed, an ASSMP plan must indicate the amount and frequency of future dredging

⁶ Nattaporn P, et al - Mineralogy and chemistry of sandy acid sulphate soils in the Perth metropolitan area of the Swan Coastal Plain (2011)

and how spoil can be disposed of and managed without progressively increasing the area of impact.

Minimisation of sediment re-suspension is therefore an important consideration when developing dredging proposals. The mobilisation and bioavailability of metals in sediment is influenced by changes in pH, redox conditions, desorption kinetics, particle size distribution, AVS concentration and organic complexation. The effect of sediment re-suspension on benthic communities should be assessed as part of any estuary or river-monitoring program, to identify particular impacts and enable evaluation of future dredging proposals.

Double handling of dredge spoil should be avoided unless there is no practical alternative to deliver the spoil to its final destination. Where disposal of spoil is within the estuarine system, the fate of the dredged sediments should be confirmed by subsequent monitoring including the effects on benthic communities.

The potential reuse of dredge spoils for land-filling or foreshore restoration should comply with the DER guideline '*Treatment and management of soils and water in acid sulfate soil landscapes*' (DER 2015), Contaminated Sites guidelines and DER material re-use guidelines.

Inappropriate disposal of estuarine sediments, including dredge spoils, can also provide ideal conditions for secondary pyrite formation. As the sediments age, there will be an increase in pyrite content due to sulfate reduction. At the same time carbonate buffering capacity of the sediments will be depleted over time. Older dredge spoils can have little or no buffering capacity and if these sediments are disturbed and exposed on a large scale, sulfide oxidation will quickly deplete the limited bicarbonate buffering capacity and cause offsite impact with large amounts of acidic and potentially metal-rich waters.

To ensure dredging proposals do not present an ongoing environmental risk, a risk assessment framework as outlined below is recommended:

- Assess potential impacts on the environment – this should include assessment of the physical and biological environment including operational feasibility and potential risk to sensitive environmental receptors. Refer to guidance documents National Assessment Guidelines for Dredging (2009), and Guidelines for Dredging (EPA Victoria, 2001) and guidelines for the use of hydrodynamic numerical modeling for dredging projects in the Great Barrier Reef Marine Park (Australian Government, Great Barrier Reef Marine Park Authority, 2012).
- Once the likelihood and consequences of potential impacts of the proposed dredging activity are determined, management measures should be evaluated to determine if the impacts can be controlled or mitigated. Consider adopting assessment and management approaches consistent with the National Environmental Protection (Assessment of Site Contamination) Measure 2013 and National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000).
- Establish appropriate monitoring programs which are site and project specific and developed in consultation with regulatory agencies. Monitoring measures include compliance with the agreed outcomes and permit conditions, including field monitoring, to detect changes in the receiving environment.
- Evaluate alternatives to estuarine disposal – it is important to clearly characterise disposal sites to avoid causing onsite and/or offsite contamination. This may involve baseline assessment of the receiving environment at or near the disposal

areas, including sensitive receptors such as Class A Conservation or Ramsar-listed wetlands.

1.4 ASS disturbance processes

ASS materials are benign when in a waterlogged state. However, when these soils or sediments are drained or excavated, oxygen from the atmosphere reacts with the iron sulfides in the soil resulting in the production of sulfuric acid. This acidity releases elements such as metals and nutrients from the soil profile which can then be mobilised/transported to waterways, wetlands and groundwater systems, often with deleterious environmental and economic impacts.

Projects and developments in ASS risk areas which involve excavation, lowering of the watertable (temporarily or permanently), compaction of saturated soils or sediments and/or lateral displacement of previously saturated sediments, may adversely disturb ASS.

The types of development that may cause ASS problems include:

- coastal developments, such as residential estates, canal estates, tourist developments, marinas, golf courses;
- estate and underground infrastructure development (including installation of sewage pipework and pump station infrastructure);
- major infrastructure projects, such as bridges, roads, tunnels, port facilities, flood gates, dams, railways and flood mitigation works;
- major development projects involving construction at depths at and beyond the standing groundwatertable;
- developments involving disturbance to wetlands, mangrove swamps, salt marshes, lakes and waterways;
- dewatering operations (including those of minor scale);
- compacting saturated soils or sediments;
- drainage works;
- groundwater pumping;
- ditching for mosquito control;
- artificially deepening lakes, waterways and wetlands;
- de-sludging or otherwise cleaning open drains;
- removal or mining of sulfidic peat;
- mining and quarrying operations, including the extraction of sand or gravel;
- dredging operations;
- rural drainage which lowers the watertable;
- laterally displacing previously saturated sediments, resulting in groundwater extrusion and aeration of ASS;
- aquaculture developments, such as prawn farms in mangrove communities; and

- disturbance of areas that have been previously irrigated with wastewater or treated wastewater.

1.5 Potential impacts due to the disturbance of ASS

The disturbance of ASS has the capacity to directly impact upon the basic natural assets of soil, water and biota, and thus may affect agriculture, fishing, aquaculture, recreation and tourism, as well as human health and visual amenity. The environmental, social and economic consequences that may result include:

- soil and water acidification;
- adverse changes to the quality of soil and water (groundwater, surface water, wetlands, watercourses and estuaries);
- degradation of wetlands, water-dependent ecosystems and ecosystem services;
- loss of habitat ecosystem complexity and biodiversity;
- invasion and dominance of wetlands and waterways by acid-tolerant water plants and plankton species;
- reduction of soil stability and fertility;
- loss of/deterioration in quality of water sources for stock, irrigation and human use by increasing acidity and heavy metal concentrations;
- acid surface scalds in discharge areas;
- loss of visual amenity caused by rust coloured stains, scums and slimes from iron precipitates;
- risk of long-term infrastructure damage through acidic water corroding metallic and concrete structures (concrete cancer) such as roads, bridges, pumps, sub-surface pipes, retaining walls, brick course work and foundations;
- blocked reticulation systems and other small pipe systems due to iron precipitates;
- acidification of surface water bodies increasing mosquito breeding, which may increase the prevalence of mosquito-borne diseases such as Ross River virus; and
- increased financial burden of treating and rehabilitating affected areas and maintenance of infrastructure.

The impacts of ASS leachate may persist over a long time, or peak seasonally (after dry periods with the first drought-breaking rains). In some areas of Australia, ASS drained 100 years ago is still releasing acid (Sammut, 2000).

Any works in areas containing ASS should be governed by the guiding principle that the disturbance of ASS should be avoided wherever possible.

The accurate identification of ASS and their associated risk is the first step to ensure that any disturbance of land containing ASS is planned and managed to avoid potential adverse effects on the natural and built environment.

2 When do sites need to be investigated for acid sulfate soils?

Investigations to determine the presence and distribution of ASS should ideally be undertaken in the early stages of land-use planning processes (e.g. structure planning). Identification of ASS at this stage will allow the design of development works to be modified so as to avoid or minimise the disturbance of ASS. Further guidance on the requirements for ASS investigations at each stage of the planning process is provided in the Western Australian Planning Commission's (WAPC) *Acid Sulfate Soils Planning Guidelines* available from the [WAPC](#) website.

Proponents proposing developments which involve ground disturbance or a change of groundwater levels in ASS landscapes need to conduct investigations to determine whether or not ASS are present and fully characterise their nature and extent. ASS investigations should be undertaken prior to ground disturbing and/or groundwater disturbing activities.

Sites should be investigated for ASS if **any** of the following works are proposed:

- acid sulfate soil disturbing subdivision or development that is subject to conditional approval requiring the investigation and management of acid sulfate soils;
- soil or sediment disturbance of 100m³ or more in an area depicted on an ASS risk map as Class I 'high to moderate risk of ASS occurring within 3m of natural soil surface' (e.g. construction of roads, foundations, installation of underground infrastructure, drainage works, land forming works, dams and aquaculture ponds or sand or gravel extraction);
- soil or sediment disturbance of 100m³ or more with excavation from below the natural watertable in an area depicted on an ASS risk map as Class II 'moderate to low risk of ASS occurring within 3m of natural soil surface but high to moderate risk of ASS beyond 3m of natural soil surface';
- lowering of the watertable, whether temporary or permanent (e.g. for groundwater abstraction, dewatering, installation of new drainage, modification to existing drainage), in areas depicted in an ASS risk map as Class I 'high to moderate risk of AASS or PASS occurrence' or Class II 'moderate to low risk of AASS or PASS occurrence within 3m of natural soil surface';
- any dredging operations;
- extractive industry works (e.g. mineral sand mining) in any of the areas listed in [Table 1](#); and
- flood mitigation works, including construction of levees and flood gates, in any of the areas listed in [Table 1](#).

2.1 Risk maps

As a first step, ASS risk maps should be consulted to determine if the proposed works are in an area where there is a known acid sulfate soil risk. DER has published ASS risk maps for most coastal regions of WA where high and moderate to low probability of ASS occurrence has been identified.

DER emphasises that the risk maps are designed to be used for broad-scale planning

purposes and are not intended to depict actual acid sulfate soil risk at an individual property level. The maps should be read at the scale of their intended use (i.e. 1:50,000 to 1:100,000), and are not suitable for interpretation at a smaller scale unless more detailed risk mapping has been carried out by the proponent. The ASS risk maps are not intended to provide site-specific ASS information.

The ASS risk maps are accessible via Landgate's Shared Land Information Platform (SLIP) which delivers land-based spatial information. Acid sulfate soil data and information can be accessed through a number of Landgate's infrastructure and online services including SLIP Enabler, Data Downloads, WA Atlas and Interest Enquiry.

2.1.1 SLIP Enabler – supporting end user GIS applications/software

The SLIP Enabler allows public access to spatial datasets from across several government departments. The acid sulfate soil datasets are now available through this service and can be imported into your own GIS application/software for viewing.

To gain access to acid sulfate soils datasets you first need to self register for SLIP Enabler access. To do so you will need to register on the SLIP Enabler website at <https://www2.landgate.wa.gov.au/web/guest>.

The SLIP Enabler allows you to download the latest datasets to your own PC or server. By registering as a SLIP Enabler user, a 'Data Download' service is made available giving the user access to acid sulfate soils data files in shp, tab and xml formats.

2.1.2 WA Atlas – viewing ASS through Landgate's mapviewer service

Using the SLIP Enabler infrastructure, WA Atlas provides a free mapviewer service for accessing public data from across-government and presenting it in a visual format. WA Atlas is free to use and can be accessed publicly at <https://www2.landgate.wa.gov.au/bmvf/app/waatlas/>.



By registering as a SLIP Enabler user through the SLIP Enabler website a user automatically gains access to SLIP Enabler, data downloads and WA Atlas – registration need only occur once. Further information on how to access or download acid sulfate soils datasets via the SLIP Enabler or WA Atlas is available on Landgate's website at <https://www2.landgate.wa.gov.au/slip/portal/links/how-to.html> or by contacting Landgate on (08) 9273 7373, email onlinesupport@landgate.wa.gov.au.

2.1.3 Interest Enquiry

Interest Enquiry provides the user with access to the same mapviewer information online. Due to the scale dependencies of seeing some information online, Interest Enquiry also provides additional services, including checking whether or not a property or area of interest falls within a risk class area as well as an ability to receive confirmation in writing of the outcome by ordering an Acid Sulfate Soil Risk Interest Report. Gaining access to Interest Enquiry requires registering as a user to Landgate's *My Landgate* website – access can be granted by applying for an account to access Landgate's Interest Enquiry service.

Further information is available by contacting Landgate on (08) 9273 7373, email onlinesupport@landgate.wa.gov.au or via www.landgate.wa.gov.au selecting the 'Subscribe to My Landgate' link under 'I would like to...'

2.2 How to use WA Atlas to assess acid sulfate soil risk

- Visit www.landgate.wa.gov.au.
- Select 'SLIP Enabler Portal' under 'Quick Links'.
- Select the 'WA Atlas' button on the left of screen.
- Use the Search button to search for the property you are interested in.
- Select the 'Add Layers' button and choose the 'Add WMS layer' option. Note: WMS stands for Web Map Service.
- Default connection options will be displayed – select 'Connect to WMS Server'. This will bring back a list of datasets available through SLIP from various sources.
- Find the dataset you would like to view – ASS datasets are available by expanding the Geological & Geophysical layer. Check box required, scroll down and click 'Add WMS Layers' button.
- Your layers will be added to the context layers already available in the Layer Selector.
- Your view will be updated to see the datasets in your map view.
- To view data attributes, go to the toolbar, expand the list using  and click on . This will activate the information enquiry tool.
- Go to the area of land or attribute you would like to know more information about and click on the map.
- The left hand panel will refresh providing you with data.

2.2.1 How to access the map legend:

- Select the Layer Selector button.
- On the layer for which you wish to see the legend, right mouse click. A small window will appear with additional options.
- Select the 'Legend' option in this window—a new window will be displayed showing the different legend images for that layer.

These steps are the same for Interest Enquiry and WA Atlas. For Interest Enquiry 'Legend' is called 'wms legend'.

It should be noted that the ASS risk map is based on the likelihood of ASS materials occurring within soil profiles. The development of the map is based on available desk-top information together with some on-ground assessment and soil analysis to validate ASS occurrence. ASS risk based on map unit polygons, is classified into two categories:

Table 2. Classification scheme for acid sulfate soil risk maps

| Class of land as shown on acid sulfate soils risk map | Nature of disturbance that triggers ASS investigation |
|--|--|
| <p>Class 1 – high to moderate risk of ASS occurring within 3m of natural soil surface</p> | <ul style="list-style-type: none"> ▪ earthworks that will disturb more than 100m³ of soil ▪ dewatering or soil draining activity |
| <p>Class 2 – moderate to low risk of ASS occurring within 3m of natural soil surface but high to moderate risk of ASS beyond 3m of natural soil surface</p> | <ul style="list-style-type: none"> ▪ works involving lowering of watertable (temporary or permanent) ▪ earthworks extending to beyond 3 metres below natural ground surface ▪ works within 500m of wetlands |

The risk maps do not describe the actual severity of ASS in a particular area but provide a first indication that ASS could be present on the site. For each class of land, the maps identify the type of works likely to present an environmental risk. Further investigation is required to determine if ASS are actually present and whether they are present in such concentrations as to pose a risk to the environment. If the concentration meets or exceeds the ‘*action criteria*’, an acid sulfate soil management plan should be prepared for DER.

National maps of acid sulfate soil risk areas within Australia can be viewed at http://www.asris.csiro.au/index_ie.html.

When using ASS risk maps, consider the following:

- expect extreme variations in the nature and distribution of ASS; and
- depth to the ASS layer can be highly variable. The depths indicated should be used as a guide only and are not suitable for specific assessment of development potential.

Use of an ASS risk map will not replace the need to undertake a detailed desktop assessment and site inspection.

2.3 Investigation process

The required steps in the ASS investigation process are as follows:

- Step 1: desktop assessment and site inspection;
- Step 2: soil sampling;
- Step 3: laboratory analysis; and
- Step 4: reporting of results.

Proponents should allow sufficient time in the project schedule to ensure that ASS investigations are completed and required management plans are developed well before earth works commence.

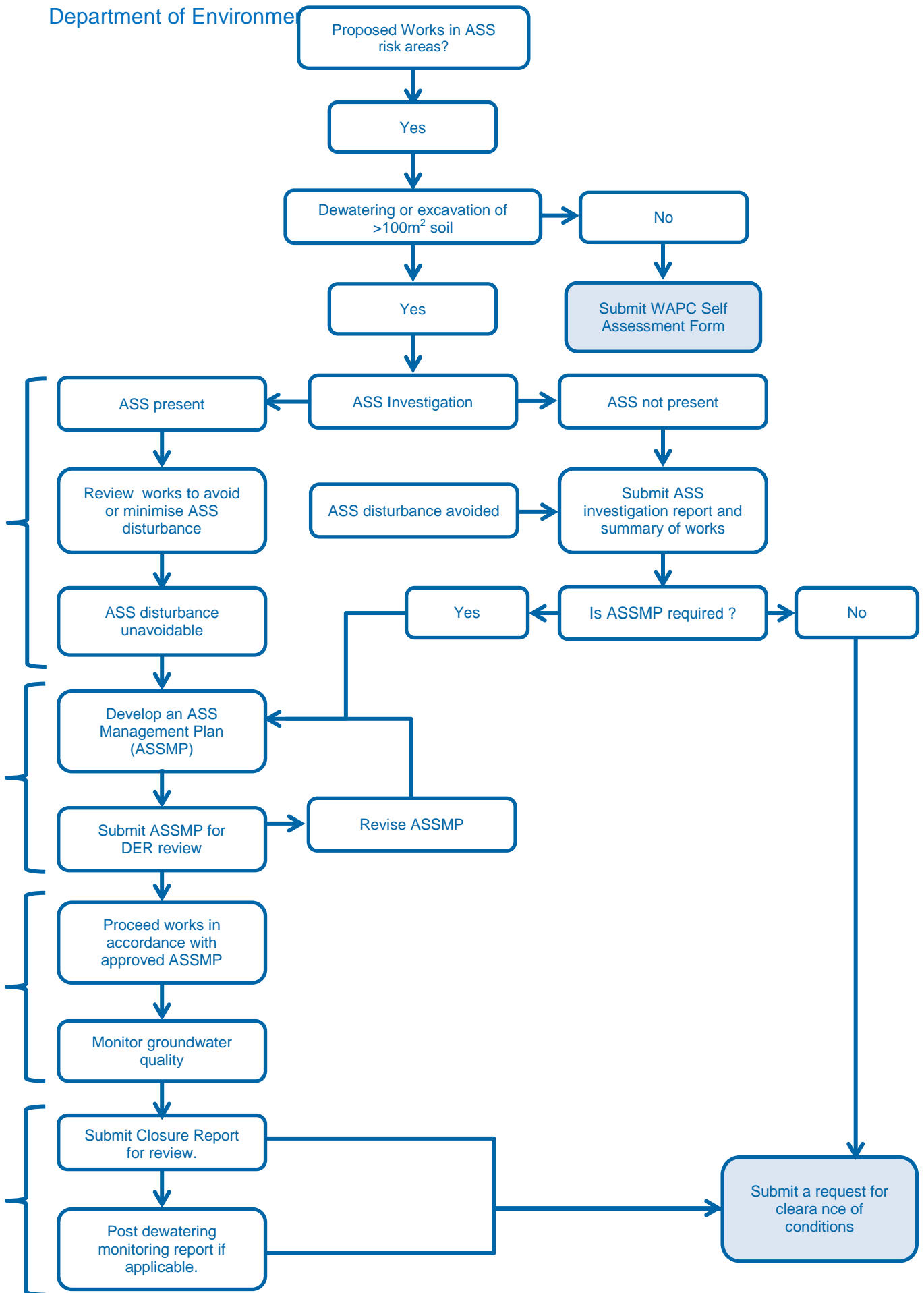


Figure 2: The assessment process for works in ASS areas

3 Step 1: Desktop assessment and site inspection

Step 1 involves a desktop assessment and a site visit to identify indicators of ASS.

(To assist in planning project timelines, it is recommended that the project manager allow a minimum of three to four weeks for completion of this stage of the investigation.)

3.1 Desktop assessment

A desktop assessment should aim to provide a description of the site using published data including maps, photographs and any other relevant available reports and/or studies in order to determine the likelihood of the site containing ASS.

A desk top assessment should include the following elements:

- review of the ASS risk map for the area;
- a site description compiled from topographic maps and aerial photographs. As a minimum, a site description should include a delineation of the area to be disturbed on an appropriately-scaled map. Further information from maps describing the soil landscapes/attributes, geology, hydrogeology/groundwater (Perth Groundwater Atlas WA), vegetation communities and topography can also be used to provide a preliminary evaluation of the site. A recent colour or high-quality black and white aerial photo will assist in identifying vegetation communities and other site characteristics; and
- a review of geomorphic and geological maps to determine if the area includes units where ASS materials are expected to occur in the superficial formation. This is usually principally based on the existing 1:50,000 urban (1977–1982) and environmental geology (1984–1991) map series published by the Geological Survey of WA. This step also acts as a quick backup procedure to validate the current ASS risk maps and areas that are not covered by the ASS risk mapping program.

The following geomorphic and site criteria should be used to determine if ASS are likely to be present:

- sediments of recent geological age (Holocene);
- marine or estuarine sediments and tidal lakes;
- coastal wetlands or back swamp areas;
- waterlogged or scalded areas;
- interdune swales or coastal sand dunes (if deep excavation or drainage proposed);
- areas where the dominant vegetation is mangroves, reeds, rushes and other vegetation associated with areas of shallow watertables such as flooded gums (*Eucalyptus rudis*) (*Eucalyptus robusta*), paperbarks (*Melaleuca* spp.) and *Casuarina* spp.;
- areas identified in geological descriptions or in maps as bearing sulfide minerals, coal deposits or former marine shales/sediments (geological maps and accompanying descriptions may need to be checked); and
- deep older estuarine sediments >10 metres below ground surface, Holocene or Pleistocene age (only an issue if deep excavation or drainage is proposed).

3.2 Site inspection

In all cases, a site inspection is required to support the findings of the desktop assessment. The site inspection should include, as a minimum:

- visual assessment of topography and geomorphology;
- visual assessment of surface water and hydrology;
- visual assessment of prevalent plant communities; and
- examination of surface soils and the soil profile (hand auger sufficient at this stage).

When reporting on a site assessment, it is important to describe the area of the total site, with emphasis on the area of any proposed disturbance. It is important to also inspect the surrounding area. Consideration should be given to the identification of both potential acid sulfate soils (PASS) and actual acid sulfate soils (AASS). Also note that it is common to have an AASS that also contains some un-oxidised iron sulfides (i.e. extra potential acidity is present as well as actual acidity).

If the proposed development is in an area mapped as possibly having ASS present onsite, the proponent will be required to undertake soil and groundwater analysis to validate ASS risk and possibly prepare a management plan. [Table 3](#) provides a summary of the preliminary ‘desktop’ assessment to this point.

Table 3. Summary of typical desktop assessment options and outcomes

| Location of works likely to disturb ASS with reference to ASS risk maps | Assessment options and outcomes |
|--|---|
| In Class I – high to moderate risk of ASS occurrence | Assess the potential impacts of ASS disturbance associated with the planned development |
| In Class II – moderate to low risk of ASS occurrence | Undertake site inspection for soil and water indicators to verify whether ASS are present on the land in question and whether a more detailed investigation is required |
| Not in Class I or II, but a probability of ASS being present based on landscape characteristics. | Undertake site investigation to verify whether ASS are present based on soil, surface and subsurface water characteristics including groundwater. |

[Table 4](#) provides a list of soil, water and vegetation indicators that are suggestive of the presence of ASS. Some of the indicators will only be visible in boreholes/soil sections.

Table 4. Indicators of ASS

| Soil type | Indicators |
|---|---|
| Potential acid sulfate soil (PASS) | <p>Soil characteristics</p> <ul style="list-style-type: none"> • soil $pH_F > 4$ and commonly neutral; • soil $pH_{FOX} < 3$, with large unit change from pH_F to pH_{FOX}, together with volcanic reaction to peroxide⁷; • waterlogged soils—unripe muds (soft, sticky and can be squeezed between fingers, blue grey or dark greenish grey mud with a high water content), silty sands or sands (mid to dark grey) or bottom sediments (dark grey to black e.g. iron monosulfide ‘black oozes’) possibly exposed at sides and bottom of drains, cuttings or in boreholes; • peat or peaty soils; • coffee rock horizons; and • a sulfurous smell e.g. hydrogen sulfide or ‘rotten egg’ gas. <p>Water characteristics</p> <ul style="list-style-type: none"> • waterlogged soils; and • water pH usually neutral but may be acidic • oily looking iron bacterial surface scum (the similar appearances of iron bacterial scum and a hydrocarbon slick can be differentiated by disturbing the surface with a stick—bacterial scum will separate if agitated whereas a hydrocarbon slick will adhere to the stick upon removal) <i>NB: Caution should be taken when inspecting highly-altered landscapes in the field (e.g. where inert fill has been placed over ASS material, dredge spoil, etc). Soil, water and landscape indicators may be masked by past landscape and drainage modifications and this should be taken into consideration when determining borehole locations.</i> <p>Vegetation characteristics</p> <ul style="list-style-type: none"> • dominant vegetation is tolerant of salt, acid and/or waterlogging conditions e.g. samphires, salt couch, <i>Phragmites</i> (a tall acid-tolerant grass species), swamp-tolerant reeds, rushes, paperbarks (<i>Melaleuca</i> spp.) and casuarinas (<i>Casuarina</i> spp.). |
| Actual acid sulfate soil (AASS) | <p>Soil characteristics</p> <ul style="list-style-type: none"> • field $pH_F < 4$ (when field $pH_F > 4$ but < 5 this may indicate some existing acidity and other indicators should be used to confirm presence or absence of AASS); • sulfurous smell e.g. hydrogen sulfide or ‘rotten egg’ gas; |

⁷ Further guidance on the interpretation of field testing results for ASS is provided in Appendix 1

| | |
|--|---|
| | <ul style="list-style-type: none"> • any jarositic horizons or substantial iron oxide mottling in the surface encrustations or in any material dredged or excavated and left exposed; and • presence of corroded shells. <p>Water characteristics</p> <ul style="list-style-type: none"> • water of pH <5.5 (and particularly below 4.5) in surface water bodies, drains or groundwater (this is not a definitive indicator as organic acids may contribute to low pH in some environments such as <i>Melaleuca</i> swamps); • unusually clear or milky blue-green water flowing from or within the area (aluminium released by ASS acts as a flocculating agent); • extensive iron stains on any drain or pond surfaces, or iron-stained water and ochre deposits; and • oily looking bacterial surface scum (differentiated from a hydrocarbon slick of similar appearance as described for PASS). <p>Vegetation characteristics</p> <ul style="list-style-type: none"> • dead, dying, stunted vegetation*; • scalded or bare low-lying areas*; and • poor vegetation regrowth in previously disturbed areas. <p>Infrastructure</p> <ul style="list-style-type: none"> • corrosion of concrete and/or steel structures* (including foundations, fences, masonry/brick walls, pipes). <p><i>* May also be due to excessive salinity or to salinity in combination with AASS.</i></p> |
|--|---|

3.3 Field soil and water characteristics as indicators of ASS

If soils or associated water bodies demonstrate one or more of the indicators in [Table 4](#), it can be assumed ASS are present and a full assessment should be undertaken. Soil field pH provides a useful quick indication of the likely presence and severity of 'actual' ASS. In undertaking field pH testing at this preliminary assessment phase the sampling frequency, as a minimum, should be similar to that required for a detailed assessment with a higher density of testing in areas where the site characteristics indicate that ASS may be present.

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

- pH readings <4, indicates that actual ASS are present with the sulfides having been oxidised in the past, resulting in acid soils (and acid soil pore water).
- pH readings >4 may indicate the absence of 'actual' ASS but 'potential' ASS may still be present.

A preliminary test for 'potential' ASS uses 30 per cent hydrogen peroxide to rapidly oxidise sulphides within a sample of soil, resulting in the production of acid and a corresponding drop in pH.

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

- change in colour of the soil from grey tones to brown tones;
- effervescence;
- the release of sulfur smelling gases such as sulfur dioxide or hydrogen sulphide;
- a lowering of the soil pH by at least one unit; and
- a final pH <3.0.

3.4 Groundwater analysis as indicators of ASS

The analysis of groundwater or drain water for ratio of soluble chloride to soluble sulfate ($\text{Cl}^-:\text{SO}_4^{2-}$) can provide an indication of whether sulfidic material in the vicinity of the site is being, or has been, oxidised. In order to undertake this test, water samples should be submitted for laboratory analysis. The location of each borehole or sampling site should be clearly marked on a map with grid references for each sample site and elevation (m AHD).

As seawater has a Cl^- concentration of approximately 2,700 mg/L and SO_4^{2-} concentration of approximately 19,400 mg/L, the ratio of $\text{Cl}^-:\text{SO}_4^{2-}$ on a mass basis is 7.2. As the ratios of the dominant ions in saline water remains approximately the same when diluted with rainwater, estuaries, coastal saline creeks and associated groundwater can be expected to have similar ratios of the dominant ions as seawater. Where the analysis indicates that there is an elevated level of oxidised sulfate ions relative to chloride ions, these results provide an indication of the possible presence of ASS in the landscape. A $\text{Cl}^-:\text{SO}_4^{2-}$ ratio of less than four, and certainly a ratio less than two, is a strong indication of an extra source of sulfate from previous sulfide oxidation (Mulvey, 1993).

Caution must be exercised in interpreting $\text{Cl}^-:\text{SO}_4^{2-}$ ratio results. The $\text{Cl}^-:\text{SO}_4^{2-}$ ratio becomes less predictive in freshwater or as brackish water approaches that of freshwater. Other parameters provided in DER's guidelines '*Treatment and management of soils and water in acid sulfate soil landscapes*'; (DER 2015), include:

- an alkalinity:sulfate ratio of less than 5 (Swedish EPA, 2002);
- a pH of less than 5 and/or; and
- a soluble aluminium concentration greater than 1 mg/L.

3.5 Microscopic soil analysis

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

3.6 Consideration of preliminary soil, water and groundwater indicators

In making a preliminary determination as to whether ASS are present or not, all field soil and water indicators, the peroxide test results and any groundwater $\text{Cl}^-:\text{SO}_4^{2-}$ ratio

results should be considered.

[Table 5](#) contains a summary of the likely outcomes and the possible interpretation of the results and suggests when further investigations may be required to clarify the presence or absence of ASS. These are general indicators.

Table 5. Deciding if ASS may be present based on soil and water indicators

| Field pH of water | Water ratio analysis Cl^{-1} SO_4^{2-} (by mass) | Field soil or water indicators | Typical soil reaction to 30% H_2O_2 | Preliminary assessment |
|-------------------|--|---------------------------------------|---|--|
| 6–8 | Approx. 7 but may be in the range 5–9 | Nil | Nil reaction and no drop in pH | No sulfidic material present |
| | | ASS indicators | Mild to strong effervescence and drop in pH | Sulfide present but probably has not been oxidised at any time |
| <5 | Approx. 7 but may be in the range 5–9 | Nil | Nil reaction and no drop in pH | No sulfidic material present and low pH can be attributed to other causes |
| | | ASS indicators | Mild effervescence and drop in pH | Sulfide present but probably not been oxidised at any time. Existing low pH can be attributed to other causes |
| 6–8 | In the range 2–5 | Unclear indicators | Mild effervescence and drop in pH | Presence of sulfidic material is uncertain; must be verified by chemical analysis or visual observation of sulfide framboids or crystals |
| | <2 | Indicators of actual or potential ASS | Mild to strong effervescence and drop in pH | Presence of sulfidic material plus the presence of a buffering agent |
| <5 | In the range 2–5 | Unclear indicators | Mild effervescence and drop in pH | Presence of sulfidic material is uncertain; must be verified by chemical analysis or visual observation of sulfide framboids or crystals |
| <5 | <2 | Indicators of actual or potential ASS | Mild to strong effervescence and drop in pH | Presence of sulfidic material with little or no buffering agent |

3.7 Chemical analysis to confirm ASS and 'Action Levels'

Although a full sampling and analysis program may not be warranted at this stage, representative sampling should be taken in all areas which have a high probability of ASS being present. Informed judgement will be needed in deciding how many samples will be required to provide sufficient proof that an ASS management plan is not required. In making a decision, the risks associated with the type of disturbance proposed should also be taken into consideration.

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

- the lowest pH;
- highest drop in pH after field peroxide testing;
- soil containing jarosite or iron mottling; and
- dark grey/green muds or dark grey sands from below the watertable.

Chemical analysis of these samples should be undertaken to ascertain if sulfidic material is present and to quantify the amount of oxidisable sulfur. Determining which soil layers do not contain ASS is just as important as finding those that do.

3.8 Establish the general parameters of the proposed works

Once the presence, location and severity of ASS in the area has been determined, the development can be planned to avoid and/or minimise the disturbance of ASS.

The general parameters of the proposed works should be described so as to ascertain whether the works are likely to disturb any ASS present onsite. Key issues to be taken into consideration are outlined below.

3.8.1 Extent of earthworks onsite

The possible depth and nature of the soil disturbance should be identified. At this stage the principle issue is to determine how ASS will be managed and treated for reuse or disposal to an approved facility. Factors to be considered at this early stage in developing mitigation strategies include:

- expected volume of soil disturbance;
- depth of soil disturbance for construction or operational works in particular that which is below the seasonal watertable level;
- duration of soil disturbance and consideration as to whether disturbance can be staged to minimise sulfide oxidation;
- management options for disturbed areas and excavated ASS;
- site constraints which may affect the implementation of mitigation measures for soil treatment and dewatering;
- potential offsite impacts, e.g. whether the proposed works will improve or exacerbate any existing acidity problem in the short or long term; and
- available soil information such as oxidisable sulfur values from other adjoining land or local areas that can assist in better quantification of risk.

3.8.2 Extent of groundwater disturbance

The other key issue is the disturbance of groundwater in ASS landscapes by dewatering activities. This can result in oxidation of sulfidic materials and acidification of both surface and groundwater. Areas classified as high to moderate risk (Class I) and moderate to low risk (Class II) are vulnerable to acidification if dewatering operations are undertaken and this should be considered in the preliminary assessment of potential impacts.

For works in areas mapped as Class I, a preliminary groundwater assessment should be undertaken to establish the background water conditions and determine if the activity is likely to affect the groundwater quality and watertable levels.

3.9 Reporting on the preliminary assessment

If ASS are present at the site and occur at such concentrations as to justify the preparation of a management plan, the preliminary assessment should document the field investigations and any analysis undertaken. The preliminary assessment should report on the following:

- details of the proposed works and the likelihood of them disturbing ASS or lowering the groundwater;
- physical characteristics and the pH for soil and groundwater tabulated by depth;
- location of each borehole or sampling site clearly marked on a map with grid references and height (m AHD);
- reaction to peroxide and pH after peroxide oxidation;
- if water analysis is required as an indication of the presence or absence of ASS, the pH and ratio $\text{Cl};\text{SO}_4^{2-}$ concentrations for each borehole site; and
- if groundwater hydrological studies are required as an indication of the likely impacts of lowering of the watertable on ASS, the piezometer locations and depths and any flow analysis must be supplied.

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

- If there is sufficient certainty that ASS will not be disturbed, no further assessment will be required. It should be noted that in most circumstances, some laboratory analysis will be required to confirm the absence of acid sulfate soil in an area which has been mapped as having a risk of ASS being present.
- If there is still a level of uncertainty or if it is clear that an acid sulfate soil management plan is required, more detailed investigations will be required.
- Before proceeding to the expense of more detailed investigations, mitigation strategies to reduce or avoid the level of disturbance should be considered.

3.10 Additional assessment resources

3.10.1 ASRIS

The Australian Soil Resource Information System (ASRIS) provides online access to the best publicly available information on soil and land resources in a consistent format across Australia. It provides information at seven different scales. ASRIS map layers can be overlaid with Google Earth images.

The three larger scales provide general descriptions of soil types, landforms and regolith across the continent while the lower scales provide more detailed information in regions where mapping is complete. Information relates to soil depth, water storage, permeability, fertility, carbon content and erodibility. Most soil information is recorded at five depths. However, the lowest scale consists of a soil profile database with fully characterised sites that are known to be representative of significant areas and environments. ASRIS is available at http://www.asris.csiro.au/index_ie.html.

3.11 Aerial photography

Aerial photos, viewed stereoscopically, are a valuable tool in understanding the geomorphology and formation or alteration of the landscape and therefore provide a broad prediction of ASS probability. There is also benefit in using old photography prior to significant vegetation and land disturbance.

3.12 Conclusion

If the results of the desktop assessment and site inspection suggest that ASS may be present, **or** the results are inconclusive, an intrusive investigation involving soil sampling and analysis should be undertaken.

The only instances in which soil sampling and laboratory analysis would not be required are:

- where soils and groundwater at a site will **not** be disturbed;
- where the site is not located within a Class I or II area; or
- where the findings of the desktop assessment and site inspection show **no** obvious indications of ASS.

No obvious indications of ASS? For example—no geomorphological, hydrological or vegetation indicators identified and inspection of the soil profile found it comprised clean yellow quartz sand overlying Tamala limestone to at least one metre beyond the maximum expected depth of disturbance; or no geomorphological, hydrological or vegetation indicators were identified and inspection of the soil profile found it comprised white sand to at least one metre beyond the maximum expected depth of disturbance.

In these instances the proponent may submit this evidence (i.e. desktop assessment report, photographs and detailed soil description) to support his/her professional opinion that soil sampling and laboratory analysis.

4 Step 2: Soil sampling

The soil sampling and laboratory analysis (Step 2) stage of an ASS assessment comprises the collection and analysis of soil samples from the site and interpretation of these results to create a detailed 3-dimensional map of ASS occurrence/absence at the site.

The aim of Step 2 is to:

- conclusively determine whether or not ASS are present;
- delineate the lateral and vertical extent of ASS horizons;
- quantify the maximum amount of existing and potential soil acidity that will require treatment and management if ASS is disturbed; and
- gather data upon which to base the development of effective management strategies for any proposed ASS disturbance.

To assist in planning project timelines, it is recommended that the project manager allow a minimum of one to three months for completion of this stage of the investigation.

4.1 Occupational health and safety considerations

It is important to note that there are occupational health and safety issues related to intrusive investigations for ASS, particularly in regard to digging soil inspection pits, working around drill rigs, use and handling of hydrogen peroxide and dangers associated with hydrogen sulfide gas poisoning.

The *Occupational Safety and Health Act 1984* places a clear obligation on a person to ensure the safety and health of anyone they engage to do work (such as drillers, earthmoving contractors and consultants). It is therefore recommended that Health, Safety and Environment Plans (HSEPs) be produced and the contents adequately communicated to all site personnel prior to the commencement of site works.

Any risks to the public, such as adjacent landowners/occupants, should also be identified and measures implemented to minimise them.

Guidance on the contents of HSEPs can be obtained from the Department of Commerce website <http://www.commerce.wa.gov.au/WorkSafe/>. The guidance note *Occupational Safety and Health Management and Contaminated Sites Work 2005* may be a useful reference <http://www.commerce.wa.gov.au/publications/guidance-note-occupational-safety-and-health-managment-and-contaminated-sites-work>.

4.1.1 Hydrogen sulfide

Disturbance of some ASS landscapes may release hydrogen sulfide gas. This gas has a characteristic offensive 'rotten egg' odour. However, at high concentrations and/or after prolonged exposure, hydrogen sulfide inhibits the sense of smell. The olfactory nerve loses sensitivity and the potentially hazardous gas is no longer detectable by smell.

Hydrogen sulfide is heavier than air and so tends to settle in depressions and may reach toxic levels within excavations and in confined spaces. Therefore, it is strongly recommended that onsite gas monitoring and occupational health and safety measures are implemented to deal with this contingency during the disturbance of ASS materials, particularly when carried out in urban environments.

More information on hydrogen sulfide can be found in the Government of Western Australia’s Department of Health document *Environmental Health Guide, Hydrogen Sulphide and Public Health* <http://www.public.health.wa.gov.au>. Guidance on the management of hydrogen sulfide in the work place can be obtained from WorkSafe (a division of the Department of Commerce, the Western Australian State Government agency responsible for the administration of the *Occupational Safety and Health Act 1984*), <http://www.commerce.wa.gov.au/WorkSafe/>.

4.2 Minimum number of sampling locations required

The necessary soil sampling intensity is dependent upon the nature and variability of the soil profile and the nature, depth and size of the proposed development. Sufficient sampling should be undertaken to create three-dimensional maps and cross-sections of soil type and oxidisable sulfur (%) content by depth.

For clarity, guidance is provided here on the minimum sampling requirements. The minimum number of sampling locations required is dependent on the area (hectares) of the site to be disturbed or, for linear disturbances, the length of the disturbance.

[Table 6](#) summarises the minimum number of sample locations required for non-linear and linear disturbances.

Table 6. Minimum number of sample locations required

| Type of disturbance | Extent of site project | Number of sampling locations |
|---------------------|-------------------------------------|------------------------------|
| Non-linear | Project Area | |
| | <1ha | 4 |
| | 1–2ha | 6 |
| | 2–3ha | 8 |
| | 3–4ha | 10 |
| | >4ha | 2 per hectare |
| Linear | Minor ⁸ width and volume | @ 100m intervals |
| | Major ⁹ width and volume | @ 50m intervals |

For projects disturbing only small volumes (<1,000m³) of soil, or existing stockpiles of ASS, see [4.8 Stockpile sample collection](#).

For large projects (> 20ha) DER may accept reduced sampling densities, providing the investigation program is designed to satisfactorily characterise the various

⁸ Minor Linear Disturbance – e.g. underground services, narrow shallow drains (<1 metre below ground level)

⁹ Major Linear Disturbance – e.g. roads, railways, canals, deep sewer, wide drains, deep drains, dredging projects

geological/geomorphological units at a site.

In some cases, especially where dewatering or other groundwater disturbance is proposed, the initial soil sampling and analysis program may not provide sufficient information upon which to base a comprehensive and effective management plan. In these instances additional investigations will be required before an appropriate management plan can be developed (see [7 Further intrusive investigations to support management plans for the disturbance of ASS](#) for guidance on requirements for further investigations to support management plans).

4.3 Location of sampling points

The findings of the desktop assessment and site inspection should be used in conjunction with an understanding of the nature of the proposed soil disturbance to judge the best locations for investigative boreholes. Undertaking a mapping exercise, which seeks to delineate the lateral and vertical extent of ASS horizons, is usually more useful than a gridded sampling pattern, particularly for large project areas.

Factors to consider when deciding upon sample locations include:

- nature of the disturbance (e.g. excavation, dewatering, drainage, surcharging);
- specific location or locations of disturbance (including any underground service pipes such as sewerage or drains);
- total area of the site to be disturbed;
- volume of material to be disturbed;
- maximum depth of disturbance;
- topography/geomorphology;
- sensitivity of the surrounding environment;
- location of sensitive environmental receptors; and
- estimated lateral and vertical extent of cone of depression during dewatering.

Soil sampling locations should be representative of the site and particularly of the area of disturbance. Care should be taken to ensure representative samples are collected especially on sites with more than one type of geological/geomorphological unit, or clearly different land surface elevations, so that sampling is representative of the entire area.

4.4 Depth of sampling points

Soil sampling locations need to extend to at least one metre below the maximum depth of disturbance.

Where alteration of groundwater levels by drainage, pumping, etc. is envisaged, then soil sampling should extend to at least one metre below the depth of the lowest estimated groundwater drawdown.

4.5 Sampling equipment

Choice of equipment for sample collection depends on the natural sensitivity of the site (e.g. proximity to Class A conservation reserves or wetlands, soil texture, soil moisture, sampling depth required, and accessibility).

A range of manual and mechanical equipment is available for soil sampling including a variety of drilling rigs that are now available to drill on soft ground. In particular, sonic drilling rigs allow rapid soil penetration and better sample recovery. In some instances, where soils are very soft, hand augering may be most appropriate.

4.6 Soil sampling procedure

The following information should be recorded as part of the soil sampling procedure:

- the full grid reference of each sampling location using Australian Metric Grid and its current surface height (expressed relative to Australian height datum (AHD));
- the exact location of each sampling location shown on an appropriately-scaled map;
- an exact description of the vertical dimensions of the borehole or test pit relative to existing surface height and AHD, so that accurate cross-sections can be produced;
- a brief description of the equipment and methods used to retrieve the samples;
- a field description for each soil profile including:
 - soil texture, grain size, roundness, sorting and sphericity using the Australian Soil and Land Survey Field Handbook (McDonald *et al.*, 1990) as a guide
 - colour using a Munsell colour chart
 - mottling, organic matter, moisture content, watertable level and other diagnostic features (e.g. jarosite, shell); and
- photographs of the soil profile clearly identifying each stratum in the soil profile.

An example of a field log is presented in [Figure 3](#).

Once boreholes have been drilled and/or test pits dug, and the profiles described and photographed, soil samples should be collected from each profile. Starting from the present ground surface, soil samples should be collected at intervals not exceeding 0.25 metres down the profile and field tested. Where individual soil units or soil horizons are encountered with a thickness of less than 0.25 metres, sampling frequency should be increased to ensure that at least one sample is collected from each unit or horizon.

The field operator should identify any significant changes with depth down the profile in field description properties (such as colour, texture, moisture content, field pH_F and pH_{FOX} test results etc.). Soils with clearly different physical, visual or chemical properties should not be 'bulked' together, as this will affect how the laboratory results can be interpreted. Again, field personnel should keep in mind that investigations should aim to fully characterise each soil unit at the site.

Ideally, each soil sample should constitute 200–500 grams to allow sufficient sample mass for physical and chemical analysis. It is important to note that compositing over too large a vertical interval to achieve this sample weight will tend to skew results. The absolute mass required will be dependent upon the specific gravity of the sample medium (i.e. a greater volume of peat would be required than for clay). DER recommends confirming the required soil sample quantity with the chosen NATA accredited analytical laboratory before sample collection commences.

Any visible shell or carbonate nodules should be removed from the soil sample in the field. Laboratories routinely sieve samples (<2 millimetres) submitted for ASS testing, after drying, and prior to grinding and analysis. However, this sieving is frequently difficult, particularly on clayey samples as these often set hard on drying, making removal of shell or carbonate nodules without breakage/shattering extremely difficult. Shells or carbonates disturbed in this manner have an increased reactive surface area which can lead to an overestimation of the true neutralising capacity of a soil. Most drilling techniques also shatter some shell and carbonate materials and this should be considered when selecting appropriate sampling methods for a site.

The presence of shell, its location within the profile, its size and abundance must be recorded on field logging sheets for later interpretation with laboratory data.

When collecting samples in the field it is important to prevent oxidation of the soil as much as possible. This can be achieved by immediately placing the sample in plastic snap-lock bags or other suitable containers, excluding air, then placing in a field freezer or with sufficient ice in an esky. Samples should also be kept out of direct sunlight. The sample bags/containers should be carefully marked (using a waterproof pen) for easy identification and should be immediately cooled or frozen and maintained at less than 4 degrees Celsius, until received by the laboratory, to reduce the possibility of oxidation as per Australian Standard AS 4969.1–2008 *Method: Pre-treatment of samples*.

All samples should be retained in storage (frozen or specially dried) until the field investigation report and any related ASS management strategy for the development has received DER approval. Until this time, further laboratory analysis may be required to clarify results, or provide a more accurate understanding of the soil for management purposes.

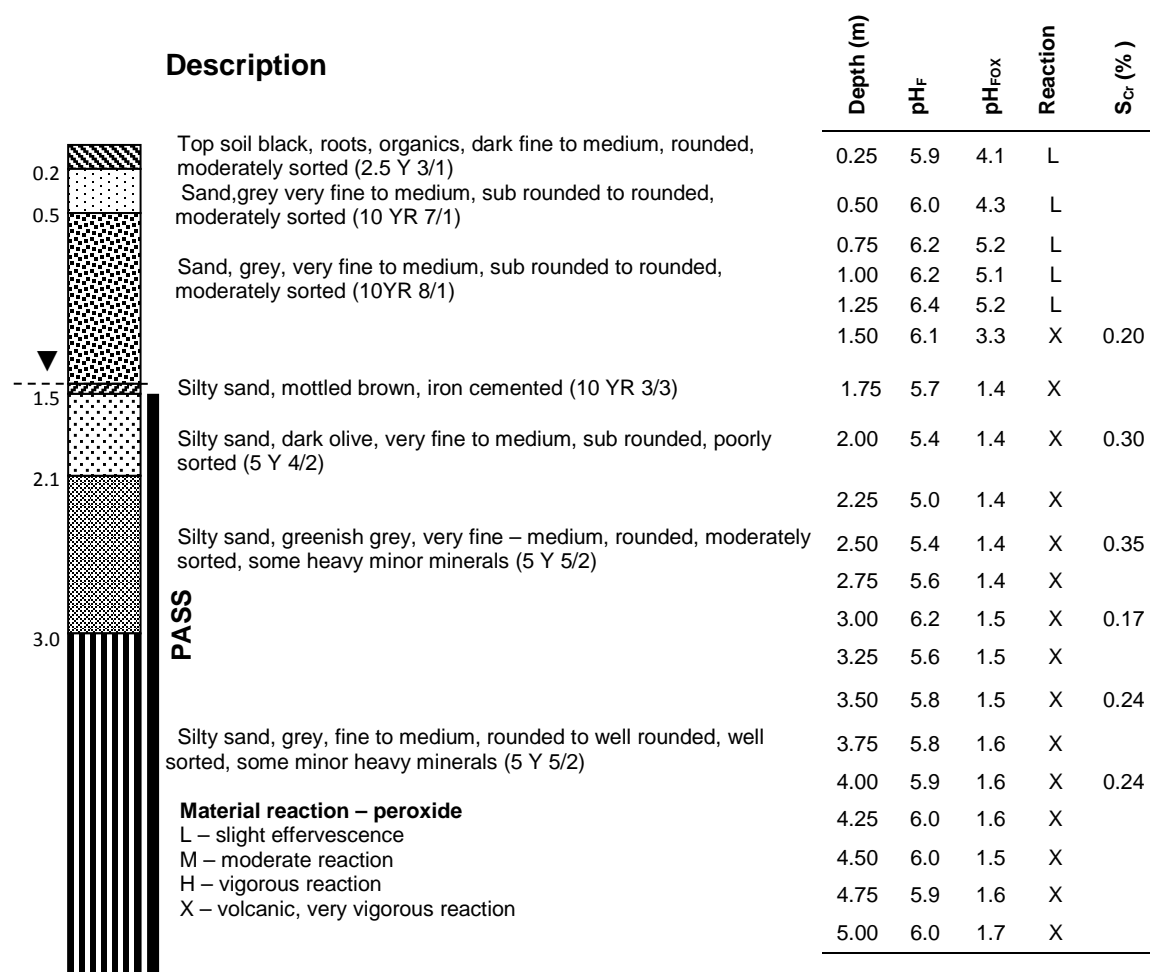


Figure 3: An example of a bore log, showing correct sample collection from a soil profile for field testing and sample selection for laboratory analysis

4.7 Sediment sample collection

For sampling purposes, dredging/de-sludging of coastal rivers, lakes, dams, drains, canals and wetlands should be treated as a major linear disturbance. Sampling of the material to be dredged/de-sludged should be undertaken at 50-metre intervals. At a minimum, samples should be collected from the sediment profile as per [4.6 Soil sampling procedure](#) to at least one metre below the maximum depth of expected material extraction, ensuring that samples from all sedimentary layers are collected.

When collecting underwater sediment samples, careful attention must be paid to ensure that all sediment particle sizes are collected. The fine silt and clay fraction (typically less than 65µm) of the dredged material may contain high concentrations of sulfide, but these materials can easily drain/disperse from the sample during collection. In some wet dredging operations, fine-grained, sulphide-rich sediment (fine silt and clay fractions) can separate from the coarse-grained, sulfide-poor, carbonate-rich sediments (sands and carbonates) during stockpiling. Assessment of such dredged material may require the constituent fractions of the resource to be separated and tested accordingly. Interpretation of soil analysis on the dredge material may be complicated due to the neutralising influences of fine shell material or trapped pore water within the sample. Refer to the *Handbook for Sediment Quality Assessment* (Simpson, S.L. et al., CSIRO 2005) and the *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analysis* (US EPA, 2001)

for further guidance.

Sediment characterisation should be undertaken to determine the particle size distribution, total organic carbon content total metal concentrations in solution and in solid phase.

Care must be taken when sampling bottom sediments in drains or sediments likely to contain iron monosulfides, commonly known as monosulfidic materials (formerly known as monosulfide black oozes (MBO)). These will require special sampling, storage, and treatment. Iron monosulfides oxidise readily (within minutes) at room temperature and are therefore required to be frozen immediately after sample collection. Sediments containing monosulfides will require analysis by the acid volatile sulfur (AVS) method developed by Bush and Sullivan (1998).

Particular attention should be given to dredge spoil containing significant amounts of monosulfides as these have the tendency to cause severe deoxygenation and acidification following re-suspension in the water column. Such materials should be managed so that they do not impact water quality and/or sensitive receptors.

Laboratory methods suitable for acid sulfate soil analysis are described in Australian Standard AS4969–2008 documents, *Analysis of Acid Sulfate Soil*, published by Australian Standard®.

4.8 Stockpile sample collection

Some sites may contain existing stockpiles of suspected or known ASS materials (e.g. dredge spoil stockpiles, excavated peat or sand stockpiles). These are most likely to be found in areas where there has been historic development prior to the widespread adoption of ASS management procedures within the state.

When encountered, such stockpiles should be assessed for their acid-generating potential. The minimum number of samples which should be collected from such stockpiles is dependent upon the volume of the stockpile, as outlined in [Table 7](#). These sampling densities can also be used where only small volumes (<1000m³) of soil are proposed to be disturbed.

Table 7. Minimum number of samples to be collected from stockpiles, based on volume in cubic metres.

| Volume (m ³) | Number of samples |
|--------------------------|-------------------------|
| <250 | 2 |
| 251–500 | 3 |
| 501 to 1000 | 4 |
| >1,000 | 1 per 500m ³ |

Samples should be collected in such a way as to be properly representative of the material contained within the stockpile, i.e. samples should be collected from various depths and locations within the stockpile. It is not sufficient to collect only surface or near-surface samples.

Any material taken to landfill should be sampled according to DER's guideline *Landfill Waste Classification and Waste Definitions* 1996 (as amended December 2009).

4.9 Field tests

Soil field pH (pH_F) tests should be conducted on all samples collected as they provide important information about the existing acidity of the soil profile. The pH_F test measures the existing acidity of a soil:water paste, and can therefore help identify actual ASS (AASS). To ensure accurate results these tests must be conducted in the field as soon as the sample is collected. The pH of the soil sample can change relatively quickly with time, due to soil oxidation such that a pH test carried out on the soil sample once it arrives at a laboratory or other testing facility is likely to be different from that which would have been measured in the field and thus not be representative of true field conditions.

Field pH (pH_F) tests combined with field pH peroxide tests (pH_{FOX}), are helpful in identifying PASS and the results may help with soil sample selection for laboratory analysis. The pH_{FOX} test may be used to give an indication of the presence of stored (potential) acidity.

[Appendix A](#) provides information on how to perform and interpret the results of soil field pH_F and pH_{FOX} tests.

It is important to note that while a useful exploratory tool, soil field pH_F and pH_{FOX} tests are indicative only and cannot be used as a substitute for laboratory analysis to determine the presence or absence of ASS. Review of field pH_F and pH_{FOX} tests in Western Australian soils indicates that these tests provide an accurate identification of ASS in only 60 per cent to 80 per cent of cases and are capable of providing both false positives and false negatives (i.e. may underestimate or overestimate acid-generating potential). Acid-generating potential is commonly underestimated in the sandy soils of the Bassendean Dune System (BDS) which have poor acid buffering capacity. A combination of highly reactive pyrite and the extremely low pH buffering capacity of these soils makes them prone to acidification even after only short exposure (less than a week) to air during temporary excavation or dewatering.

It has been established that horizons of podosols that are at or below the watertable frequently contain small amounts of pyrite, marcasite, elemental sulfur and jarosite. Pyrite is the main acid-generating mineral while elemental sulfur and marcasites also occur as minor constituents in some horizons with high organic matter content.

A combination of $\text{pH}_{\text{FOX}} < 3$ and an analytical value of 0.01%Scr or greater are excellent indicators of ASS and can be used as a basis for managing potential ASS in the BDS.

5 Step 3: Laboratory analysis

5.1 Submission of soil samples for quantitative laboratory analysis

The number of samples that should be submitted to a laboratory for analysis is dependant on the size and type of disturbance as outlined below.

5.2 Linear disturbances, any disturbance >1000m³ and/or for any groundwater disturbance

Starting from the present ground surface¹⁰, soil samples should be submitted for quantitative laboratory tests at intervals not exceeding 0.5metres down the profile from each sampling location. Where individual soil strata units or soil horizons are encountered with a thickness of less than 0.5metres, the frequency of laboratory analysis will need to be increased to ensure that at least one sample is analysed from each unit or horizon. Figure 3

[Figure 3](#) shows the correct sample selection for laboratory analysis from a hypothetical soil profile and [Table 6](#) indicates the number of sampling locations required.

Laboratory analysis confirming the absence of sulfides is just as important as determining the actual sulfide content on a positive sample

For large projects (>20ha) DER may accept reduced laboratory testing frequencies, providing the investigation program satisfactorily characterises the various geological/geomorphological units at a site.

5.3 Small-scale non-linear disturbance (<1000m³) with no groundwater disturbance

For small scale non-linear disturbances (i.e. <1000m³ and not drains or trenches) where no dewatering or groundwater pumping is to be conducted, a reduced number of laboratory analyses may be performed (refer to [Table 5](#)), provided sufficient information is collected upon which to base sound management practices.

Samples should be collected as per the standard protocol for disturbances >1000m³, including the appropriate number of sample locations, detailed soil profile descriptions and sample collection at minimum intervals of 0.25 metres.

The sampling protocol outlined below can be used as a guide to selecting samples for laboratory analysis:

- Using the field observations and the soil profile descriptions as a guide, select the sample location(s) most likely to contain ASS.
- From these selected location(s), select the one sample that is most likely to contain ASS from each metre interval.
- Additionally, select a minimum of one sample most likely to contain ASS from each

¹⁰ In landscapes that have never been disturbed, it is not necessary to perform full acid-base accounting laboratory analyses on sections of the soil profile which are permanently dry (i.e. above the highest ever seasonal groundwater level), unless the results of the field assessment program suggest that the soils may have significant existing or potential acidity. This approach is not appropriate in previously disturbed landscapes - for example land previously used for mineral sand mining or for the disposal of dredge spoil.

of the other sampling locations.

- Submit the selected samples for laboratory analysis, and store the remaining samples frozen or specially dried for possible future use.

All soil samples should be retained until DER has assessed the ASS investigation report. DER will compare the laboratory results with the field logs and, if not satisfied with the sample selection, may request that additional samples be analysed.

[Table 8](#) shows the minimum number of samples to be submitted for laboratory analysis under this protocol.

Table 8. Minimum number of soil samples to be submitted for laboratory analysis for small-scale non-linear disturbances (<1000m³) with no dewatering or groundwater pumping

| | Maximum disturbance depth | | | |
|--|---------------------------|-------------------|-------------------|-------------------|
| | <1m | 1–2m | 2–3m | 3–4m |
| | Borehole depth 2m | Borehole depth 3m | Borehole depth 4m | Borehole depth 5m |
| Volume of disturbed soils ≤250m ³ | 3 | 4 | 5 | 6 |
| Volume of disturbed soils 251–1000m ³ | 4 | 5 | 6 | 7 |

Note: Number of samples to be analysed per total volume of soil to be disturbed, not per borehole. Depth of disturbance to be measured from ground surface. Borehole depth must be at least 1m below maximum proposed depth of disturbance.

5.4 Stockpiles

Quantitative laboratory tests need to be conducted on all samples collected as per the procedures outlined in [4.8 Stockpile sample collection](#).

5.5 Quantitative laboratory analysis

5.5.1 Acid-base accounting

Chemical analysis is undertaken as part of an ASS investigation to determine whether these soils are likely to generate any net acidity and, if so, to quantify this acidity. The analytical results can be further used to calculate the amount of neutralising materials required to be added to these soils to counteract any potential and existing acidity.

Quantitative laboratory analyses for ASS have been developed to measure the net effect of acid-generating processes in the soil, balanced against acid-neutralising (or basic) components that may be present i.e. an acid-base account (ABA).

The underlying principle of acid-base accounting is outlined in the following equation:

- **Net acidity = potential acidity + existing acidity – acid neutralising capacity (ANC¹¹)**

Existing acidity is defined as follows:

- **Existing acidity = actual acidity + retained acidity¹²**

ANC is defined as follows:

- **ANC¹¹ = measured ANC/fineness factor¹³.**

The components on the right hand side of the **net acidity** expression (or various combinations of these components) are determined using appropriate analytical methods.

5.5.2 SPOCAS suite and chromium reducible sulfur suite

Laboratory methods suitable for acid sulfate soil analysis are detailed in Australian Standard AS4969–2008 documents, *Analysis of Acid Sulfate Soil*, published by Australian Standard[®].

The net acidity of soil samples collected in ASS investigations should be analysed using at least one of the two recommended standard analytical suites for ASS analysis—suspension peroxide oxidation combined acidity and sulfate (SPOCAS) suite and chromium reducible sulfur suite.

5.5.2.1 SPOCAS suite

The SPOCAS method is a self-contained ABA test.

The complete SPOCAS method provides 12 individual analytes (plus five calculated parameters), enabling the quantification of some key fractions in the soil sample, leading to better prediction of its likely acid-generating potential. It involves the measurement of pH, titratable acidity, sulfur and cations on two soil sub-samples. One soil sub-sample is oxidised with hydrogen peroxide and the other is not. The differences between the two values of the analytes from the two sub-samples are then calculated.

The Titratable Actual Acidity (TAA), the first part of the acid trail, provides a measure of the actual acidity (i.e. soluble and readily exchangeable acidity) within a soil sample.

The Titratable Peroxide Acidity (TPA) measurement (the second part of the acid trail) is the net result of the reactions between the acidifying and neutralising components in the soil (following peroxide digestion). A TPA of zero indicates that for a finely-ground sample (under laboratory oxidation conditions), the soil's buffering/acid-neutralising capacity exceeds (or equals) the potential acidity from oxidation of sulfides. A valuable feature of the TPA peroxide digestion component of the SPOCAS method is that for

¹¹ Due to the particular characteristics of the soil and groundwater regime in Western Australia, DER does not recognise the validity of ANC values without confirmatory kinetic testing or modified laboratory methods to provide a more accurate estimate of the actual amount of neutralising capacity that would be available under real field conditions.

¹² Refer to *Acid Sulfate Soils Laboratory Methods Guidelines* produced by the Queensland Department of Natural Resources, Mines and Water, Queensland (Ahern et al. 2004) for further explanation of terms.

¹³ When ameliorating ASS by mixing it well with finely divided pure agricultural lime, a safety factor of 1.5 must be applied. Equally, a minimum safety factor (otherwise known as 'fineness factor') of 1.5 should be applied to any naturally occurring ANC that is present in the soil.

soils with $\text{pH}_{\text{Ox}} > 6.5$, any excess acid neutralising capacity (ANC_E) can be quantified by means of a hydrochloric acid titration. This feature is particularly useful when trying to confirm whether a soil has been treated with sufficient lime (including whether an appropriate liming safety factor has been applied, i.e. verification testing). The TPA, being a measure of net acidity, includes a contribution from the material's ANC.

Titrateable Sulfidic Acidity (TSA) is calculated by TPA minus TAA.

The 'sulfur trail' of SPOCAS (i.e. S_{POS}) gives a measure of the maximum 'oxidisable' sulfur (usually predominantly sulfides) present in the soil sample. Since the chemical oxidising conditions employed in the laboratory are more rigorous than those experienced in the field, the S_{POS} result may, as a consequence, include some of the sulfur from the organic fraction in soil layers with appreciable organic matter. In such soil samples, S_{POS} is often slightly greater than chromium reducible sulfur (S_{CR}) (which specifically excludes organic forms of sulfur). Generally, S_{CR} and S_{POS} results are well correlated for redox-reduced or PASS samples, but may differ on partially oxidised and surface samples.

In some ASS, S_{CR} or S_{POS} may be below the action limit but soils may still have an appreciable TPA. Sometimes this may reflect organic acidity, but it may also reflect acidity from oxidation and/or titration of iron-containing or manganese-containing compounds. This is particularly the case in Western Australia for Bassendean Sands and coffee rock formations. Various aluminium-containing compounds, or complexes, may also contribute to this acidity. This acidity may be present whether or not there is any appreciable potential sulfidic acidity (i.e. any significant S_{CR} or S_{POS} result). While this acidity is commonly not rapidly released into the environment in the short term, it is often released over a slower time-frame and so should not be dismissed as being of no consequence.

5.5.2.2 Chromium reducible sulfur suite

The chromium reducible sulfur suite is a set of independent analytical methods each of which determines a component of the ABA. Only specific components of the ABA are measured using this approach. The initial step in the chromium reducible sulfur suite is to measure the reduced inorganic sulfur content (by the chromium reducible sulfur (S_{CR}) method) to estimate the potential sulfidic acidity. Measurements of existing acidity and ANC are also made.

The chromium suite provides accurate, low-cost determination of (non-sulfate) inorganic sulfur and is not subject to significant interferences from sulfur, either in organic matter or sulfate minerals e.g. gypsum (Sullivan et al. 1999).

The inorganic sulfur compounds measured by this method are: i) pyrite and other iron disulfides; ii) elemental sulfur (S_E); iii) thiosulfate, tetrathionate, polythionites; and iv) S_{AV} , acid volatile sulfides (S_{AV}), (e.g. greigite, mackinawite, amorphous FeS), provided these have not been lost during sample transport and preparation. When interpreting results, it should be noted that laboratories routinely oven-dry and grind samples, causing some or all of the acid volatile sulfides to oxidise (Bush and Sullivan, 1997). Thus the S_{CR} results reported for oven-dry samples may only contain a small proportion of the acid volatile sulfur that was present in the original wet sample. With the exception of specific depositional environments (e.g. drains and lake bottom sediments), this is not considered a significant issue as the sulfide content of most Australian ASS is generally dominated by pyrite.

On wet samples, the chromium reduction method can be made specific to the iron disulfide fraction if pre-treatments are used to remove the acid volatile sulfide and elemental sulfur fractions.

Many sandy soils in the Swan Coastal Plain contain negligible acid-neutralising components but have appreciable amounts of TPA. In the absence of any appreciable amount of ANC, where TSA substantially exceeds the sulfidic acidity predicted from the sulfur trial (S_{POS} , S_{CR}), a precautionary approach should be adopted. The proponent should be aware that there may be some risk if soils are only managed according to S_{CR} or S_{POS} values. In such circumstances, the proponent should increase the application rate of neutralising materials to nearer that indicated when TSA is substituted into the ABA equation, as below:

- **Net acidity = potential acidity (TSA) + existing acidity – ANC¹¹**

Note: If there is no obvious reason (e.g. a highly organic/peaty sample) for a substantial variation (between S_{CR} and S_{POS}), then the first step is to conduct a repeat analysis to confirm the analytical results.

A combination of analyses may be required if more detailed knowledge of the soil chemistry is necessary e.g. to determine the most appropriate neutralising agent or management technique.

Whichever laboratory method is used, a full ABA calculation should be completed and analysis and reporting of the resultant data should include a full discussion of all the components of the analysis. For more information refer to Australian Standard AS4969–2008 documents, *Analysis of Acid Sulfate Soil*, published by Australian Standard®.

Samples should be submitted to a laboratory that is NATA-accredited for all of the analyses to be undertaken for all media.

5.6 Acid neutralising capacity (ANC)

Acid neutralising capacity (ANC) is a measure of a soil's inherent ability to buffer acidity and resist the lowering of the soil pH. Acid buffering in the soil may be provided by dissolution of calcium and/or magnesium carbonates (e.g. shell or limestone), cation exchange reactions, and by reaction with the organic and clay fractions. The effectiveness of these buffering components in maintaining soil pH at acceptable levels (e.g. pH 6.5–9.0) will depend on the types and quantities of clay minerals in the soil, and on the type, amount and particle size of the carbonates or other minerals present.

Further information on ANC can be obtained from *ASS Laboratory Methods Guidelines* produced by the Queensland Department of Natural Resources, Mines and Water (Ahern et al., 2004).

DER has experience with many projects in Western Australia where the level of ASS management undertaken was reduced because laboratory soil analyses indicated that the ASS materials in question had sufficient ANC to render them self-neutralising. However, it was found that under real field conditions, disturbance of the soil profile did in fact result in the generation of significant acidity, with resultant environmental damage including release of heavy metals into groundwater and surface waters. Once this mobilisation of acidity and metals has occurred, it is very difficult, if not impossible, to reverse.

The net acidity leached to the environment when ASS is disturbed depends not only on the amount and rate of acid generation, but also on the amount and reactivity of the neutralising components in the soil. The actual amount of neutralising capacity available under real field conditions is influenced by the factors outlined below.

5.6.1 Particle size or fineness of acid-neutralising material

The larger the particle size of a material, the lower the surface area to volume ratio, and thus the lower the reactivity which, in turn, reduces the effective ANC. Titratable sulfidic acidity (TSA) results and ANC results often underestimate the potential risk of acid leakage to the environment as it is likely that not all shell/carbonate materials within the soils would be available for immediate neutralisation of acid because of low unit surface area likelihood of insoluble coatings forming on the shell/carbonate surfaces. ‘Utilisation factors’ recognise the difference in reactivity of different particle sizes. Estimates of utilisation factors for limestone of various particle sizes are listed in [Table 9](#).

Table 9. Utilisation factors for limestone of various particle size (adapted from NSW ASSMAC guidelines)

| Particle size | Utilisation factor |
|---------------|--------------------|
| >0.85mm | 10% |
| 0.3–0.85mm | 60% |
| <0.3mm | 100% |

For example limestone with a particle size of 0.5 millimetres has a utilisation factor equivalent to 60 per cent of the neutralising value of finer grade limestone of particle size <0.300 millimetres.

Utilisation factors for shell fragments of comparable sizes would be expected to be lower than these values due to stronger chemical binding of calcium carbonate within shell bodies.

5.6.2 Armouring

Shells and carbonate materials found in ASS commonly have a coating (or ‘armouring’) of insoluble or sparingly soluble gypsum, silica or iron compounds, rendering much of their carbonate content unavailable for neutralisation.

5.6.3 Reaction kinetics

Even when of small particle size, neutralising materials present in the soil profile may not be able to react quickly enough to counteract developing acidity. In this case, there may be a net export of acid despite the presence of neutralising materials.

5.6.4 Laboratory methods

Standard laboratory methods for ASS involve removing coarse shell fragments and sieving the sample to <2 millimetres, prior to grinding and analysis. Potential neutralising materials in the fraction <2 millimetres remain in the sample and are very finely ground, greatly increasing their reactivity. Those potential neutralising materials in the particle size fraction 0.3 millimetres to 2 millimetres would not be 100 per cent available under real field conditions (see [Table 9](#)). The analysis of the finely-ground

sample may yield an analytical ANC in excess of what would normally be available from the soil *in situ*.

Recent research by Southern Cross Geoscience (Sullivan, et al, 2012) prompted a revision of the ANC assessment criteria based on readily available alkalinity and effective carbonaceous materials within the <0.5 millimetres particle size fraction of unground soil samples.

Available ANC can be defined as:

- **ANC = titratable actual alkalinity (TAAIk) + effective carbonate (eCarb)**

To determine the available ANC in an un-ground soil sample the following rules apply (so as to avoid double counting of ANC):

- If the soil material is not calcareous, then the ANC is equivalent to the TAAIk; and
- If the soil material is calcareous, then ANC should be taken as either the TAAIk or the eCarb, whichever is the greatest.

For all of the above reasons, DER considers that, without confirmatory kinetic testing or modified laboratory methods, ANC values cannot be used as an argument to reduce the level of management required for the disturbance of ASS.

Given the sensitivity of groundwater resources in Western Australia, and the uncertainty surrounding reaction kinetics, an ASSMP should still be developed for sites with 'potential sulfidic acidity + existing acidity' in excess of texture-based action criteria (see [Table 10](#)), regardless of the outcome of standard ANC testing. Further guidance on management measures for ASS, including dewatering management, can be obtained from DER's guidance document '*Treatment and management of soils and water in acid sulfate soil landscapes*' (DER 2015).

6 Step 4: Reporting results

The ASS investigation report describes the findings of the desktop assessment and site inspection, soil sampling, field testing and laboratory analysis and makes recommendations regarding the need for ASS management.

A checklist is provided in [Appendix C](#) that outlines the information which should be considered when reporting on ASS investigations. DER acknowledges that the level of information required may vary from site to site, according to variables such as the nature of the proposed development, soil type, groundwater depth, surrounding sensitive receptors and the complexity of the issues.

However, some information is, mandatory. The provision of this information is required by DER regardless of the site. The following information is required by DER regardless of the site:

- site identification (including certificates of title, co-ordinates of site boundaries);
- executive summary;
- scope of work;
- basis for adoption of assessment criteria;
- quality assurance/quality control (QA/QC) protocols for field and laboratory work;
- results; and
- conclusions and recommendations.

DER requires the certificates of title (hard copy) and the coordinates of site boundaries (eastings/northings) to establish a legal description of a site. If this information is not provided, assessment of the report(s) will not proceed.

Where a practitioner chooses to deviate from the mandatory information requirements of the checklist, the deviations should be highlighted and clear reasons should be given for the deviation from the standard format.

Consideration of the information provided in the checklist will facilitate consistent reporting and aid in the efficient and accurate assessment and management of existing and potential acidity in the landscape.

Where reporting results are not considered consistent, in either content or format, with this guideline, DER may return the report without assessing the information and request that the report be re-submitted with the missing information included. This will increase the time taken for DER to provide review and comment on the report.

When submitting any report to DER, all components of the report must be submitted as a hard copy.

Further information in relation to the content, compilation and presentation of site investigations can be found in the DER contaminated sites guidelines. These guidelines are available on the DER website at <http://www.der.wa.gov.au/your-environment/contaminated-sites>

As acid-generating potential is related to geological strata, ASS investigations should aim to clearly focus on characterising each geological unit beneath the site. For clarity and to expedite the review process, soil test results, including laboratory results, should be reported in tables and figures, clearly showing the corresponding geological description so that the characteristics of each soil

horizon can be identified more easily.

Further information in relation to assessment criteria and quality assurance/quality control is provided below.

6.1 Assessment criteria

The assessment criteria adopted for ASS in Western Australia are the *Texture-based ASS Action Criteria* as developed by QASSIT and outlined in the *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland 1998* (excluding the consideration of ANC).

The *Action Criteria* are based on **Net acidity** ([5.5 Quantitative laboratory analysis](#)) where:

- **Net acidity = potential acidity + existing acidity**

calculated as equivalent sulfur (e.g. $S_{POS} + TAA$ in %S units) or equivalent acidity (e.g. $S_{POS} + TAA$ in mol H^+ /tonne). The highest laboratory result(s) should always be used to assess against the action criteria.

As clay content tends to influence a soil's natural buffering capacity, the action criteria are grouped by three broad texture categories—coarse, medium and fine (see [Table 10](#)).

Table 10. Texture-based ASS 'action criteria'.

| | | Net acidity action criteria | | | |
|--|--------------------------|--|---|--|---|
| Type of material | | <1000 tonnes of materials disturbed | | >1000 tonnes of materials disturbed | |
| Texture range McDonald <i>et al.</i> (1990) | Approx. clay content (%) | Equivalent sulfur (%S) (oven-dry basis) | Equivalent acidity (mol H^+ /tonne) (oven-dry basis) | Equivalent sulfur (%S) (oven-dry basis) | Equivalent acidity (mol H^+ /tonne) (oven-dry basis) |
| Coarse texture sands to loamy sands and peats | <5 | 0.03 | 18 | 0.03 | 18 |
| Medium texture sandy loams to light clays | 5–40 | 0.06 | 36 | 0.03 | 18 |
| Fine texture medium to heavy clays and silty clays | >40 | 0.1 | 62 | 0.03 | 18 |

Bassendean sands—It should be noted that Bassendean sands contain single crystal and framboidal aggregates of sub-micron-sized pyrites. They generally have less than one per cent clay and therefore, extremely poor acid-buffering capacity.

Soil column studies undertaken by DER demonstrated that a sulfur content less than 0.03%S in Bassendean sands can produce a soil Field pH Peroxide Test (pH_{Fox}) of <3 .

In the absence of a revised trigger value for Bassendean sands, where a chromium reducible sulfur (Scr) value is less than 0.03%S and field $\text{pH}_{\text{Fox}} < 3$, the soil should be treated by neutralisation with alkaline materials as if it had an inorganic sulfur content of 0.03%S.

Additionally, a detection limit of 0.005%S is recommended for all sandy soils.

- The *action criteria* refer to existing plus potential acidity for given volumes of ASS. The highest result(s) should always be used to assess if the relevant *action criteria* level has been met or exceeded. Using the mean or mean plus one standard deviation of a range of results is not appropriate.
- When calculating the total amount of material to be disturbed, the calculations must include any ASS material exposed by groundwater drawdown from dewatering and/or drainage works (i.e. the mass of ASS materials contained within the groundwater cone of depression needs to be included within calculations).

The action criteria refer to net acidity for a given volume of ASS disturbance. If groundwater disturbance is proposed, the volume of ASS disturbance should include the volume of any ASS which may be exposed to air due to lowering of the groundwater level (whether temporary or permanent).

If the *texture-based ASS action criteria* are exceeded by any sample result, an ASSMP will need to be developed and implemented for disturbance of ASS at a site.

6.2 Quality assurance/quality control (QA/QC)

ASS investigations should include measures to ensure the quality and reproducibility of all sampling methods used at the site. Accurate QA/QC is required to ensure that the samples collected are of the highest quality and integrity and that analysis is completed with the highest accuracy. Where results are produced with inadequate QA/QC procedures, they cannot be accepted as being accurate or representative of the site conditions.

QA/QC measures are required regardless of the number of samples taken.

6.2.1 Field QA/QC

The minimum field QA/QC procedures that should be performed are:

- collection of field duplicates as quality control samples;
- use of standardised field sampling forms (including Chains of Custody) and methods; and
- documenting calibration and use of field instruments.

Field duplicate samples (also known as blind replicates) are used to identify the variation in analyte concentration between samples collected from the same sampling point and also the repeatability of the laboratory's analysis. Field duplicates should be

collected at the rate of no less than one field duplicate for every 20 investigative samples. The field duplicate sample and investigative sample from the same sample location should be submitted to the laboratory as two individual samples without any indication to the laboratory that they have been duplicated.

6.2.2 Laboratory QA/QC

Analysis of samples should be completed by laboratories which hold National Association of Testing Authorities (NATA) accreditation for the particular parameters and methodologies required. Information on QA/QC methods should be obtained from the designated laboratory prior to sampling to ensure that they meet acceptable standards.

The laboratory report should be a NATA-endorsed report and include the results of the analyses, sample numbers, laboratory numbers, a statement about the condition of the samples when they were received (e.g. on ice, cold, ambient, etc.), date and time of receipt, dates and times of extraction and analysis of samples, quality control results and a report on sampling and extraction holding times.

6.2.3 Data review

Following receipt of field and/or laboratory data, a detailed review of the data should be completed to determine their accuracy and validity, prior to them being used to make any decisions. Analytical data should be reviewed against field data and field observations to identify any spurious results inconsistent with field findings. Where inconsistencies are identified, re-sampling or re-analysis may be required.

Table 11. Example of combined field description and ASS data presentation table.

| Sample ID | | | Field Observations | | | | Field Test | | | | | Lab pH | | SPOCAS | | | | | SCR Suite | | | Action Criteria | | | |
|-----------|----|------|---------------------|----------|----------|--------|----------------|-----------------|-------------------|-------------------------------------|---------------|-------------|--------|--------|------|------|-----|------------------|------------------|-------------|--------|-----------------|-----------------|----------------------|---------------------------------|
| | | | | | | | Depth to Water | pH _F | pH _{FOX} | pH _F - pH _{FOX} | Reaction Rate | Temperature | pH KCl | pH OX | TAA | TPA | TSA | S _{POS} | ANC _E | Net Acidity | pH KCl | TAA | S _{CR} | Net Acidity (SPOCAS) | Net Acidity* (S _{CR}) |
| From | To | mBGL | pH units | pH units | pH units | LMHX V | | | | | | | | | | | | | | | | | | | |
| | | | Assessment Criteria | | | | - | 4 | 4 | 1 | NV | NV | NV | NV | 0.03 | 0.03 | NV | 0.03 | NV | NV | NV | 0.03 | 0.03 | 0.03 | 0.03 |

DER1: 395565.32mE / 6390725.45mN

| | | | | | | | | | | | | | | | | | | | | | | |
|------|------|------|--|------|------|------|------|---|----|-----|-----|-------|-------|--------|------|---|------|-----|---|------|------|------|
| DER1 | 0 | 0.2 | Sandy silt. Grass root zone. Sand component mostly fine grained, well sorted, very angular. Munsell colour 7.5YR 3/2 dark brown. | | 5.85 | 3.14 | 2.71 | L | - | 4.7 | 4.1 | 0.036 | 0.000 | -0.036 | 0.03 | - | 0.06 | 4.3 | 0 | 0.02 | 0.03 | 0.02 |
| DER1 | 0.2 | 0.5 | Peaty silty clay. Roots (fine fibrous). Munsell colour 7.5YR 2.5/1 black. | 0.35 | 4.76 | 2.37 | 2.39 | M | 42 | 5.2 | 4.2 | 0.033 | 0.000 | -0.033 | 0.01 | - | 0.04 | 4.4 | 0 | 0 | 0.01 | 0.00 |
| DER1 | 0.5 | 0.7 | Clayey sand. Minor root matter. Greyish brown sand very fine to fine grained, angular, moderately sorted. Munsell colour 2.5Y 5/1 grey. | | 3.92 | 2.10 | 1.82 | V | 85 | 3.9 | 3.4 | 0.034 | 0.000 | -0.034 | 0.05 | - | 0.08 | 4.2 | 0 | 0.01 | 0.05 | 0.01 |
| DER1 | 0.7 | 0.85 | Sand. Very fine to coarse grained, angular, poorly sorted quartz. Munsell colour 5Y 8/1 white. | | 5.40 | 2.73 | 2.67 | M | 37 | 5.1 | 4.1 | 0.072 | 0.072 | 0.000 | 0.02 | - | 0.1 | 5.3 | 0 | 0.01 | 0.02 | 0.01 |
| DER1 | 0.85 | 0.95 | Sand. Very fine to coarse grained, angular, poorly sorted quartz (with some grains Fe stained). Intensely mottled yellow orange. Munsell colour 10YR 7/8 yellow. | | 5.55 | 2.67 | 2.88 | M | 46 | 5.0 | 3.0 | 0.034 | 0.000 | -0.034 | 0.04 | - | 0.07 | 5.2 | 0 | 0.01 | 0.04 | 0.01 |
| DER1 | 0.95 | 1.1 | Sand. Fine to medium grained, angular, moderately sorted. End of mottled zone. Predominantly. Munsell colour 10YR 8/1 white with Munsell colour 10YR 7/8 yellow. | | 5.62 | 2.28 | 3.34 | H | 72 | 4.9 | 4.5 | 0.046 | 0.000 | -0.046 | 0.04 | - | 0.09 | 4.8 | 0 | 0.02 | 0.04 | 0.02 |
| DER1 | 1.1 | 1.25 | Sand. Fine grained, angular, well sorted. White light grey. Munsell colour 10YR 8/1 white. | | 5.70 | 2.77 | 2.93 | H | 75 | 5.6 | 3.4 | 0.036 | 0.072 | 0.036 | 0.07 | - | 0.1 | 5.3 | 0 | 0.02 | 0.07 | 0.02 |
| DER1 | 1.25 | 1.5 | Sand. Fine grained, angular, well sorted. Munsell colour GLEY#2 10B 4/1 dark bluish grey. | | 5.97 | 3.78 | 2.19 | X | 82 | 6.2 | 2.8 | 0.033 | 0.222 | 0.190 | 0.16 | - | 0.19 | 5.5 | 0 | 0.02 | 0.16 | 0.02 |

DER2: 395357.21mE / 6390310.82mN

| | | | | | | | | | | | | | | | | | | | | | | |
|------|------|------|---|-----|------|------|------|---|----|-----|-----|-------|-------|-------|------|---|------|-----|---|------|------|------|
| DER2 | 0.5 | 1.1 | Peat. Black, fibric to hemic peat with fine fibrous roots. No sediment - all organic matter. Munsell colour GLEY#1 N 2.5/ black. | | 5.20 | 2.80 | 2.40 | X | 64 | 6.3 | 3.5 | 0.255 | 1.406 | 1.151 | 0.52 | - | 0.78 | 6.0 | 0 | 0.15 | 0.52 | 0.15 |
| DER2 | 1.1 | 1.45 | Peat. Dark red brown fibric peat. Fibrous roots up to 2mm thick. Increased root content when compared to above interval. All organic - no sediment. Munsell colour 2.5YR 2.5/3 dark reddish brown. | 1.2 | 3.97 | 3.00 | 0.97 | X | 68 | 5.2 | 3.4 | 0.114 | 0.278 | 0.164 | 0.08 | - | 0.2 | 5.4 | 0 | 0.03 | 0.08 | 0.03 |
| DER2 | 1.45 | 1.6 | Peat. Dusky red sapric peat. Fibrous roots as above, but DERreased content. No sediment - organic matter almost gelatinous. Munsell colour 2.5YR 3/2 dusky red. | | 5.32 | 1.83 | 3.49 | V | 90 | 6.0 | 3.1 | 0.036 | 0.425 | 0.389 | 0.45 | - | 0.49 | 4.9 | 0 | 0.39 | 0.45 | 0.39 |
| DER2 | 1.6 | 2.1 | Peat. Black sapric peat (very little root matter preserved). Munsell colour GLEY#2 5PB 2.5/1 bluish black. | | 6.12 | 2.98 | 3.14 | M | 53 | 5.5 | 3.8 | 0.131 | 0.981 | 0.850 | 0.44 | - | 0.57 | 4.6 | 0 | 0.11 | 0.44 | 0.11 |
| DER2 | 2.1 | 2.3 | Peat. Black peat becoming sandy with depth. Sand fraction very fine to fine grained, rounded to angular. | | 6.09 | 1.90 | 4.19 | X | 83 | 5.8 | 4.5 | 0.082 | 0.752 | 0.670 | 0.63 | - | 0.71 | 4.8 | 0 | 0.46 | 0.63 | 0.46 |
| DER2 | 2.3 | 2.8 | Sand. Brown black sand comprised of fine grained, well rounded, well sorted predominantly quartz with high sphericity. Minor pea and some carbonate fragments. Munsell colour 2.5Y 3/2 very dark greyish brown. | | 6.44 | 2.67 | 3.77 | M | 53 | 5.7 | 4.9 | 0.082 | 1.635 | 1.553 | 0.36 | - | 0.44 | 5.7 | 0 | 0.07 | 0.36 | 0.07 |
| DER2 | 2.8 | 4 | Sand. Cream sand comprised of quartz and carbonate. Munsell colour 2.5Y 6/3 light yellowish brown. Quartz fraction well rounded, well sorted, fine grained with high sphericity. Carbonate fraction - off-white, well sorted, well rounded, fine grained, moderate sphericity. Some shell material present as evidenced by laminated fragments. | | 6.20 | 2.13 | 4.07 | H | 70 | 5.9 | 5.3 | 0.079 | 0.324 | 0.245 | 0.21 | - | 0.29 | 5.9 | 0 | 0.13 | 0.28 | 0.13 |

Notes: mBGL = metres below ground level

7 Further intrusive investigations to support management plans for the disturbance of ASS

In some cases, especially where dewatering or other groundwater disturbance is proposed, the initial soil sampling and analysis program may not provide sufficient information upon which to base a comprehensive and effective management plan. In these instances additional investigations will be required before an appropriate management plan can be developed.

The amount and type of further information required will vary, dependent upon the nature of the geology and sulfide distribution at the site and the nature of the proposed development. It may include the following:

- groundwater quality assessment to determine appropriate management options for groundwater;
- site-specific hydrogeological investigations and modelling to predict the extent of the dewatering cone of depression;
- ASS investigation of the area of the dewatering cone of depression (if not already undertaken);
- in-fill characterisation, if required—e.g. in areas with highly variable sulfide distribution and/or highly variable geology, where initial intrusive investigations have not provided sufficient data to characterise each geological unit;
- analysis of arsenic and other metals in soils; and
- soil/sediment contamination assessment or metal analysis to determine appropriate disposal options.

In such instances, management plans will not be approved by DER until sufficient further investigations have been undertaken.

Further guidance on the requirements for further intrusive investigations to support ASSMPs for the disturbance of ASS can be obtained from the guideline, '*Treatment and management of soils and water in acid sulfate soil landscapes*' (DER 2015).

8 Further information

Further information in relation to ASS can be obtained from guidelines and manuals developed by the Queensland and New South Wales State governments, in particular:

- Queensland Acid Sulfate Soil Technical Manual 2014, Soils Management Guidelines, v4.0, Department of Science, Information Technology, Innovation and the Arts, Queensland Government;
- *Acid Sulfate Soils Laboratory Methods Guidelines*. In *Queensland Acid Sulfate Soils Manual 2004*. Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia;
- *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998*, Queensland Acid Sulfate Soils Investigation Team; and
- *New South Wales Acid Sulfate Soil Manual 1998*, Acid Sulfate Soil Advisory Committee.

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Western Australian Planning Commission (WAPC), October 2012, Model Subdivision Conditions Schedule.

Appendices

Appendix A Performing and interpreting soil field pH tests

It is important to note that, while a useful exploratory tool, soil field pH tests are indicative only. They are not quantitative and cannot be used as a substitute for laboratory analysis to determine the presence or absence of ASS. Laboratory analysis is needed to quantify the amount of existing, plus potential, acidity. This Appendix provides information on how to perform field pH tests and interpret the results from them. For further information on how to conduct and interpret these tests, consult 'Queensland Acid Sulfate Soil Technical Manual 2014, Soils Management Guidelines, v4.0', Department of Science, Information Technology, Innovation and the Arts, Queensland Government.

Field pH tests should be conducted using a field pH meter calibrated according to the manufacturer's instructions. All results (pH_F and pH_{FOX} values, peroxide reaction) should be tabulated and reported.

A1 Suggested equipment for field tests

It is important that prior to conducting the field tests, the appropriate testing equipment is obtained. For a basic setup the following items would be required:

1. pH meter and electrode—charged and calibrated
2. at least 2 buffer solutions—e.g. pH 4.0 and pH 7.0
3. test tubes or beakers—wide, unbreakable, heat resistant, and clear e.g. Falcon 50ml polypropylene (pH_F test tubes are ideally shallow to facilitate cleaning e.g. cut the top off a 50ml tube at about 10ml)
4. test tube rack or jar rack marked with depths—use a separate rack for pH_F tests and pH_{FOX} tests in case they bubble over
5. skewers or stirrers—wooden, for test tubes
6. 30% hydrogen peroxide (H_2O_2) pH adjusted to 4.5–5.5
7. storage bottle for H_2O_2
8. sodium hydroxide (NaOH)—to raise pH of peroxide to 4.5–5.5 (pH 5.5 ideal)
9. deionised (DI) water
10. squirt bottle for DI water
11. tissues
12. gloves and safety glasses
13. protective clothing
14. bucket—to tip used soil and hydrogen peroxide into
15. bucket and brush—to rinse tubes out in ready for next site
16. recording sheets
17. excess water for rinsing
18. first aid kit—especially eye wash solutions
19. 1M hydrochloric (HCl) acid—to test for shell presence

A2 Conducting field tests—some considerations

When the analytical results are reported, the field test results (when accompanied by good soil profile descriptions) will help increase the understanding of profile processes with respect to acidity.

When performing field tests, the soil samples must not be left in the open air in the test tubes or beakers for an extended period of time before conducting the tests. If sulfides are present, there is a risk that they will oxidise, and this will substantially affect the end pH result by lowering the pH_F . This will give a misleading result that the soil profile is more acid than it really is. It would be preferable (and more efficient) to prepare the field pH test tubes with the soil:water pastes and the soil:peroxide mixtures and commence the soil profile descriptions while the reactions are occurring. This way, the soils are given time to react and there is no time wasted waiting for pH_{FOX} samples to cool. It is important though, to keep an eye on the reactions as some may be vigorous and overflow, and result in contamination of nearby soil samples.

When conducting the pH_{FOX} test, it is important to allow enough time for the reaction to occur, especially if low strength (i.e. <30%) hydrogen peroxide is used.

The field pH_F and pH_{FOX} tests can be made more consistent if a fixed volume of soil (using a small scoop) is used, a consistent volume of peroxide is added and left to react for at least an hour (at a secure location, the pH_{FOX} can be left overnight). The sample can then be moistened with deionised water before reading the pH_F and pH_{FOX} .

Field tests should preferably be performed on site, however there are many areas (e.g. wetlands) where performing field tests can prove difficult (e.g. too wet, mosquito problems). In this situation, samples must be placed on dry ice and taken to a suitable location for conducting field tests. These tests should be performed ideally within 24 hours. As some samples may contain large amounts of organic matter (especially in wetland situations) and may also contain monosulfides, any delay in performing field tests could result in misleading pH_F results.

A3 On-site chemical and material safety precautions

A3.1 Hydrogen peroxide

Care needs to be taken when using hydrogen peroxide (H_2O_2) in the field. H_2O_2 (30 per cent) is used as the primary reagent in the pH_{FOX} test. The concentration is 10 times stronger than the peroxide commonly found in household medicine cabinets. The reaction of peroxide with soil containing iron sulfides may produce sulfurous gases and generate heat in excess of 90 degrees Celsius.

Caution: 30 per cent Hydrogen peroxide is a strong oxidising agent and should be handled carefully with appropriate eye and skin protection. **This test is suitable for experienced operators only.** Even the less concentrated 6 per cent peroxide (which some operators are using) should be used with caution.

The peroxide when first received may have a pH of 3.5 or lower. Chemical companies commonly put stabilisers in the peroxide to prevent it from decomposing and releasing oxygen by keeping the pH low. The pH required for the field pH peroxide test is pH 4.5–5.5. This may be obtained by adding sodium hydroxide (pH 14) to the peroxide.

Since both of these chemicals are highly corrosive and many of the long-term side effects are not fully known, it is recommended that the following precautions are taken when performing field tests.

Always:

- use gloves, safety glasses, lab coat or protective clothes;
- conduct pH peroxide test in a well-ventilated area;
- use test tubes capable of withstanding rapid heat changes and high temperatures;
- avoid skin and eye contact with peroxide; and
- label all peroxide bottles with safety data information.

A3.2 Other chemicals

Several other chemicals are used in the field when sampling for ASS. Buffering solutions and potassium chloride (KCl) solutions are used to calibrate and maintain pH meters and care should be exercised when using these substances. Follow safety directions on material safety data sheets (MSDS).

Hydrochloric acid (HCl) is used when performing tests to assess the presence of carbonates in soil material. HCl is strongly acidic and is very corrosive to skin therefore caution is required when using it. Again, follow directions on MSDS. Store HCl separate from buffer solutions as HCl gas may slowly diffuse through the plastic bottles and alter the buffer solutions.

A4 Field pH test (pH_F)

The pH_F test measures the existing acidity of a soil:water paste, and is therefore used to help identify if ASS are present. If the measured pH of the soil paste is $pH_F < 4$, oxidation of sulfides has probably occurred in the past, indicating the presence of AASS. Highly organic soils or heavily fertilised soils may also return a pH_F close to 4. A $pH_F > 4$ but ≤ 5 indicates an acid soil, but the cause of the acidity will need to be further investigated by laboratory analysis. The pH_F test does not detect any unoxidised sulfides (i.e. PASS). For this reason, this test must be used in conjunction with the pH_{FOX} test.

A4.1 Soil:water mixtures and soil pastes

Standard field soil pH tests have been conducted using a 1:5 soil:water mixture. This is quite successful where sands are concerned (as they breakdown readily); however, in a field situation it is often difficult to get all soil into solution by shaking only for a brief period of time. In particular, where wet clays are present, it becomes very difficult in the field to shake the mixture to suspend all the clay particles in solution. It is more likely that the clay will stay in a ball and while some fine particles previously attached to the edge of the clay bolus are suspended, the remainder sticks to the bottom of the test tube. This means that the soil:liquid ratio is widened substantially and the pH of the mixture will have a higher reading, so that it will not give a true and accurate measurement of the pH of the soil. In the laboratory, this sample would be dried, ground, mixed, and shaken mechanically for hours allowing substantial time for the clay to be broken down—in the field, this option is not practical. Furthermore, it is not practical to weigh out soils in the field to obtain a perfect 1:5 soil:water mixture, and so any solutions made up are usually done on a volumetric basis assisted by graduated

test tubes, flasks, or beakers.

Making a soil:water paste is more practical for field situations and is recommended for ASS field pH (pH_F) tests. This is detailed in the procedure below. It is recommended that short test tubes are used for pH_F tests as they are easy to clean. Furthermore, the paste must be stirred using a stirring implement (e.g. skewer or strong toothpicks). Stirring the paste well will enhance the accuracy of the pH result as the electrode will get good contact with the soil.

A4.2 Field pH test procedure

Procedural outline—field pH_F test:

1. Calibrate battery powered field pH meter.
2. Prepare the test tubes in the test tube rack. Make sure the rack is marked with the depths so there is no confusion about the top and bottom of the profile. Use of separate racks for the pH_F and pH_{FOX} tests is recommended as contamination may occur when the pH_{FOX} reactions are violent.
3. Conduct tests at intervals on the soil profile of 0.25 metres or at least one test per horizon, whichever is lesser.
4. Remove approximately one teaspoon of soil from the profile. Place approximately $\frac{1}{2}$ teaspoon of the soil into the pH_F test tube and place $\frac{1}{2}$ teaspoon of the soil into the pH_{FOX} test tube for the corresponding depth test. It is important that these two sub-samples come from the same depth and that they are similar in characteristics. For example, DO NOT take $\frac{1}{2}$ teaspoon of soil from the 0–0.25-metre depth that is grey mud, while selecting $\frac{1}{2}$ teaspoon from the same depth that is a yellow mottled sample. These will obviously give different results independent of the type of test conducted.
5. Place enough deionised water (pH 5.5) in the pH_F test tube to make a paste similar to 'grout mix' or 'white sauce', stirring with a skewer or similar to ensure all soil 'lumps' are removed. Do not leave the soil samples in the test tubes without water for more than 10 minutes. This will reduce the risk of sulfide oxidation—the pH_F is designed to measure existing acidity, any oxidation subsequent to the soil's removal from the ground will not reflect the true situation. In some instances, in less than five minutes, monosulfidic material may start to oxidise and substantially affect the pH_F results.
6. Immediately place the spear point electrode (preferred method) into the test tube, ensuring that the spear point is totally submerged in the soil:water paste. Never stir the paste with the electrode. This will damage the semi-permeable glass membrane.
7. Measure the pH_F using a pH meter with spear point electrode.
8. Wait for the reading to stabilise and record the pH measurement. All measurements and pH calibration should be recorded on a data sheet.

Table A1. results—field pH test

| pH value | Result | Comments |
|----------------------------|---|--|
| $\text{pH}_F \leq 4$ | Actual acid sulfate soils (AASS) indicating oxidation of sulfides | This is generally <u>not</u> conclusive because highly organic soils such as peats and occasionally heavily fertilised soils may also give $\text{pH}_F \leq 4$. |
| $\text{pH}_F \leq 3.7$ | Expected if jarosite exists in the sample | This is also an AASS. Jarosite needs a pH of 3.7 or lower to form. Horizons containing some jarosite and some other mottling (iron, grey) may have a pH >3.7 if the sample contains a mixture of jarosite and higher pH soil. This depends on the level of oxidation and the ability of the soil to 'hold' the acid. |
| $\text{pH}_F > 7$ | Expected in waterlogged, unoxidised, or poorly drained soils | Marine muds commonly have a pH >7 and this reflects seawater (pH 8.2) influence. May be a PASS after oxidation with H_2O_2 . |
| $4 < \text{pH}_F \leq 5.5$ | An acid soil | Investigate further for possible ASS link, e.g. AASS with shell presence. |

A5 Field pH peroxide test (pH_{FOX})

The pH_{FOX} test is used to indicate the presence of iron sulfides or PASS. This test involves adding 30 per cent hydrogen peroxide (pH adjusted to 4.5–5.5) to a sample of soil. If sulfides are present a reaction will occur. The reaction can be influenced by the amount of sulfides present in the sample, the presence of organic matter, or the presence of manganese. Once the reaction has occurred, the pH is measured.

Adding hydrogen peroxide, a strong oxidising agent, 'mimics' what would naturally occur if the soil was exposed to air. In a natural environment, if left exposed, soils may take from two hours for sands, possibly through to many decades for heavy marine clays, for some or all of the oxidation reactions to take place. Obviously it is not practical to wait for this long for a reaction to occur.

It should be noted that although the iron sulfides are oxidised and acid is produced over a shorter amount of time than would occur naturally, the total amount of acid produced is the same. It is important to assess first the likely presence (through field tests) and secondly the level of iron sulfides present (through laboratory analyses) so that management can prevent any undesirable impacts.

The pH_{FOX} test is purely qualitative. No calculations can be performed to give an accurate account of the levels of sulfides present in the sample. Rather, the test gives an indication of whether sulfides may occur (or whether there is another form of compound contributing to acidity).

This means that a pH_{FOX} test CANNOT give an accurate measurement of how much lime should be added to the soil.

The sample of soil must be taken from the same depth increment (sub-sample) for which the pH_F was measured. It is important that the pH_{FOX} is performed on a

separate sub-sample, and NOT on the soil:water paste that was prepared for the pH_F test. This will ensure that the minimal degree of dilution occurs during the oxidation phase and that the resulting pH_{FOX} measurement is as accurate as possible an indication of the potential for oxidation of that particular sub-sample of soil.

A combination of three factors is considered in arriving at a 'positive field sulfide identification':

- a reaction with hydrogen peroxide—the strength of the reaction with peroxide is a useful indicator but cannot be used alone. Organic matter, coffee rock and other soil constituents such as manganese oxides can also cause a reaction. Care should be exercised in interpreting a reaction on surface soils and high organic matter soils such as peats and coffee rock and some mangrove/estuarine muds and marine clays. This reaction should be rated, e.g. L = low reaction, M = medium reaction, H = high reaction, X = extreme reaction, V = volcanic reaction.
- The actual value of pH_{FOX} —if $\text{pH}_{\text{FOX}} < 3$, and a significant reaction occurred, then it strongly indicates PASS. The more the pH_{FOX} drops below 3, the more positive the presence of inorganic sulfides.
- A much lower pH_{FOX} than field pH_F —the lower the final pH_{FOX} value and the greater the difference between the pH_{FOX} compared to the pH_F , the more indicative of the presence of PASS. This difference may not be as great if starting with an already very acid pH_F (close to 4), but if the starting pH is neutral or alkaline then a larger change in pH should be expected. Where fine shell, coral or carbonate is present the change in pH may not be as large due to buffering. The 'fizz test' (effervescence with 1 M HCl) should be used to test for carbonates and shell.

Of these three factors, the final pH_{FOX} value is the most conclusive indicator, and the lower the final pH_{FOX} , the more confident one can be that PASS may be present.

A5.1 Strength and pH of peroxide

The pH and strength of peroxide used is important. The pH of the peroxide should be pH 4.5–5.5 (ideally pH 5.5). This ensures that the result measured is a reflection of the oxidation of the soil (if any) and not of the existing pH of the peroxide. When peroxide is purchased often the stabilisers added by the chemical companies will result in a pH of approximately 3.5. This pH can be raised by adding small amounts of sodium hydroxide (NaOH)—failure to adjust the pH can lead to false field results.

Analytical grade peroxide (30 per cent) is most suitable for field pH_{FOX} tests as an oxidation agent that is highly effective and 'quick' to react with any iron sulfides in a soil sample. This strength of peroxide is highly corrosive, slightly unstable, highly reactive and can cause severe skin irritation. As such, a high level of safety precautions is required. However, there is no reason why a well-trained officer cannot safely and responsibly conduct field tests with 30 per cent hydrogen peroxide.

A5.2 Field pH peroxide test procedure

Procedural outline—field pH peroxide test

1. Adjust the pH of the hydrogen peroxide to 5.0–5.5 before going into the field. This can be done by adding a few drops of NaOH at a time, checking the pH with the electrode regularly. NaOH is highly caustic so safety precautions must be exercised. Also, NaOH will raise the pH quickly so the pH needs to be monitored. Do NOT buffer a large quantity of hydrogen peroxide at one time. Only buffer the

amount to be used in the field. Hydrogen peroxide should be well labelled and only small quantities should be taken into the field at any one time. This will ensure the longevity of the peroxide. Further, over time, the pH of the peroxide that has already been buffered may change. It is important to check the pH of the peroxide in the morning before departing to the field. Having a small quantity of NaOH in the field kit is recommended so the pH of the peroxide can be adjusted if required.

2. Calibrate battery powered field pH meter.
3. Prepare the test tubes in the test tube rack as for pHF test. Make sure the rack is marked with the depths so there is not confusion about the top and bottom of the profile. Use of separate racks for the pHF and pHFOX tests is recommended as contamination may occur when the pHFOX reactions are violent.
4. Conduct pHF tests at intervals of 0.25 metres down the soil profile or at least one per horizon, whichever is lesser.
5. Remove approximately one teaspoon of soil from the profile. Place approximately $\frac{1}{2}$ teaspoon of that soil into the pHF test tube and place $\frac{1}{2}$ teaspoon of soil into the pHFOX test tube for the corresponding depth test. It is important that these two sub-samples come from the same depth and that they are similar in characteristics. For example, DO NOT take $\frac{1}{2}$ teaspoon of soil from the 0–0.25-metre depth that is grey mud, while selecting $\frac{1}{2}$ teaspoon from the same depth that is a yellow mottled sample. These will obviously give different results independent of the type of test conducted.
6. Add a few drops of 30 per cent H₂O₂ adjusted to pH 4.5–5.5 to the soil in a heat-resistant test tube and stir the mixture. DO NOT add the peroxide to the test tube in which the pHF test was conducted. The pHFOX test tube should not have any deionised water in it. Beakers can be used however when multiple tests are being conducted it is difficult to handle the large beaker size efficiently. DO NOT add more than a few drops of H₂O₂ at a time. This will prevent overflow and wastage of peroxide. A day's supply of peroxide should be allowed to reach room temperature prior to use (cold peroxide from the fridge may be too slow to react).
7. Ideally, allow approximately 20 minutes for any reactions to occur. If substantial 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 test tube rack. If the reaction is violent and the soil/peroxide mix is escaping from the test tube, a small amount of de-ionised water can be added to cool and calm the reaction. Usually this controls overflow. DO NOT add too much de-ionised water as this may dilute the mixture and affect the pH value. It is important to only use a small amount of soil otherwise violent reactions will overflow and the sample will be lost.
8. Steps 6 and 7 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 judgment is recommended.
9. If there is no initial reaction, individual test tubes containing the soil/peroxide mixture can be placed into a cup of hot water (especially in cooler weather) or in direct sunlight. This will encourage the initial reaction to occur. When the sample starts to 'bubble', remove the test tube immediately from the cup and replace into

test tube rack.

10. Wait for the soil/peroxide mixture to cool (may take up to 10 minutes). The reactions often exceed 90 degrees Celsius. Placing an electrode into these high temperature situations may result in physical damage and inaccurate readings as most pH meters are set to record a result for an ambient temperature of approximately 25 degrees Celsius.
11. Use an electronic pH meter (preferred method) to measure the pHFOX. Place a spear point electrode into the test tube, ensuring that the spear point is totally submerged in the soil/peroxide mixture. Ensure that the plastic soil sleeve that exposes the spear point totally is used on the end of the electrode in preference to the protective pronged sleeve that almost totally conceals the spear point. This will ensure good contact with the soil. Never stir the mixture with the electrode. This will damage the semi-permeable glass membrane.
12. Rate the reaction using a LMHXV scale (Section A5).
13. Wait for the reading to stabilise and record the pHFOX measurement.
14. All measurements and pH calibration measurements should be recorded on a data sheet.

Table A2: Results – field pH_{FOX} test

| pH value and reaction | Result | Comments |
|--|--|---|
| A strong reaction of soil with peroxide – X or V | A useful indicator but cannot be used alone. | Organic matter, coffee rock, and other soil constituents such as manganese oxides can also cause a reaction. Care must be exercised in interpreting a reaction on surface soils and high organic matter soils such as peats and coffee rocks, and some mangrove/estuarine muds and marine clays. |
| pH _{FOX} value at least one unit below field pH _F and reaction to peroxide | May indicate PASS but depends on the initial and resultant pH | The greater the difference between the two measurements (Δ pH), the more indicative the value is of a PASS. The lower the final pH _{FOX} , the better the indication of a positive result (e.g. a 1 unit change from pH 8 to 7 would not indicate PASS, however a 1-unit change from pH 3.5 to 2.5 would be indicative). |
| pH _{FOX} <3, strong reaction with peroxide, and large Δ pH | Strongly indicates PASS – potential for the soil to produce sulfidic acid upon oxidation | The lower the pH _{FOX} below 3, the more positive the likely presence of sulfides. A combination of all three parameters (reaction strength, unit pH change, and final pH _{FOX} result) is most confirmatory. |
| A pH _{FOX} 3–4 and reaction to peroxide | The test is less positive and is a borderline result | Sulfides may be present however organic matter may also be responsible for the decrease in pH. Laboratory analyses are required to confirm if sulfides are present. |
| pH _{FOX} 4–5 | The test is neither positive nor negative | Sulfides may be present either in small quantities and be poorly reactive under quick test field conditions, or the sample may contain shell/carbonate, which neutralises some or all acid produced by oxidation. Equally the pH _{FOX} value may be due to the production of organic acids and there may be no sulfides present in this situation. In such cases, the chromium reducible sulfur method would be best to check for the presence of iron sulfides. |
| pH _{FOX} >5 and little or no drop in pH from pH _F but reaction to peroxide | Little net acidifying ability is indicated | On soils with neutral to alkaline field pH and shell or white concretions present, the fizz test with 1M HCl should be used to test for carbonates. The SPOCAS method should be used to check for any oxidisable sulfides and the presence of self-neutralising ability. |

A6 field test results interpretation

Field test results are dependent on many factors including accuracy of pH meters, strength of reagents and operator skill. The reactions and results obtained from the field pH peroxide test can be further influenced by additional factors such as soil type, moisture content, ambient air temperature, presence of organic matter, or bicarbonate as shell or seawater in the soil sample. Some of these reactions are listed in [Table A3](#) together with explanatory comments.

Table A3: Some common field test results

| pH _F | pH _{FOX} (at completion of reaction) | ΔpH | Reaction rate | Result (e.g. **PASS or ***AASS) | Comments / Possible explanation |
|-----------------|--|-----|---------------|---|---|
| 3.5 | 3.3 | 0.2 | L | AASS present | Oxidation has occurred and sulfuric acid has formed in the past. This soil may not have much more potential to oxidise further as the pH _F and pH _{FOX} are similar. |
| 3.7 | 1.4 | 2.3 | X or V | AASS present; PASS—strong indication | Oxidation has occurred in the past. This soil has the potential to oxidise further indicated by the strong reaction, appreciable pH unit difference (pH _{FOX} is significantly lower than the pH _F) and the very low final pH _{FOX} . |
| 6.5 | 2.1 (1.9)* | 4.4 | X or V | No AASS; PASS—strong indication | This soil is not yet oxidised but has the ability to produce sulfuric acid if exposed. Little buffering capacity in the soil. Laboratory analysis using SPOCAS could confirm this. |
| 8.5 | 3.0 (3.2)* | 5.5 | H | No AASS; PASS—likely | The initial pH may be reflecting a strong seawater influence (pH 8.2) or some form of dissolved carbonates. The large ΔpH indicates a strong likelihood of PASS even though the pH _{FOX} is borderline. Here, the ΔpH and the reaction gives strength to the argument. Laboratory analysis using |

| | | | | | |
|-----|---------------|-----|-------------------|---|--|
| | | | | | SPOCAS and reacted calcium (Ca_A) could confirm this (see Ahern & McElnea (1999)). |
| 8.0 | 2.0 (6.0)* | ? | H | No AASS; PASS— strong indication; Considerable buffering capacity | The initial alkaline pH_F indicates a seawater influence. The initial large decrease in pH indicates the soil is likely to contain sulfides. The pH measured after 20 minutes may indicate a large % of shell dissolving into solution as the acid contacts it (a small amount of HCl added to a sample of soil could confirm its presence). Laboratory analysis using SPOCAS and Ca_A could confirm this (see Ahern & McElnea (1999)). |
| 5.5 | 5.4 (5.3)* | 0.2 | X or V | No AASS; PASS— unlikely | The strong reaction is probably due to the presence of manganese in the soil sample. |
| 5.5 | 3.8 (3.5)* | 2.0 | H (slow froth) | No AASS; PASS— possible | The strength of the reaction indicates possible organic matter. There may be some sulfides present also. Laboratory analysis using the S_{CR} could confirm this. |

* pH_{FOX} after 20 minutes (or overnight)

** PASS—Potential Acid Sulfate Soils

*** AASS—Actual Acid Sulfate Soils

Appendix B Glossary

(Acid) Fizz test: The field test used for soils to test for the presence of carbonate minerals. Dilute hydrochloric acid is added to the soil and an effervescent fizzing reaction indicates the presence of carbonate minerals.

Acid-base accounting (ABA): The process by which the various acid-producing components of the soil are compared with the acid neutralising components so the soil's net acidity can be calculated.

Action criteria: The critical net acidity values (expressed in units of equivalent % pyrite sulfur, or equivalent mol H⁺/t), for different soil texture groups and sizes of soil disturbance that trigger the need for ASS management.

Actual acidity: A component of existing acidity. The soluble and exchangeable acidity already present in the soil, often as a consequence of previous oxidation of sulfides. It is this acidity that will be mobilised and discharged following a rainfall event. It is measured in the laboratory using the TAA method. It does not include the less soluble acidity (i.e. retained acidity) held in hydroxy-sulfate minerals such as jarosite.

ANC: Acid-neutralising capacity. A measure of a soil's inherent ability to buffer acidity and resist the lowering of the soil pH.

ANC_{BT}: Acid-neutralising capacity by back titration. Acid-neutralising capacity measured by acid digest followed by back titration of the acid that has not been consumed.

ANC_E: Excess acid neutralising capacity. Found in soils with acid-neutralising capacity in excess of that needed to neutralise the acidity generated by oxidation of sulfides. The soil is oxidised with peroxide, then a titration is performed with dilute hydrochloric acid to a pH of 4, followed by a second peroxide digestion. If a soil has a positive ANC_E result then the TPA result is zero and vice versa.

ASS: Acid sulfate soil

ASSMP: Acid sulfate soil management plan

Ca_{HCl}: Calcium soluble in 4 m HCl, which includes soluble and exchangeable calcium as well as calcium found in certain carbonate minerals (e.g. dolomite, calcite, aragonite).

Ca_{KCl}: Potassium chloride extractable calcium measured following the TAA analysis,

which includes soluble and exchangeable calcium as well as calcium from gypsum.

Ca_{NAS}: Net acid soluble calcium. The calcium soluble in 4 m HCl that is not soluble in 1 m KCl.

(Ca_{HCl} – Ca_{KCl}). It can be used (in combination with Mg_{NAS}) to provide an estimate of the soil carbonate content, but may be an overestimate if calcium is dissolved from non-carbonate or non-acid-neutralising minerals.

Ca_p: Peroxide calcium. Calcium measured following the TPA analysis, which includes soluble and exchangeable calcium, calcium from gypsum, as well as calcium (e.g. from carbonates) dissolved as a result of acid produced due to oxidation of sulfides by peroxide.

Chromium suite: The acid-base accounting approach used to calculate net acidity which uses the chromium reducible sulfur method to determine potential sulfidic acidity. A decision tree approach based on the pH_{KCl} result is then used to determine the other components of the acid-base account.

C_{IN}: Inorganic carbon (C_T – C_{TO}), used to estimate the carbonate content of the soil.

CRS: The acronym often given to the chromium reducible sulfur method.

C_T: Total carbon. A measure of the total carbon content of the soil, encompassing both organic and inorganic forms.

C_{TO}: Total organic carbon. The carbon in sample measured following a sulfurous acid digestion procedure used to remove carbonate carbon.

eCarb: The appropriate particle size range of carbonate liming materials that can effectively neutralise the existing acidity and potential acidity production within acid sulfate soils.

ENV: Effective neutralising value of a liming product takes into consideration of the chemical composition of the lime (NV), particle size distribution (% by weight) and the solubility of a lime.

Existing acidity: The acidity already present in acid sulfate soils, usually as a result of oxidation of sulfides, but which can also be from organic material or acidic cations. It can be further sub-divided into actual and retained acidity, i.e. existing acidity = actual acidity + retained acidity.

Fineness factor: A factor applied to the acid-neutralising capacity result in the acid base account to allow for the poor reactivity of coarser carbonate or other acid neutralising material. The minimum factor is 1.5 for finely divided pure agricultural lime, but may be as high as 3.0 for coarser shell material.

Jarosite: Jarosite is a characteristic pale yellow mineral deposit that can precipitate as pore fillings and coatings on fissures. Where there is a fluctuating watertable, jarosite may be found along cracks and root channels in the soil. However, jarosite is not always found in AASS

MGA94: The Geocentric Datum of Australia (usually referred to as GDA94, or just GDA), is a coordinate system for Australia. That is, it's a system of latitudes and longitudes, or east and north coordinates, used to keep track of locations. GDA94 is compatible with modern positioning techniques such as the Global Positioning System (GPS). It supersedes the existing Australian Geodetic Datum 1984 (AGD84) and older coordinate systems. GDA94 is based on a global framework, the IERS Terrestrial Reference Frame (ITRF), but is fixed to a number of reference points in Australia.

Mg_A: Reacted magnesium. The magnesium soluble after the peroxide digest and TPA titration that was not soluble following KCl-extraction and TAA titration ($Mg_P - Mg_{KCl}$). It can be used (in combination with Ca_A) to provide an estimate of the soil carbonate content, but may be an underestimate if the HCl-titration to pH 4 has not been performed as part of the TPA/ANC_E procedure.

Mg_{HCl}: Magnesium soluble in 4M HCl, which includes soluble and exchangeable magnesium as well as magnesium found in certain carbonate minerals (e.g. dolomite, magnesite).

Mg_{KCl}: Potassium chloride extractable magnesium measured following the TAA analysis, which includes soluble and exchangeable magnesium.

Mg_{NAS}: Net acid soluble magnesium. The calcium soluble in 4M HCl that is not soluble in 1M KCl. ($Mg_{HCl} - Mg_{KCl}$). It can be used (in combination with Ca_{NAS}) to provide an estimate of the soil carbonate content, but may be an overestimate if magnesium is dissolved from non-carbonate or non-acid-neutralising minerals.

Mg_P: Peroxide magnesium. Magnesium measured following the TPA analysis, which includes soluble and exchangeable magnesium, as well as magnesium (e.g. from carbonates) dissolved as a result of acid produced due to oxidation of sulfides by peroxide.

Monosulfides: The term given to the highly reactive iron sulfide minerals found in ASS that have the approximate formula 'FeS' and are soluble in hydrochloric acid (as

opposed to iron disulfides such as pyrite that are not appreciably soluble in hydrochloric acid).

Monosulfidic black ooze (MBO): The term used to describe black, oily in appearance, gel-like substances (moisture content >70%), greatly enriched in monosulfides (up to 27%), high in organic matter (usually 10% organic carbon) and can form thick (>1.0m) accumulations in waterways (including drains), in acid sulfate soil landscapes.

NATA: National Association of Testing Authorities, Australia. Provides independent assurance of technical competence through a proven network of best practice industry experts.

Net acidity: The result obtained when the values for various components of soil acidity and acid neutralising capacity are substituted into the Acid-Base Accounting equation. Calculated as:

$$\text{Net Acidity} = \text{Potential Sulfidic Acidity} + \text{Existing Acidity} - (\text{Acid-Neutralising Capacity/Fineness Factor})$$

pH_F: Field pH—field determination of pH in a soil:water paste.

pH_{FOX}: Field peroxide pH—field determination of pH in a soil:water mixture following reaction with hydrogen peroxide.

pH_{KCl}: Potassium chloride pH—pH in a 1:40 (W/V) suspension of soil in a solution of 1M potassium chloride measured prior to TAA titration.

pH_{OX}: Peroxide oxidised pH—pH in a suspension of soil in a solution after hydrogen peroxide digestion in the SPOCAS method.

POCAS: An acronym standing for peroxide oxidation combined acidity and sulfate method (Method Code 21). This method has been superseded by the SPOCAS method.

POCASm: An acronym standing for the modified peroxide oxidation combined acidity and sulfate method. This method has been superseded by the SPOCAS method.

Potential (sulfidic) acidity: The latent acidity in ASS that will be released if the sulfide minerals they contain (e.g. pyrite) are fully oxidised. It can be estimated by titration (i.e. TSA) if no acid-neutralising material is present, or calculated from S_{POS} or S_{CR} results.

Ramsar wetland: an area that has been designated under Article 2 of the Ramsar Convention or declared by the Minister to be a declared Ramsar wetland under the *Environment Protection and Biodiversity Conservation Act*.

Retained acidity: The 'less available' fraction of the existing acidity (not measured by the TAA) that may be released slowly into the environment by hydrolysis of relatively insoluble sulfate salts (such as jarosite, natrojarosite, and other iron and aluminium hydroxy-sulfate minerals).

S_{CR}: The symbol given to the result from the chromium reducible sulfur method (Method 22B). The S_{CR} method provides a measure of reduced inorganic sulfide content using iodometric titration after an acidic chromous chloride reduction. This method is not subject to interferences from organic sulfur.

S_{HCl}: Sulfur soluble in 4M HCl which includes soluble and adsorbed sulfate, sulfate from gypsum, as well as sulfate from hydroxy-sulfate minerals such as jarosite and natrojarosite.

S_{KCl}: Potassium chloride extractable sulfur measured following the TAA analysis, which includes soluble and adsorbed sulfate as well as sulfate from gypsum.

S_{NAS}: Net acid soluble sulfur ($S_{HCl} - S_{KCl}$). The sulfur soluble in 4M HCl that is not soluble in 1 m KCl. It provides an estimate of the sulfate contained in jarosite and similar low solubility hydroxy-sulfate minerals (can be used to estimate retained acidity).

S_P: Peroxide sulfur. Sulfur measured following the TPA analysis, which includes soluble and exchangeable sulfate, sulfate from gypsum, as well as sulfide converted to sulfate and that released from organic matter as a result of peroxide oxidation.

S_{POS}: Peroxide oxidisable sulfur from the SPOCAS method. The sulfur soluble after the peroxide digest and TPA titration that was not soluble following KCl-extraction and TAA titration. ($S_P - S_{KCl}$). It provides an estimate of the soil sulfide content, but is affected by the presence of organic sulfur.

S_{RAS}: Residual acid soluble sulfur. The sulfur measured by 4M HCl extraction on the soil residue remaining after peroxide digestion and TPA titration of the SPOCAS method. It provides an estimate of the sulfate contained in jarosite and similar low solubility hydroxy-sulfate minerals (can be used to estimate retained acidity).

S_T: Total sulfur. A measure of the total sulfur content of the soil, encompassing both organic and inorganic forms.

S_{TOS}: Total oxidisable sulfur. An estimate of soil oxidisable sulfur made from determining the sulfur not soluble in 4 m HCl. ($S_T - S_{HCl}$). It tends to provide an overestimate of soil sulfide content.

Self-neutralising soils: This term is given to ASS where there is sufficient acid-neutralising capacity (with the relevant safety factor applied) to neutralise the potential sulfidic acidity held in the soil (i.e. the net acidity from the acid-base account is zero or negative). Soils may be 'self-neutralising' due to an abundance of naturally occurring calcium or magnesium carbonates (e.g. crushed shells, marine animal exoskeletons, coral) or other acid-neutralising material.

SPOCAS: An acronym standing for suspension peroxide oxidation combined acidity and sulfur method (Method Code 23), the peroxide-based method that supersedes the previous POCAS and POCASm methods.

SPOCAS Suite: The acid-base accounting approach used to calculate net acidity based on the Suspension Peroxide Oxidation Combined Acidity and Sulfur method. A decision tree approach based on the values of pH_{KCl} and pH_{OX} is used to decide what analytical path is followed in order to allow calculation of net acidity.

TAA: Titratable actual acidity. The acidity measured by titration with dilute NaOH following extraction with KCl-solution in the SPOCAS method. Previously referred to as Total Actual Acidity in the POCAS and POCASm methods.

TPA: Titratable peroxide acidity. The acidity measured by titration with dilute NaOH following peroxide digestion in the SPOCAS method. Previously referred to as Total Potential Acidity in the POCAS and POCASm methods.

TSA: Titratable sulfidic acidity. The difference in acidity measured by titration with dilute NaOH following extraction with KCl-solution and the acidity titrated following peroxide digestion in the SPOCAS method. ($TPA - TAA$). Previously referred to as Total Sulfidic Acidity in the POCAS and POCASm methods.

WAPC: Western Australian Planning Commission

UWPCA: Under Water Pollution Control Area

Appendix C Acid sulfate soil investigation reporting checklist

| Report sections | Information to be included, where relevant | Comments |
|---------------------------------|---|------------------------------|
| 1 Executive summary | <ul style="list-style-type: none"> • Background • Objectives of the investigation • Scope of work • Summary of analytical results (where applicable) • Summary of conclusions and recommendations | Mandatory information |
| 2 Scope of work | <ul style="list-style-type: none"> • Clear statement of the scope of work | Mandatory information |
| 3 Site identification | <ul style="list-style-type: none"> • Street number, lot number, street name and suburb • Common title/name of site (e.g. Sparkling Waters Residential Estate) • Certificate of title (copy of document including survey plan) • Coordinates of site boundaries (Northings/Eastings—specify datum set) • Locality map • Current site plan showing any existing infrastructure, scale bar, north arrow, local environmentally significant features, 'stages' of development • Local government authority | Mandatory information |
| 4 Details of development | <ul style="list-style-type: none"> • Full description of proposed development • Full description of proposed ground disturbing activities (including soil and water disturbance, anticipated time-lines) • Details of proponent and Project Manager • Details of planning conditions including <u>full</u> and <u>clear</u> identification of section of the development project for which clearance of conditions is sought—i.e. site plans clearly showing cadastral boundaries, 'stage' boundaries, spatial co-ordinates, gazetted roads etc, (where applicable) | Mandatory information |

| Report sections | Information to be included, where relevant | Comments |
|--|--|------------------------------|
| | <ul style="list-style-type: none"> List of <u>all</u> other names under which the development has been known or referred to as (where applicable) | |
| 5 Site history | <ul style="list-style-type: none"> Land owner—past and present Zoning—previous, present and proposed Land use—previous, present and proposed, focusing on history of ground disturbance on site <u>or in vicinity of site</u> (e.g. disposal of dredge spoil, mineral sand or peat mining, previous dewatering, drainage or deep excavation) Local usage of ground/surface waters, and location of groundwater bores Integrity assessment (assessment of the accuracy of information) | Mandatory information |
| 6 Site conditions and surrounding environment | <ul style="list-style-type: none"> Topography Drainage/hydrology Soil, water, vegetation and infrastructure characteristic indicators of AASS and/or PASS Flood potential Preferential pathways for contaminants, e.g. drains Residents in close proximity to site Details of any relevant local sensitive environment, e.g. water courses, wetlands, local habitat areas Photographs of site and surrounds Photographs of characteristic indicators of AASS and/or PASS (where applicable) | Mandatory information |
| 7 Geology and hydrogeology | <ul style="list-style-type: none"> DER ASS risk mapping Published geological mapping Soil stratigraphy using recognised geological classification method Location and extent of imported and locally derived fill Site borehole logs or test pit logs showing | Mandatory information |

| Report sections | Information to be included, where relevant | Comments |
|--|--|---|
| | <ul style="list-style-type: none"> • Stratigraphy • Detailed description of the location, design and construction of on-site groundwater bores • Description and location of springs and wells within a 1km radius of the site • Known or expected depth to groundwater table • Presence of multi-layered aquifer (investigations may result in cross-contamination of aquifers if there is no detailed knowledge of site conditions and contaminants) • Direction and rate of groundwater flow • Permeability of strata on the site • Direction of surface water runoff • Groundwater discharge location • Groundwater quality • Groundwater/surface water interaction • Groundwater conditions (e.g. unconfined, confined, ephemeral or perched) • Beneficial use of groundwater in the vicinity such as public drinking water supply and source areas, domestic irrigation, aquatic ecosystems, and the potential impacts on these uses • Location and use of groundwater bores within a 1km radius of the site • Location of sensitive receptors/users • Preferential migratory pathways | |
| 8 Sampling and analysis plan and sampling methodology | <ul style="list-style-type: none"> • The exact location of each borehole shown on an appropriately scaled map • Justification for the density of the sampling program • Justification for the locations of sampling points • Justification for the selection of samples for laboratory analysis | Mandatory information, where sampling was undertaken |

| Report sections | Information to be included, where relevant | Comments |
|--|--|---|
| | <ul style="list-style-type: none"> • A brief description of the equipment and/or methods used to retrieve the samples • Calibration certificates or calibration results • For further guidance refer to the DER contaminated sites guidelines | |
| 9 Field quality assurance quality control (QA/QC) | <ul style="list-style-type: none"> • Decontamination procedures carried out between sampling events • Logs for each sample collected including time, location, initials of sampler, duplicate type, chemical analyses to be performed, site observations • Chain of custody identifying (for each sample), the sampler, nature of the sample, collection date and time, analyses to be performed, sample preservation method, departure time from the site • Statement of duplicate frequency • Field blank results • Rinsate sample results • Field instrument calibrations | Mandatory information, where sampling was undertaken |
| 10 Laboratory quality assurance quality control (QA/QC) | <ul style="list-style-type: none"> • A copy of signed chain-of-custody forms acknowledging receipt date and time, identity of samples included in shipments, description of condition of samples received (cold, on ice, frozen, etc.) • Record of holding times and a comparison with methods specification • Analytical methods used • Laboratory accreditation for analytical methods used • Sample splitting techniques • Description of surrogates and spikes used • Percent recoveries of spikes and surrogates • Instrument and method detection limits • Matrix or practical quantification limits • Laboratory duplicate and blanks results | Mandatory information, where sampling was undertaken |

| Report sections | Information to be included, where relevant | Comments |
|---|--|---|
| 11 QA/QC data evaluation | <ul style="list-style-type: none"> • Evaluation of all QA/QC information listed above against the stated data quality objectives (DQO), including discussion of: documentation completeness, data completeness, data comparability, data representativeness, precision and accuracy of both sampling and analysis for each analyte in each environmental matrix informing data users of the reliability, unreliability or qualitative value of the data • Data comparability checks, which should include collection and analysis of samples by different personnel, use of different methodologies, collection and analysis by the same personnel using the same methods but at different times, spatial and temporal changes (because of the environmental dynamics) | Mandatory information, where sampling was undertaken |
| 12 Basis for adoption of assessment criteria | <ul style="list-style-type: none"> • Table listing all selected assessment criteria and references • Rationale for and appropriateness of the selection of criteria • Assumptions and limitations of criteria | Mandatory information, where sampling was undertaken |
| 13 Results | <ul style="list-style-type: none"> • Summary of all soil results in a table with observations and data, similar to Table 11 including: <ul style="list-style-type: none"> ○ the full grid reference of each borehole using Australian Metric Grid ○ an exact description of the vertical dimensions of the borehole relative to existing surface height in <u>both</u> metres below ground level (mBGL) <u>and</u> metres above AHD ○ soil texture, grain size, roundness, sorting and sphericity using the Australian Soil and Land Survey Field Handbook (McDonald <i>et al.</i>, 1990) as a guide; ○ colour using a Munsell colour chart ○ mottling, organic matter, moisture content, watertable level and other diagnostic features (e.g. jarosite, shell) | Mandatory information, where sampling was undertaken |

| Report sections | Information to be included, where relevant | Comments |
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| | <ul style="list-style-type: none"> ○ results from field soil pH_F and pH_{FOX} tests, including the pH of water and peroxide used (where conducted) ○ tabulated summary of results of laboratory analyses in %S units ○ all results exceeding the adopted assessment criteria highlighted ● Summary of all water quality results in a table that shows essential details such as sampling locations and depths, assessment criteria, highlights all results exceeding the adopted assessment criteria (where water quality testing has been undertaken) ● Calibration certificates or calibration results ● Cross-sections of the soil profile beneath the study area ● Copies of original laboratory result certificates including NATA accreditation details ● Discussion of any discrepancy between field observations and laboratory analyses results ● Site plan showing all sample locations, sample identification numbers and sampling depths ● Discussion and interpretation of results to create detailed 3-dimensional maps and cross-sections of ASS occurrence/absence at the site, including soil type and net acidity by depth ● Site plan showing extent of groundwater acidity and/or metal contamination beneath site (where applicable) ● Photographs of the soil profile, identifying each stratum | |
| <p>14 Risk assessment</p> | <ul style="list-style-type: none"> ● Receptor identification ● Assessment of receiving environment's sensitivity ● Exposure assessment ● Discussion of the potential risk of harm to | <p>Mandatory information, where disturbance of ASS is proposed</p> |

| Report sections | Information to be included, where relevant | Comments |
|--|---|---|
| | <p>human health and/or the environment associated with disturbance of the site</p> <ul style="list-style-type: none"> • Discussion of assumptions • Risk management decisions based on outcome of the assessment | |
| <p>15 Conclusions and recommendations</p> | <ul style="list-style-type: none"> • Brief summary of all findings • Assumptions used in reaching the conclusions • Extent of uncertainties in the results • A clear statement that the consultant considers the subject site to be suitable for the proposed development (where applicable) • Recommendations of further sampling and/or the need for an ASS Management Plan for the proposed development (where applicable) • A statement detailing all limitations, constraints and cautions on the development of the site (where applicable) | <p>Mandatory information</p> |
| <p>16 HSEP</p> | <ul style="list-style-type: none"> • Confirm that a Health, Safety & Environmental Plan (HSEP) has been prepared and adhered to | <p>A copy of the HSEP is not required by DER</p> |